Review Article

The Protocol of Low-level Laser Therapy in Orthodontic Practice: A Scoping Review of Literature

Rochaya Chintavalakorn, Nuntinee Nanthavanich Saengfai, Kawin Sipiyaruk

ABSTRACT

Low-level laser therapy (LLLT) has been widely investigated as an adjunct technique for orthodontic treatment due to photobiomodulation effect. LLLT appears to be supportive for an orthodontic practice in terms of tooth movement acceleration, pain relief, and root resorption management. The decrease in these adverse effects will enhance the compliance in orthodontic patients, which could positively impact treatment outcomes. However, there seemed to be inconsistency in the impact of LLLT as well as its laser and treatment parameters. This scoping review aimed to evaluate the impact of different irradiation parameters on tooth movement acceleration, pain relief, and root resorption as well as to construct a protocol of LLLT in orthodontic practice. The search was conducted across PubMed, Scopus, Web of Science, Embase, Google Scholar, and the reference lists of identified articles. The last search was conducted on October 10, 2021 to identify experiments in humans regarding the application of LLLT as noninvasive treatment in orthodontic practice published between 2010 and 2021. However, they were excluded if they were not clinical research, if they did not report the source of laser, or if they were not relevant to tooth movement, pain perception, and root resorption, or if they were not available in English or in full-text. Following the systematic search and selection process, 60 articles were included in this review. A majority of included articles were published in the past few years. The findings of this review supported the application of LLLT in orthodontic practice with purposes of tooth movement acceleration and pain reduction. The positive impact of LLLT on root resorption had not been clearly evident yet. As this review demonstrated heterogeneity of both laser and treatment parameters, further research should be required to ensure the effectiveness of its specific parameters in orthodontic practice.

KEYWORDS: LLLT, low-level laser therapy, orthodontic practice, pain, photobiomodulation, root resorption, scoping review, tooth movement

INTRODUCTION

Orthodontic care is a treatment procedure where long-term compliance of patients is required. The treatment duration can range from 14 to 33 months, with an average time of 19.9 months. The long treatment time is not only burdensome for patients which could negatively impact the compliance of patients, but also there are a variety of side effects, such as root resorption, alveolar bone resorption, and caries. There is evidence reporting the association between the duration of orthodontic treatment and...
the degree of root resorption. Orthodontic pain is another unpleasant side effect, which seems to be one of the concerns among patients. Discomfort, dull pain, and hypersensitivity from orthodontic care are unavoidable, which can lead to incompliance or early termination of treatment. Consequently, research to minimize these adverse effects has currently been a focus of orthodontics, with the purpose of the enhancement in compliance and comfort among patients.

The application of noninvasive low-level laser therapy (LLLT) has been introduced in an orthodontic practice in order to favor the biomechanics of tooth movements. LLLT can be considered as an alternative approach in offering analgesic and anti-inflammatory effects. It can have a positive impact on pain relief, tooth movement, and root resorption. With a low energy output, LLLT should not raise the temperature of a targeted tissue to over normal body temperature to avoid negative thermal effects. There seems to be no significant adverse effect of LLLT, compared to drug usage, corticotomy, and electric simulation. This leads to an increase in a number of studies of LLLT as a noninvasive approach in orthodontic practice with the expectation of promoting better experience in patients.

With a large number of studies in the use LLLT in orthodontic practice, there appears to be inconsistency in the impact of LLLT on pain relief, tooth movement, and root resorption. In addition, the variation of LLLT implementation in orthodontic practice was identified, in terms of irradiation (wavelength and radiant power) and treatment parameters (exposure duration and frequency of the therapy). The consistency of LLLT protocol should also be considered for orthodontic education, where its appropriate parameters could be delivered to residents. Therefore, the aims of this scoping review were to evaluate the clinical outcomes of different irradiation parameters on tooth movement acceleration, pain relief, and root resorption as well as to construct a protocol of LLLT in orthodontic practice.

**Materials and Methods**

**Review design**

A scoping review of the literature was selected for this study, in order to identify clinical outcomes of LLLT in orthodontic with the purpose of generating a protocol for its implementation. This method is appropriate in scoping available evidence to clarify characteristics or concepts of the focused topic. The scoping review process includes (1) defining research questions or objectives, (2) identifying relevant articles, (3) selecting articles according to inclusion and exclusion criteria, (4) charting the data extracted from included articles, and (5) summarizing and reporting the synthesized data, and (6) consulting experts or external researchers for additional suggestions or recommendations. The information of the included articles was extracted in the following themes: authors, year of publication, study design, research samples, irradiation parameters, and risk of bias assessment [Tables 1–3].

**Search strategy**

The systematic search was conducted across four databases, which included PubMed, Scopus, Web of Science, and Embase. Search terms with Boolean combinations were piloted and adjusted repetitively to assure the quality of systematic search. A PICOS strategy was employed to develop search terms including “Orthodontic patient” for Population, “Low level laser therapy,” “LLLT,” “Diode laser irradiation,” and “Photobiomodulation” for Intervention, “No intervention or non-LLLT approach” for Comparison, “Tooth movement,” “Pain,” and “Root resorption” for Outcomes, and “Experimental studies” for Study type. However, to extend our search results covering as many as available publications, only search terms for Population, Intervention, and Outcomes were implemented, where “Orthodontic” and “Orthodontics” were used instead of “Orthodontic patient.” The last search was conducted on 10 October 2021.

**Inclusion and exclusion criteria**

All types of experimental studies with humans regarding the application of LLLT as noninvasive treatment in orthodontic practice published between 2010 and 2021 were included in this review. However, the identified articles were excluded if they were not clinical research (conducted using animal testing or in vitro methods), if they did not report the source of laser, or if their research outcomes were not relevant to tooth movement, pain perception, and root resorption. They were also excluded if they were not available in English or in full text.

**Risk of bias assessment for included articles**

The Cochrane Collaboration’s tool was implemented to assess a risk of bias of all included articles. This tool was selected, as it could support the judgment in evaluating a risk of bias assessment of included studies whether their risk was “low,” “high,” or “unclear.” The six domains of bias were assessed including (1) selection bias, (2) performance bias, (3) detection bias, (4) attrition bias, (5) reporting bias, and (6) other bias. The outcomes of the bias assessment would show whether or not the included articles provided reliable evidence, reflecting the quality in conducting and reporting their experimental designs.
### Table 1: Application of LLLT for “accelerating tooth movement” in orthodontic practice

| Author(s) (year)                  | Type of study | Research samples (patients) | Comparison groups | Assessment                | Source of light | Wavelength | Average radiant power | Energy density | Exposure duration (s) | Frequency of LLLT use | Points of irradiation | Risk of bias assessment |
|----------------------------------|---------------|-----------------------------|-------------------|---------------------------|-----------------|-------------|------------------------|-----------------|-----------------------|-----------------------|------------------------|-----------------------|
| Da Silva Sousa et al., 2011[17]   | Parallel-group RCT | 10                          | 1. LLLT 2. Control | Measurement on digital casts | GaAlAs          | 780 nm      | 20 mW                  | 5 J/cm² | 100                   | Days 0, 3, and 7 (3 days each month) | 10 (Buccal: 5; Lingual: 5) | Unclear               |
| Doshi-Mehta et al., 2012[18]     | Split-mouth RCT | 20                          | 1. LLLT 2. Control | Measurement on dental casts | GaAlAs          | 808 nm      | 0.25 mW                | Not reported | 10                    | Days 0, 3, 7, 14, 21, and 28 (Lingual: 5) | 10 (Buccal: 5; Lingual: 5) | Low risk               |
| Genc et al., 2013[19]            | Split-mouth RCT | 20                          | 1. LLLT 2. Control | Measurement in oral cavity and GCF (Nitric oxide) | GaAlAs          | 808 nm      | 20 mW                  | Not reported | 100                   | Days 0, 3, 7, 14, 21, and 28 (Lingual: 5) | 10 (Buccal: 5; Lingual: 5) | Unclear               |
| Hasan et al., 2017[22]           | Parallel-group RCT | 26                          | 1. LLLT 2. Control | Measurement on dental casts | GaAlAs          | 830 nm      | 150 mW                 | 2.25 J/cm² | 60                    | Days 0, 3, 7, 14, 21, and 28 (Lingual: 5) | 4 (Buccal: 2; Lingual: 2) | High risk              |
| Kochhar et al., 2017[23]         | Split-mouth RCT | 20                          | 1. LLLT 2. Control | Measurement on dental casts | GaAlAs          | 810 nm      | 100 mW                 | 5 J/cm² | 100                   | Days 0, 3, 7, 14, 21, and 28 (Lingual: 5) | 10 (Buccal: 5; Lingual: 5) | Low risk               |
| Qamruddin et al., 2017[24]       | Split-mouth RCT | 20                          | 1. LLLT 2. Control | Measurement on 3D dental models | GaAlAs          | 940 nm      | 100 mW                 | 7.5 J/cm² | 30                    | Immediately after the force application | 10 (Buccal: 5; Lingual: 5) | High risk              |
| Ürettürk et al., 2017[25]        | Split-mouth RCT | 15                          | 1. LLLT 2. Control | Measurement on dental casts and GCF (IL-1β and TGF-β1) | GaAlAs          | 820 nm      | 20 mW                  | 5 J/cm² | 100                   | Days 0, 3, 7, 14, 21, 33, 37, 60, 63, and 67 (Lingual: 5) | 10 (Buccal: 5; Lingual: 5) | Unclear               |
| Author(s) (year) | Type of study | Research samples (patients) | Comparison groups | Assessment | Source of light | Wavelength | Average radiant power | Energy density | Exposure duration (s) | Frequency of LLLT use | Points of irradiation | Risk of bias assessment |
|------------------|---------------|-----------------------------|-------------------|------------|----------------|------------|----------------------|---------------|----------------------|----------------------|----------------------|-----------------------|
| Abdelhameed and Refai, 2018[26] | Split-mouth RCT | 30 Age range: 15-25 | 1. LLLT 2. Control 3. Micro-osteoperforations (MOPs) 4. MOPs and LLLT | Measurement in oral cavity | GaAlAs 810 nm | Not reported | Not reported | Not reported | Days 0, 3, 7, and 14 in the first month, and then every 15 days | Along both buccal and lingual surfaces of the root | Unclear |
| Arumughan et al., 2018[27] | Split-mouth RCT | 12 Age range: 17-35 | 1. LLLT 2. Control | Measurement on dental casts | GaAlAs 810 nm | 100 mW | Not reported | 100 | Days 0, 21, 42, and 63 | 10 (Buccal: 5; Lingual: 5) | Unclear |
| Guram et al., 2018[28] | Split-mouth RCT | 20 Male: 8 Female: 12 Average age: 19.75 | 1. LLLT 2. Control | Measurement on dental casts | GaAlAs 810 nm | 200 mW | 5 J/cm² | 30 | Immediately after the force application | 6 (Buccal: 3; Lingual: 3) | Low risk |
| Jose et al., 2018[29] | Split-mouth RCT | 12 | 1. LLLT 2. Control | GCF (IL-1β and PGE₂) | GaAlAs 810 nm | 100 mW | Not reported | 100 | Immediately after the force application | 10 (Buccal: 5; Lingual: 5) | Unclear |
| Dakshina et al., 2019[30] | Parallel-group RCT | 24 Age range: 18 or above | 1. LLLT 2. Control | Measurement on dental casts | GaAlAs 980 nm | 2000 mW | 15 J/cm² | 30 | Every 4 weeks | 2 (Buccal: 1; Lingual: 1) | Unclear |
| Chandran et al., 2020[31] | Experimental design | 32 Average age: 19.15 | 1. LLLT + Conventional bracket 2. LLLT + Self-ligating bracket 3. Control | Measurement on dental casts | GaAlAs 808 nm | Not reported | 8 J/cm² | 60 | Days 0, 3, 7, and 14 in the first month, and then every 15 days | 4 (Buccal: 2; Lingual: 2) | High risk |
| Jivrajani and Bhad, 2020[32] | Split-mouth RCT | 10 Male: 3 Female: 7 Age range: 14-24 | 1. LLLT 2. Control | Measurement on dental casts and GCF (MMP-9) | GaAlAs 980 nm | 30 mW | Not reported | 30 | Days 0, 3, 7, and 14 in the first month, and then every 15 days | 10 (Buccal: 5; Lingual: 5) | Low risk |
| Kamran, 2020[33] | Split-mouth RCT | 44 Male: 17 Female: 27 Average age: 14.8 | 1. LLLT 2. Control | GCF (OPG, OPN, and RANKL) Laser Duo, MMOptics | Laser 808 nm | 100 mW | 25 J/cm² | 100 | Immediately, 3 days, 1 week, and 2 weeks after the force application, and then every month | 10 (Buccal: 5; Lingual: 5) | Unclear |
| Author(s)          | Type of study | Research samples (patients) | Comparison groups | Assessment                                                                 | Source of light | Wavelength | Average radiant power | Energy density | Exposure duration (s) | Frequency of LLLT use | Points of irradiation | Risk of bias assessment |
|-------------------|---------------|-----------------------------|-------------------|----------------------------------------------------------------------------|----------------|------------|------------------------|----------------|-----------------------|-----------------------|------------------------|-------------------------|
| Lalnunpuii et al., 2020<sup>35</sup> | Parallel-group RCT | 65 Male: 24 Female: 41 Average age: 17.53 | 1. LLLT + Conventional bracket 2. LLLT + Self-ligating bracket 3. Control | Measurement on dental casts | GaAlAs | 658 nm | 8 mW | 2.29 J/cm² | 100 | Days 0, 3, 7, and 14 in the first month, and then every 15 days | 10 (Buccal: 5; Lingual: 5) | High risk |
| Storniolo-Souza et al., 2020<sup>37</sup> | Split-mouth RCT | 11 | 1. LLLT 2. Control | Measurement on 3D dental models | ArGaA | 780 nm | 40 mW and 70 mW (maxillary palatal) | 10 J/cm² and 35 J/cm² (maxillary palatal) | 150 | Every 4 weeks | 10 (Buccal: 5; Lingual: 5) | Unclear |
| Farhadian et al., 2021<sup>38</sup> | Parallel-group RCT | 60 Male: 14 Female: 46 Average age: 21.7 | 1. LLLT 2. LED 3. Control | Measurement on 3D dental models | GaAlAs | 810 nm | 100 mW | 4 J/cm² | 18 | Days 0, 3, 30, and 60 | 6 (Buccal: 3; Lingual: 3) | Low risk |
| Qamruddin et al., 2021<sup>39</sup> | Split-mouth RCT | 20 Male: 10 Female: 10 Average age: 20.25 | 1. LLLT 2. Control | Measurement on dental casts | GaAlAs | 940 nm | 100 mW | 7.5 J/cm² | 30 | Every 3 weeks | 10 (Buccal: 5; Lingual: 5) | High risk |
| Türker et al., 2021<sup>40</sup> | Split-mouth RCT | 20 Average age: 16.35 | 1. LLLT 2. Piezocision | Measurement on 3D dental models | Epic 10; Biolase | 940 nm | 400 mW | 5 J/cm² | 80 | Days 0, 3, 7, 14, 21, and 28 | 8 (Buccal: 4; Unclear Lingual: 4) | Unclear |
| Zheng and Yang, 2021<sup>41</sup> | Split-mouth RCT | 12 Male: 4 Female: 8 (Age: 18-28) | 1. LLLT 2. Control | Measurement on 3D dental models and GCF (IL-1β, RANKL, and OPG) | Doctor Smile LAMBDA SpA | 810 nm | 100 mW | 6.29 J/cm² | 160 | Days 0, 7, 14, and 21 | 4 (Buccal: 2; Unclear Lingual: 2) | Unclear |
| Heravi et al., 2014<sup>20</sup> | Split-mouth RCT | 20 Male: 3 Female: 17 Average age: 22.1 | 1. LLLT 2. Control | Measurement on dental casts | GaAlAs | 810 nm | 200 mW | 21.4 J/cm² | 300 | Immediately after the force application and on Days 3, 7, 11, and 15 | 10 (Buccal: 5; Lingual: 5) | High risk |

No positive impact on tooth movement
Results

Literature identified from the search

There were 818 articles identified across the four databases (PubMed, Scopus, Web of Science, and Embase). There were also five additional articles identified from Google Scholar and the reference lists of identified articles. Following the removal of 492 duplicates, 331 titles and abstracts were initially screened against the inclusion and exclusion criteria. One hundred and ninety-nine articles were excluded, as they were not experimental research with humans of LLLT in orthodontic practice. Finally, 134 full-texts were considered, and 74 of them were excluded: 36 articles were not conducted with an experimental design (e.g., case reports or reviews); eleven were animal research; ten did not report the source of laser; six were not the use of noninvasive LLLT in orthodontic practice (with purposes of tooth movement, pain reduction, or root resorption); eight were the use of light-emitting diode (LED); one was not available in full-text; and two were not available in English. Consequently, 60 articles were included in this scoping review. This article selection process was presented in Figure 1.

Characteristics of included articles

The 60 experimental studies included in this review. The tooth movement acceleration was evaluated as the outcomes in 25 articles. The pain reduction was assessed in 40 experiments. Only five articles evaluated the impact of LLLT on root resorption. The included experiments consisted of 24 parallel-group randomized control trials (RCTs), and 34 split-mouth RCTs, whereas two articles did not report how their subjects were allocated into each group. Fifty articles assessed only an aspect of LLLT impact in orthodontic practice (tooth movement, pain perception, or root resorption), whereas 10 studies evaluated multiple outcomes.

According to the year of publication, 31 articles were made available in the past few years (2019–2021), whereas 29 publications were published between 2010 and 2018.

Characteristics of included low-level laser therapy

As expected, there appeared to be various parameters of LLLT used in orthodontic practice, especially when considering the laser parameters. A couple of laser sources were used including GaAlAs, GaAs, InGaAlP, He-Ne, InAlAs, Nd:YAG, and InGaAs. GaAlAs was used as a laser diode in a majority of experiments, whereas six articles reported just the model and registered trademark without reporting the chemical elements. The wavelength of laser ranged from 630 to 1064 nm, which 810–980 nm appeared to be the common parameters used...
Table 2: Application of LLLT for “relieving pain” in orthodontic practice

| Author(s) (year) | Type of study | Research samples (patients) | Comparison groups | Assessment | Source of light | Wavelength | Average radiant power | Energy density (J/cm²) | Exposure duration (s) | Frequency of LLLT use | Points of irradiation | Risk of bias assessment |
|------------------|---------------|-----------------------------|-------------------|------------|----------------|------------|----------------------|-----------------------|----------------------|----------------------|----------------------|------------------------|
| Bicakci et al., 2012⁴² | Split-mouth RCT | 19 Male: 8 Female: 11 Average age: 13.9 | 1. LLLT 2. Control | VAS and GCF (PGE₂) | GaAlAs | 820 nm | 50 mW | 7.96 J/cm² | 20 | Just before and 24 h after the force application | 4 (Buccal: 2; Lingual: 2) | Unclear |
| Doshi-Mehta et al., 2012⁴³ | Split-mouth RCT | 20 Male: 8 Female: 12 Age range: 12-23 | 1. LLLT 2. Control | VAS | GaAlAs | 800 nm | 0.7 mW | Not reported | 30 | Days 0, 3, 7, and 14 in the first month, and then every 15 days | Day 1: 2 (Buccal: 1; Lingual: 1) Day 3: 10 (Buccal: 5; Lingual: 5) | Low risk |
| Artés-Ribas et al., 2013⁴⁴ | Split-mouth RCT | 20 Male: 6 Female: 14 Average age: 26.4 | 1. LLLT 2. Control | VAS | GaAlAs | 830 nm | 100 mW | Not reported | 120 | Immediately after the force application | | Low risk |
| Domínguez et al., 2013⁴⁵ | Parallel-group RCT | 59 Male: 19 Female: 40 Average age: 24.3 | 1. LLLT 2. Control | VAS | GaAlAs | 830 nm | 100 mW | Not reported | 44 | At the final archwire visit | Along both buccal and lingual surfaces of the root | Low risk |
| Kim et al., 2013⁴⁶ | Parallel-group RCT | 88 Male: 23 Female: 65 Average age: 22.7 | 1. LLLT 2. Control | VAS | AlGaInP | 635 nm | 6 mW | Not reported | 120 | Every 12 h for a week | | Low risk |
| Nóbrega et al., 2013⁴⁷ | Parallel-group RCT | 60 Male: 22 Female: 38 Average age: 17.5 | 1. LLLT 2. Control | VAS | GaAlAs | 830 nm | Not reported | Not reported | 125 | Immediately after the force application | | Low risk |
| Eslamian et al., 2014⁴⁸ | Split-mouth RCT | 37 Male: 12 Female: 25 Average age: 24.97 | 1. LLLT 2. Control | VAS | GaAlAs | 810 nm | 100 mW | 2 J/cm² | 200 | Immediately after and 24 h after the force application | 10 (Buccal: 5; Lingual: 5) | Low risk |
Table 2: Continued

| Author(s) (year) | Type of study | Research samples (patients) | Comparison groups | Assessment | Source of light | Wavelength | Average radiant power | Energy density | Exposure duration (s) | Frequency of LLLT use | Points of irradiation | Risk of bias assessment |
|------------------|---------------|----------------------------|-------------------|------------|----------------|------------|-----------------------|---------------|----------------------|----------------------|----------------------|------------------------|
| Marini et al., 2015 | Parallel-group RCT | 120 Male: 64 Female: 56 Average age: 23.01 | 1. LLLT 2. Placebo 3. Control | VAS | GaAs | 910 nm | 160 mW | Not reported | 340 | Immediately after the force application | 2 (Buccal: 1; Lingual: 1) | Low risk |
| Sobouti et al., 2015 | Split-mouth RCT | 27 Male: 16 Female: 11 Average age: 15.3 | 1. LLLT 2. Control | VAS | He-Ne | 632.8 nm | 10 mW | 6 J/cm² | 240 | Immediately after the force application | Along both buccal and lingual surfaces of the root | Low risk |
| Almallah et al., 2016 | Split-mouth RCT | 36 Male: 10 Female: 26 Average age: 18.4 | 1. LLLT 2. Control | VAS | GaAlAs | 830 nm | 100 mW | 4 J/cm² | 28 | Immediately after and 24h after the force application | 16 (Buccal: 8; Lingual: 8) | Low risk |
| Bayani et al., 2016 | Split-mouth RCT | 100 Male: 34 Female: 66 Average age: 17.6 | 1. LLLT 660nm 2. LLLT 810nm 3. Ibuprofen 4. bite wafer 5. Placebo medication | VAS | GaAlAs | 660 nm | 200 mW | 14.3 J/cm² | 30 | Immediately after the force application | 6 (Buccal: 3; Lingual: 3) | Low risk |
| Farias et al., 2016 | Split-mouth RCT | 28 Male: 13 Female: 15 Average age: 23.85 | 1. LLLT 2. Control | VAS | GaAlAs | 810 nm | 100 mW | 2 J/cm² | 45 | Immediately after the force application | 3 (Buccal: 3) | Low risk |
| Pesevska et al., 2016 | Experimental design | 30 | 1. LLLT 2. Control | NRS | Scorpion D-405 7A® | 630-670 nm | 20 mW | Not reported | 60/Q | Immediately after and 4 days after the force application | Not reported | High risk |
| Qamruddin et al., 2016 | Parallel-group RCT | 88 Male: 28 Female: 60 Average age: 18.56 | 1. LLLT 2. Control | NRS | GaAlAs | 940 nm | 200 mW | 4 J/cm² | 60 | Immediately after the force application | 3 (Buccal: 3) | Low risk |
| Author(s) (year) | Type of study | Research samples (patients) | Comparison groups | Assessment | Source of light | Wavelength | Average radiant power | Energy density | Exposure duration (s) | Frequency of LLLT use | Points of irradiation | Risk of bias assessment |
|-----------------|---------------|----------------------------|------------------|------------|----------------|------------|-----------------------|---------------|-----------------------|----------------------|----------------------|----------------------|
| Kochar et al., 2017 | Split-mouth RCT | 20 Male: 12; Female: 8 Age range: 16-24 | 1. LLLT 2. Control | VAS | GaAlAs | 810 nm | 100 mW | 5 J/cm² | 100 Days 0, 3, and 7 (3 days every 21 days) | 10 (Buccal: 5; Lingual: 5) | Low risk |
| Qamruddin et al., 2017 | Split-mouth RCT | 20 Male: 10; Female: 10 Average age: 19.8 | 1. LLLT 2. Control | NRS | GaAlAs | 940 nm | 100 mW | 7.5 J/cm² | 30 Immediately after the force application | 10 (Buccal: 5; Lingual: 5) | Low risk |
| Guram et al., 2018 | Split-mouth RCT | 20 Male: 8; Female: 12 Average age: 19.75 | 1. LLLT 2. Control | Wong-Baker faces pain rating scale | GaAlAs | 810 nm | 200 mW | 5 J/cm² | 30 Immediately after the force application | 6 (Buccal: 3; Lingual: 3) | Low risk |
| Qamruddin et al., 2018 | Split-mouth RCT | 42 Male: 16; Female: 26 Average age: 19.81 | 1. LLLT 2. Control | NRS | GaAlAs | 940 nm | 100 mW | 7.5 J/cm² | 30 Immediately after the force application | 10 (Buccal: 5; Lingual: 5) | Low risk |
| Wu et al., 2018 | Parallel-group RCT | 40 Male: 10; Female: 30 Average age: 20.8 | 1. LLLT 2. Control | NRS | GaAlAs | 810 nm | 400 mW | 2 J/cm² | 120 Immediately after, and then 2h, 24h, 4 days and 7 days after the force application | 6 (Buccal: 3; Lingual: 3) | Low risk |
| Celebi et al., 2019 | Parallel-group RCT | 60 Male: 30; Female: 30 Age range: 11-23 | 1. LLLT 2. Mechanical vibration 3. Control | VAS | GaAlAs | 820 nm | 50 mW | 1.76 J/cm² | 96 Immediately after the force application | 6 (Buccal: 3; Lingual: 3) | Unclear |
| Giudice et al., 2019 | Parallel-group RCT | 84 Male: 41; Female: 43 Average age: 16.5 | 1. LLLT 2. Placebo 3. Control | NRS | GaAlAs | 980 nm | 1000 mW | 27 J/cm² for molar segment 24 J/cm² of anterior segment | Immediately after the force application | Not reported | Low risk |
| Author(s) (year) | Type of study | Research samples (patients) | Comparison groups | Assessment | Source of light | Wavelength | Average radiant power | Energy density | Exposure duration (s) | Frequency of LLLT use | Points of irradiation | Risk of bias assessment |
|-----------------|----------------|-----------------------------|-------------------|------------|----------------|------------|------------------------|--------------|------------------------|----------------------|----------------------|------------------------|
| Martins et al., 2019 | Parallel-group RCT | 62 Male: 26 Female: 36 Average age: 19.8 | 1. LLLT 2. Control | VAS | GaAlAs | 830 nm | 100 mW | 95 J/cm² | 240 | Just before and immediately after, 14 h and 28 h after the force application | 8 (Buccal: 4; Lingual: 4) | Low risk |
| Almallah et al., 2020 | Split-mouth RCT | 36 Male: 12 Female: 24 Average age: 17.44 | 1. LLLT 2. Control | VAS | GaAlAs | 830 nm | 100 mW | 4 J/cm² | 224 | An hour before and an hour after the force application | 8 (Buccal: 4; Lingual: 4) | Low risk |
| Anicic et al., 2020 | Split-mouth RCT | 22 Male: 10 Female: 12 Average age: 15.1 | 1. LLLT 2. Control | VAS | Laser HF, Hager-Werken GmbH & Co. | 660 nm | 90 mW | 21.6 J/cm² | 480 | Immediately after and 24 h after the force application | 6 (Buccal: 3; Lingual: 3) | Low risk |
| El Shehawy et al., 2020 | Parallel-group RCT | 26 Male: 10 Female: 16 Average age: 21.7 | 1. LLLT 2. Control | VAS | GaAlAs | 635 nm | 20 mW | 6.5 J/cm² | 100 | Days 0, 3, 7, and 14 in the first month | 10 (Buccal: 5; Lingual: 5) | Unclear |
| Liu et al., 2020 | Parallel-group RCT | 150 Male: 88 Female: 72 Average age: 21.7 | 1. LLLT 2. Placebo 3. Control | VAS and GCF (proinflammatory factors and pain related substance) | Nd:YAG | 1064 nm | Not reported | Not reported | 120 | Immediately after the force application and then every day for the first week | 6 (Buccal: 3; Lingual: 3) | Low risk |
| Matys et al., 2020 | Parallel-group RCT | 76 Male: 21 Female: 55 Average age: 35.1 | 1. LLLT 2. Ozone 3. Control | NRS | Lasotronix | 635 nm | 400 mW | 1.59 J/cm² | 115 | Immediately after the force application | 23 (from maxillary right first molar to the maxillary left first molar) | Unclear |
| Nicotra et al., 2020 | Parallel-group RCT | 56 Male: 29 Female: 27 Average age: 12.03 | 1. LLLT 2. Placebo 3. Control | NRS | GaAlAs | 980 nm | 1000 mW | 1 J/cm² | 30 | Immediately after the force application | Along both buccal and lingual sides | Low risk |
| Oza et al., 2020 | Parallel-group RCT | 120 Male: 47 Female: 73 Average age: 18.04 | 1. LLLT 2. Topical anesthetic gel 3. TENS 4. Control | VAS | GaAlAs | 830 nm | 200 mW | Not reported | 60 | Immediately after the force application | 3 (Buccal: 3) | Unclear |
| Author(s) | Type of study | Research samples (patients) | Comparison groups | Assessment | Source of light | Wavelength | Average radiant power | Energy density | Exposure duration (s) | Frequency of LLLT use | Points of irradiation | Risk of bias assessment |
|-----------|---------------|-----------------------------|-------------------|------------|----------------|------------|----------------------|--------------|----------------------|----------------------|-------------------|---------------------|
| Ren et al., 2020 | Split-mouth RCT | 27 Male: 5 Female: 22 Average age: 47 | 1. LLLT 2. Control | VAS and GCF (IL-1β, PGE₂, substance P) | GaAlAs | 940 nm | 800 mW | 8.6 J/cm² | 60 | Immediately, 1 day, 1 week, 2 weeks, 3 weeks, 4 weeks, 5 weeks, 6 weeks after the force application, and then every month | Along buccal surface of the root | Low risk |
| Sfondrini et al., 2020 | Parallel-group RCT | 26 Male: 9 Female: 17 Average age: 11.8 | 1. LLLT 2. Control | Wong-Baker faces pain rating scale | GaAlAs | 830 nm | 150 mW | 7.5 J/cm² | 20 | Immediately after the force application | 4 (Buccal: 2; Lingual: 2) | Low risk |
| Qamruddin et al., 2021 | Split-mouth RCT | 20 Male: 10 Female: 10 Age range: 12-30 | 1. LLLT 2. Control | NRS | GaAlAs | 940 nm | 100 mW | 7.5 J/cm² | 30 | Every 3 weeks | 10 (Buccal: 5; Lingual: 5) | Low risk |
| Abtahi et al., 2013 | Split-mouth RCT | 29 Male: 24 Female: 5 Average age: 15.03 | 1. LLLT 2. Control | VAS | GaAs | 904 nm | 200 mW | Not reported | 30 | Daily for five days | 4 (Buccal: 2; Lingual: 2) | Low risk |
| Heravi et al., 2014 | Split-mouth RCT | 20 Male: 3 Female: 17 Average age: 22.1 | 1. LLLT 2. Control | VAS | GaAlAs | 810 nm | 200 mW | 21.4 J/cm² | 300 | Immediately after the force application and on Days 3, 7, 11, and 15 | 10 (Buccal: 5; Lingual: 5) | Low risk |
| Dalaie et al., 2015 | Parallel-group RCT | 12 Male: 3 Female: 9 Average age: 20.1 | 1. LLLT 2. Control | Wong-Baker faces pain rating scale | GaAlAs | 880 nm | 100 mW | 5 J/cm² | 80 | Not reported | 8 (Buccal: 4; Lingual: 4) | Low risk |
| Hasan et al., 2018 | Split-mouth RCT | 26 Male: 7 Female: 19 Age range: 16-22 | 1. LLLT 2. Control | VAS | GaAlAs | 830 nm | 150 mW | 2.25 J/cm² | 30 and 9 J/cm² | 120 | Immediately after the force application | 2 (Buccal: 2) | Low risk |

No positive impact on pain relief
| Author(s)          | Type of study | Research samples (patients) | Comparison groups | Assessment | Source of light | Wavelength (nm) | Average radiant power (mW) | Energy density (J/cm²) | Exposure duration (s) | Frequency of LLLT use | Risk of bias assessment |
|-------------------|---------------|-----------------------------|-------------------|------------|----------------|-----------------|-------------------------|------------------------|----------------------|----------------------|------------------------|
| Hasan et al., 2020 | Parallel-group RCT | Male: 6 Female: 20 Average age: 20.07 | 1. LLLT 2. Control 3. Control | VAS CMS Dental APS | ArGaA | 830 nm | 150 mW | Not reported | Immediately after the force application | 4 (Buccal: 2; Lingual: 2) | Low risk |
| Storniolo-Souza et al., 2020 | Split-mouth RCT | Male: 11 Female: 11 Average age: 14.04 | 1. LLLT 2. Control 3. Control | VAS VAS | GaAlAs | 780 nm | 40 mW | 10 J/cm² | Every 4 weeks | 150 | Not reported |
| Celebi et al., 2021 | Parallel-group RCT | Male: 30 Female: 33 | 1. LLLT 2. Chewing gum 3. Control 4. Control | VAS VAS VAS | GaAlAs | 820 nm | 50 mW | 1.76 J/cm² | Immediately after the force application | 6 (Buccal: 3; Lingual: 3) | Unclear |
| Farhadian et al., 2021 | Parallel-group RCT | Male: 60 Female: 46 | 1. LLLT 2. LED 3. Control 4. Control | VAS VAS | GaAlAs | 810 nm | 100 mW | 4 J/cm² | Days 0, 3, 30, and 60 | 18 | Low risk |
| Author(s) (year) | Type of study | Research samples (patients) | Comparison groups | Assessment | Source of light | Wavelength | Average radiant power | Energy density | Exposure duration (s) | Frequency of LLLT use | Points of irradiation | Risk of bias assessment |
|-----------------|---------------|-----------------------------|-------------------|------------|----------------|------------|----------------------|-------------|---------------------|---------------------|----------------------|------------------------|
| Nayyer et al., 2021[76] | Split-mouth RCT | 22 Male: 11 Female: 11 Average age: 20 | 1. LLLT 2. Control | Root surface analysis with a non-contact 3D optical profilometer | InGaAs | 980 nm | 100 mW | Not reported | 100 | Days 0, 3, 7, 11, 15, and 28 | 10 (buccal: 5; lingual: 5) | Unclear |
| Da Silva Sousa et al., 2011[17] | Parallel-group RCT | 10 Male: 4 Female: 6 Average age: 13.1 | 1. LLLT 2. Control | Measurement on radiograph | GaAlAs | 780 nm | 20 mW | 5 J/cm² | 100 | Days 0, 3, and 7 (3 days each month) | 10 (buccal: 5; lingual: 5) | Unclear |
| Khaw et al., 2018[73] | Split-mouth RCT | 20 Male: 8 Female: 12 Average age: 15.75 | 1. LLLT 2. Control | Micro-CT | GaAlAs | 660 nm | 75 mW | Not reported | 120 | Every week | 8 (buccal: 4; lingual: 4) | Low risk |
| Ng et al., 2018[74] | Split-mouth RCT | 20 Male: 10 Female: 10 Average age: 16.55 | 1. LLLT 2. Control | Micro-CT | GaAlAs | 808 nm | 180 mW 360 mW | 1.6 J/point 36 (pulse) | Days 0, 2, 3, 7, 14, and 21 | 8 (buccal: 4; lingual: 4) | Low risk |
| Goymen et al., 2020[75] | Parallel-group RCT | 30 Male: 14 Female: 16 Average age: 16.27 | 1. LLLT 2. LED 3. Control | Micro-CT | GaAlAs | 810 nm | Not reported | Not reported | Days 0, 3, 7, 14, 21, and 28 | Not reported | Unclear |
for LLLT in orthodontic practice. The selection of LLLT operating mode seemed to be consistent, as nearly all of the included articles considered the use of continuous wave, rather than a pulsed mode.

According to the treatment parameters, there were several points to be considered such as exposure duration, frequency of laser therapy, and application techniques (irradiation points). The exposure durations were varied from 10 to 480 s, depending on the area exposed to the irradiation. The frequency of LLLT seemed to be very varied, and most studies employed LLLT immediately after the application of orthodontic force. In case that the multiple sessions were designed, LLLT appeared to be more frequently applied in the initial phase (the first 2 weeks). The irradiation points were mostly applied on both buccal and palatal/lingual surfaces, with the common techniques being 6–8 points for a tooth. A couple of studies applied LLLT by moving a laser tip along the root of a tooth on buccal and/or lingual surfaces, rather than as a point.

The outcome of LLLT on tooth movement acceleration was evaluated in 25 articles [Table 1]. The acceleration of tooth movement could be evaluated by measuring the moving distance during the canine retraction or the duration of complete treatment for decrowding. The tooth movement could be measured in an oral cavity,[19,26] on dental casts,[17,18,20-23,25,27,28,30-33,35,39] or digital models[24,36-38,40,41] by using a digital caliper or stereomicroscope with appropriate reference points. Irregularity index representing horizontal overlapping or crowding can also be used for the evaluation.[22] Six experiments additionally collected gingival crevicular fluid (GCF) to analyze tooth movement-related substance, including IL-1β, TGF-β1, PGE2, MMP-9, OPG, OPN, and RANKL.[19,25,29,33,34,41]

The impact of low-level laser therapy on tooth movement acceleration
LLLT was found to be effective in accelerating tooth movement, as positive outcomes were shown in 21 from 25 articles [Table 1]. According to the four studies reporting no positive outcomes,[20,21,31,36] one experiment evaluated the effect of LLLT as supplementary to corticotomy.[31] This might result in no significant difference between LLLT and non-LLLT groups, as corticotomy had already accelerated the tooth movement.

The parameters of low-level laser therapy for a purpose of tooth movement acceleration
GaAlAs appeared to be the most common laser diode used for accelerating tooth movement, which was used in 20 from 25 articles [Table 1]. Other laser diodes
included ArGaA and InAlAs. The wavelength was ranging from 658 nm to 980 nm, with the most common protocol seemed to be 810 nm. The average radiant power was very varied, ranging from 0.25 to 2000 mW, which was likely to depend on the size of laser tip. In terms of clinical application, a majority of research applied LLLT immediately after the force application followed by Days 3, 7, and 14 for the first month and then every 15 days. The irradiation points for each tooth were varied from two to ten, which the 10-point protocol appeared to be the most common. All experiments applied LLLT on both buccal and lingual surfaces; however, one of them moved the laser tip along the root area, rather than a points technique. The exposure time was varied from 10 to 300 s, leading to the variation of irradiation target from 2.25 to 25 J/cm².

The application of low-level laser therapy for “relieving pain” in orthodontic practice

Overview of low-level laser therapy research on pain relief

Pain relief seemed to be the most common outcome of LLLT research. There were 40 experimental studies reporting the outcomes of LLLT on pain relief [Table 2]. The level of pain was typically measured at leveling and canine retraction phases as well as at the period of separator placement. A couple of methods were designed to assess level of pain in orthodontic patients. Visual analog scales (VASs) appeared to be the most popular tool to gather self-perceived pain, which was used in 29 articles. Eight articles employed numerical rating scales (NRS) in three articles, could also be applied to collect self-reported pain. Three studies GCF to measure pain-related substance, including prostaglandin E₂ (PGE₂), substance P, and pro-inflammatory factors.

The impact of low-level laser therapy on pain relief

LLLT appeared to have a positive impact on the reduction of orthodontic treatment-related pain. There were 32 experimental researches reporting the positive impact of LLLT on pain relief, compared with conventional or other techniques. There was an experiment comparing the impact of LLLT on pain reduction with anesthetic gel and transcutaneous electrical nerve stimulation, which the laser method appeared to be more effective. Only eight articles reported no positive impact of LLLT on pain reduction.

The parameters of low-level laser therapy for a purpose of pain relief

When considering the laser parameters, GaAlAs was the most popular laser diode for pain relief, as reported in 30 from 40 articles [Table 2]. Other laser diode included He-Ne, GaAs, InGaAlP, Nd:YAG, and ArGaA. The wavelength was ranging from 630 to 1064 nm, where 830 nm seemed to be the most common wavelength (reported in ten experiments) followed by 810 (eight articles) and 940 nm (five articles). The average radiant power was very varied, ranging from 0.7 to 800 mW.

Similar to the clinical application for tooth movement acceleration, nearly all experiments applied LLLT immediately after the force application. In case more than a session of LLLT was applied, the application tended to be more frequent during the first week (Days 0, 3, and 7). There were also three articles reporting the LLLT use before the force application. The irradiation points for each tooth were varied from 2 to 16, which 6 and 10 points appeared to be the common instruction. They were typically applied on both buccal and palatal (lingual) sides. Four experiments reported the use of different technique, where the laser tip was moved along the root of tooth (both buccal and lingual surfaces), showing the positive outcome on pain relief. The exposure time was varied from 20 to 480 s, leading to the variation of energy density from 1 to 35.4 J/cm².

The application of low-level laser therapy for “reducing root resorption” in orthodontic practice

Overview of low-level laser therapy research on root resorption

The impact of LLLT on root resorption seemed to be a new research topic, which four from five studies were published over the past few years [Table 3]. A study conducted in 2021 evaluated this impact by measuring the root on the periapical radiograph from the gingival edge of the orthodontic bracket to the root apex at different periods. Following the advanced technology, three articles published between 2018–2020 evaluated the root resorption using microcomputed tomography (micro-CT). An experiment published in 2021 enhanced the accuracy of root resorption analysis by using a non-contact three-dimensional optical profilometer.

The impact of low-level laser therapy on a reduction of root resorption

The positive impact of LLLT on root resorption had not been clearly evident. Although four experiments found no positive outcome on root resorption, one study supported the use of LLLT based on the analysis with the optical profilometer.

The parameters of low-level laser therapy for a purpose of a reduction of root resorption

AlGaAs and InGaAs appeared to be a laser diode used for decreasing induced inflammatory root resorption,
with wavelength ranging from 660 nm to 980 nm [Table 3]. The research applying AlGaAs found no positive outcome on a reduction of root resorption. The average radiant power was ranging from 20 to 360 mW, which 100-mw irradiation could be sufficient to offer a positive impact on root reduction.

The clinical application of LLLT for root resorption seemed to be less varied than the other two outcomes. The exposure duration of low-level laser at each point ranged from 72 to 120 s for continuous wave, and one study applied pulsed wave for 36 s.[78] All studies conducted LLLT for a period with the purpose of root resorption, with approximately three to six sessions per month. Similar to the use of LLT for other purposes, LLLT was applied more frequently in the first week. The energy density was ranging from 5 to 8 J/cm². Based on the included studies, eight to ten irradiation points were applied for each tooth, divided equally for both buccal and lingual sides.

**Discussion**

There seems to be an increasing use of LLLT in orthodontic practice, as implied from the trend of research in this topic. There were 48 articles published between 2018 and 2021, compared to 33 publications over the 8-year period (2010–2017). More than ten articles were published in a year from 2018 to 2020. The emphasis of LLLT research has also moved to tooth movement acceleration, in which 18 of 22 articles in this topic were made available in the past 5 years. According to the impact of LLLT on root resorption, four of five articles were published since 2018.

LLLT appeared to have positive outcomes in orthodontic practice. There seemed to be a significant impact on pain relief, tooth movement, and root resorption, as evident by the results retrieved from the included articles. These findings were consistent with previous literature, which LLLT was likely to have a positive effect on healing, nerve regeneration, inflammatory process, pain reduction, proliferation of osteoblasts, bone remodeling, root resorption, and tooth movement.[77-80] Therefore, LLLT can be considered as significantly supportive for an orthodontic practice.

The reduction of orthodontic pain could be considered as one of the significant outcomes of LLLT. Pain could be considered as an important concern in orthodontic practice, as it may discourage patients from the treatment.[6,7] In addition, orthodontic pain appears to be unavoidable, as it is induced from tooth movement during the treatment. Although analgesics appear to be an effective method for pain control, pharmacological actions and adverse effects should be concerned.[81]

LLLT could be considered as an alternative option for the non-pharmacological management of pain. These reasons might lead to a popularity of research in the impact of LLLT on the orthodontic pain.

The duration of orthodontic management can be another factor to discourage patients from the treatment. Not only there can be a reduction of patient compliance throughout the long treatment duration, but also the risk of root resorption, alveolar bone resorption, dental caries, and gingivitis seems to be increasing.[3] Tooth movement acceleration, therefore, has become an important topic in orthodontic practice. A great number of studies emphasized on tooth movement acceleration as well as how to measure it.[82,83] Several techniques have been used to accelerate tooth movement, such as biological approaches (e.g., cytokines, prostaglandin, or parathyroid hormone injection), device-assisted techniques, surgical methods (e.g., corticotomy, interseptal alveolar surgery, osteotomy), and LLLT.[82] Although surgical techniques have been proved to enhance tooth movement acceleration,[84] it could be considered more aggressive than other methods. Consequently, LLLT appeared to be one of the most preferable noninvasive approaches for tooth movement acceleration without systemic adverse effects.

External apical root resorption is another major concern in orthodontic practice. It was likely to be one of the most common adverse effects of orthodontic treatment.[85,86] There is evidence reporting a correlation between root resorption and the duration of orthodontic treatment.[87,88] As orthodontically induced inflammatory root resorption seems to be an unavoidable complication,[89] a number of studies aimed to explore its influential factors.[90] One of the expectations is to prevent this adverse effect. However, the evidence of LLLT on the reduction of root resorption was not clear, as only the latest research showed the positive outcome.

This scoping review showed the heterogeneity in both laser and treatment parameters, for example, laser diodes, wavelength, average radiant power, energy density, exposure duration, frequency of LLLT applications, and points of irradiation. Although a number of studies showed no positive outcomes of LLLT in orthodontic practice, there was no clear evidence to suggest whether there were any inappropriate laser parameters for the use in orthodontic practice, as the LLLT parameters of no positive outcomes were found to effective in other research.

The findings retrieved from most of the included studies showed a positive impact of LLLT in orthodontic
practice, at least for tooth movement acceleration and pain reduction, with non-significant adverse effects; however, there are limitations and restriction for its implementation. With the laser safety concern, protective equipment such as laser-protection eyeglasses is required for both patients and operators. Another concern of LLLT is its sensitive technique, requiring professional use to obtain the optimal dose of laser. There could be no positive biological impact if too low dose is used; however, too high dose may lead to a bio-suppressive effect.\textsuperscript{[91]} Orthodontic patients, therefore, are required to receive LLLT at a dental office which could be inconvenient for them. In addition, the cost of laser device is quite high, although it is currently less expensive than the past.\textsuperscript{[72]} LED can be considered as alternative photobiomodulation therapy with similar purposes to LLLT\textsuperscript{[92,93]} as LED device can be used at home without laser safety considerations.\textsuperscript{[94]} Therefore, the impact of LED, especially with a comparison with LLLT, in orthodontic practice should be required to confirm their effectiveness.

There were a few limitations in conducting this scoping review. The data extracted for the analysis included both laser and treatment parameters; however, there were a number of the LLLT parameters that could not be identified in a number of articles. In addition, there were some difficulties in comparing these studies due to parameter variability. As discussed, there were a couple of articles reporting no positive outcomes although their laser and treatment parameters were also similarly used in other studies which supported LLLT in orthodontic practice. Furthermore, the details of research design in a number of articles were not clearly confidently defined, and they were evaluated as “high” or “unclear” risk of bias. Most of the experiments with high risk of bias had a limitation in blinding operators or assessors, so only the patient side was blinded. One of the strengths of this scoping review was the inclusion of all available experimental evidence whether it was evaluated as high, low, or unclear risk of bias, offering the promising opportunities in developing a robust and rigorous systematic review or meta-analysis. Although this review provides available options for the effective use in orthodontic practice, further clinical research with robust design should be required to assure the positive impact of LLLT on the specific parameters in orthodontic practice.

**CONCLUSION**

This scoping review supports the use of LLLT in orthodontic practice, as the available evidence tended to reveal its positive impacts on tooth movement acceleration and pain relief. However, there were a number of studies reporting no positive impact of LLLT. In addition, the impact of LLLT on a reduction of root resorption had not been yet clearly evident. As there were little inconsistency of orthodontic impact as well as heterogeneity of both laser and treatment parameters, further research should be required to ensure the effectiveness of its specific parameters in orthodontic practice.

**ACKNOWLEDGEMENT**

Not applicable.

**FINANCIAL SUPPORT AND SPONSORSHIP**

Not applicable.

**CONFLICTS OF INTEREST**

The authors declare no conflict of interest.

**AUTHORS’ CONTRIBUTION**

Conceptualization: RC, NNS, and KS; methodology: RC, NNS, and KS; investigation: RC and KS; data analysis: RC and KS; validation: RC, NNS, and KS; manuscript writing: RC and KS; manuscript review: RC, NNS and KS. All authors have read and agreed to the published version of the manuscript.

**ETHICAL POLICY AND INSTITUTIONAL REVIEW BOARD STATEMENT**

Not applicable.

**PATIENT DECLARATION OF CONSENT**

Not applicable.

**DATA AVAILABILITY STATEMENT**

The data summarized in Tables 1–3 of this review were analyzed from 60 articles listed in the reference section.\textsuperscript{[17-18]}

**REFERENCES**

1. Tsichlaki A, Chin SY, Pandis N, Fleming PS. How long does treatment with fixed orthodontic appliances last? A systematic review. Am J Orthod Dentofacial Orthop 2016;149:308-18.
2. Matsumoto T, Iimura T, Ogura K, Moriyama K, Yamaguchi A. The role of osteocytes in bone resorption during orthodontic tooth movement. J Dent Res 2013;92:340-5.
3. Segal GR, Schifffman PH, Tuncay OC. Meta-analysis of the treatment-related factors of external apical root resorption. Orthod Craniofac Res 2004;7:71-8.
4. Pizzo G, Licata ME, Guiglia R, Giuliana G. Root resorption and orthodontic treatment. Review of the literature. Minerva Stomatol 2007;56:31-44.
5. Kavaliauskien e A, Smailliene D, Buskiene I, Keriene D. Pain and discomfort perception among patients undergoing orthodontic treatment: Results from one month follow-up study. Stomatologi ja 2012;14:118-25.
6. Krishnan V. Orthodontic pain: From causes to management—a review. Eur J Orthod 2007;29:170-9.
7. Li FJ, Zhang JY, Zeng XT, Guo Y. Low-level laser therapy for orthodontic pain: A systematic review. Lasers Med Sci 2015;30:1789-803.
8. Turhani D, Scheriau M, Kapral D, Benesch T, Jonke E, Bantleon HP. Pain relief by single low-level laser irradiation in orthodontic patients undergoing fixed appliance therapy. Am J Orthod Dentofacial Orthop 2006;130:371-7.

9. Yousef 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.

10. Altan AB, Bacikci AA, Mutaf HI, Ozkut M, Inan VS. The effects of low-level laser therapy on orthodontically induced root resorption. Lasers Med Sci 2015;30:2067-76.

11. Lim HM, Lew KK, Tay DK. A clinical investigation of the efficacy of low level laser therapy in reducing orthodontic postadjustment pain. Am J Orthod Dentofacial Orthop 1995;108:614-22.

12. Ge MK, He WL, Chen J, Wen C, Yin X, Hu ZA, et al. Efficacy of low-level laser therapy for accelerating tooth movement during orthodontic treatment: A systematic review and meta-analysis. Lasers Med Sci 2015;30:1609-18.

13. Munn Z, Peters MDJ, Sterne C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMJ Med Res Methodol 2018;18:143.

14. Arksey H, O’Malley L. Scoping studies: Towards a methodological framework. Int J Soc Res Methodol 2005;8:19-32.

15. Methley AM, Campbell S, Chew-Graham C, McNally R, Cheraghi-Sohi S, Pico, Picos and Spider: A comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. BMC Health Serv Res 2014;14:579.

16. Higgins JP, Altman DG, Gotzsche PC, Juni P, Moher D, Oxman AD, et al.; Cochrane Bias Methods Group; Cochrane Systematic Methods Group. The cochrane collaboration’s tool for assessing risk of bias in randomised trials. BMJ 2011;343:d5928.

17. Sousa MV, Scanavini MA, Sannomiya EK, Velasco LG, Angelieri F. Influence of low-level laser on the speed of orthodontic movement. Photomed Laser Surg 2011;29:191-6.

18. Doshi-Mehta G, Bhad-Patil WA. Efficacy of low-intensity laser therapy in reducing treatment time and orthodontic pain: A clinical investigation. Am J Orthod Dentofacial Orthop 2012;141:289-97.

19. Genc G, Kocadereli I, Tasar F, Kilinc K, El S, Sarkarati B. Effect of low-level laser therapy (LLT) on orthodontic tooth movement. Lasers Med Sci 2013;28:41-7.

20. Heravi F, Moradi A, Ahrari F. The effect of low level laser therapy on the rate of tooth movement and pain perception during canine retraction. Oral Health Dent Manag 2014;13:183-8.

21. Dalae K, Hamedi R, Kharazifard MJ, Mahdian M, Bayat M. Effect of low-level laser therapy on orthodontic tooth movement: A clinical investigation. J Dent (Tehran) 2015;12:249-56.

22. AlSayed Hasan MMA, 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.

23. Kochar GD, Londhe SM, Varghese B, Jayan B, Kohli S, Kohli VS. Effect of low-level laser therapy on orthodontic tooth movement. J Indian Orthod Soc 2017;51:81-6.

24. Qamaruddin I, Alam MK, Mahroof V, Fida M, Khamis MF, Husein A. Effects of low-level laser irradiation on the rate of orthodontic tooth movement and associated pain with self-ligating brackets. Am J Orthod Dentofacial Orthop 2017;152:622-30.

25. Üretürk SE, Saraç M, Firatlı S, Can ŞB, Güven Y, Firatlı E. The effect of low-level laser therapy on tooth movement during canine distalization. Lasers Med Sci 2017;32:757-64.

26. Abdelhameed AN, Refaai WMM. Evaluation of the effect of combined low energy laser application and micro-osteoperforations versus the effect of application of each technique separately on the rate of orthodontic tooth movement. Open Access Muced J Med Sci 2018;6:2180-5.

27. Arumughan S, Somaiah S, Muddaiah S, Shetty B, Reddy G, Roopa S. A comparison of the rate of retraction with low-level laser therapy and conventional retraction technique. Contemp Clin Dent 2018;9:260-6.

28. Guram G, Reddy RK, Dharamsi AM, Syed Ismail PM, Mishra S, Prakashshankar M. Evaluation of low-level laser therapy on orthodontic tooth movement: A randomized control study. Contemp Clin Dent 2018;9:105-9.

29. Jose JA, Somaiah S, Muddaiah S, Shetty B, Reddy G, Roopa S. A comparative evaluation of interleukin 1 beta and prostaglandin E2 with and without low-level laser therapy during en masse retraction. Contemp Clin Dent 2018;9:267-75.

30. Dakshina CK, Hanumanthaih S, Ramaiyah PT, Thomas T, Sabu JK, Subramonia S. Efficacy of low-level laser therapy in increasing the rate of orthodontic tooth movement: A randomized control clinical trial. World J Dent 2019;10:177-80.

31. Farid KA, Eid AA, Kaddah MA, Elsharaby FA. The effect of combined corticotomy and low level laser therapy on the rate of orthodontic tooth movement: Split mouth randomized clinical trial. Laser Ther 2019;28:275-83.

32. Chandran N, Muralidhar NV, Suma S, Shashikumar P, Raghunath N. Comparing the effect of low-intensity laser therapy (LLLT) in decrowing lower anteriors using conventional and self-ligating MBT bracket systems - An in vivo study. Biomed Pharmacol J 2020;13:159-66.

33. Jivrajani SJ, Bhat Patil WA. Effect of low intensity laser therapy (Lilt) on Mmp-9 expression in gingival crevicullar fluid and rate of orthodontic tooth movement in patients undergoing canine retraction: A randomized controlled trial. Int Orthod 2020;18:330-9.

34. Kamran MA. Effect of photobiomodulation on orthodontic tooth movement and gingival crevicular fluid cytokines in adolescent patients undergoing fixed orthodontic therapy. Photobiomodul Photomed Laser Surg 2020;38:537-44.

35. Lalunpuii H, Batra P, Sharma K, Srivastava A, Raghavan S. Comparison of rate of orthodontic tooth movement in adolescent patients undergoing treatment by first bicuspid extraction and en-mass retraction, associated with low level laser therapy in passive self-ligating and conventional brackets: A randomized controlled trial. Int Orthod 2020;18:412-23.

36. Mistry D, Dalci O, Papageorgiou SN, Darendeliler MA, Papadopoulou AK. 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. World J Orthod 2020;15:445-53.

37. Storniolo-Souza J, Lima LM, Pinzan A, Alvarez F, Pereira SCDC, Janson G. Influence of low-level laser irradiation on Mmp-9 expression in gingival crevicular fluid and rate of orthodontic tooth movement: A randomized, controlled clinical trial. Photomed Laser Surg 2020;38:330-9.

38. Sarracini L, Valevičius K, Prather P, Panašauskas R, Šiliūnas D, Papioreckas G, et al.: Low-level laser therapy in orthodontic practice Chintavalakorn, et al.
39. Qamruddin I, Alam MK, Mahroof V, Fida M, Khamis MF, Husein A. Photobiostimulatory effect of a single dose of low-level laser on orthodontic tooth movement and pain. Pain Res Manag 2021;2021:690542.

40. Türker G, Yavuz İ, Gönen ZB. Which method is more effective for accelerating canine distalization short term, low-level laser therapy or piezocision? A split-mouth study. J Orofac Orthop 2021;82:236-45.

41. Zheng J, Yang K. Clinical research: Low-level laser therapy in accelerating orthodontic tooth movement. BMC Oral Health 2021;21:324.

42. Bicakci AA, Kocoglu-Altan B, Toker H, Mutaf I, Sumer Z. Efficiency of low-level laser therapy in reducing pain induced by orthodontic forces. Photomed Laser Surg 2012;30:460-5.

43. Abtahi SM, Mousavi SA, Shafaee H, Tanbakuchi B. Effect of low-level laser therapy on dental pain induced by separator force in orthodontic treatment. Dent Res J (Isfahan) 2013;10:647-51.

44. Artés-Ribas M, Arnabat-Dominguez J, Puigdollers A. Analgesic effect of a low-level laser therapy (830nm) in early orthodontic treatment. Lasers Med Sci 2013;28:335-41.

45. Dominguez A, Velásquez SA. Effect of low-level laser therapy on pain following activation of orthodontic final archwires: A randomized controlled clinical trial. Photomed Laser Surg 2013;31:36-40.

46. Kim WT, Bayome M, Park JB, Park JH, Baek SH, Kook YA. Effect of frequent laser irradiation on orthodontic pain. A single-blind randomized clinical trial. Angle Orthod 2013;83:611-6.

47. Nóbrega C, da Silva EM, de Macedo CR. Low-level laser therapy for treatment of pain associated with orthodontic elastomeric separator placement: A placebo-controlled randomized double-blind clinical trial. Photomed Laser Surg 2013;31:10-6.

48. Eslamian L, Borzabadi-Farahani A, Hassanazadeh-Azhiri A, Badiee MR, Fekrazad R. The effect of 810-nm low-level laser therapy on pain caused by orthodontic elastomer separators. Lasers Med Sci 2014;29:559-64.

49. Marini I, Bartolucci ML, Bortolotti F, Innocenti G, Gatto MR, Alessandro Bonetti G. The effect of diode superpulsed low-level laser therapy on experimental orthodontic pain caused by elastomeric separators: A randomized controlled clinical trial. Lasers Med Sci 2015;30:35-41.

50. Sobouti F, Khatami M, Chintavalakorn, et al.: Low-level laser therapy in orthodontic practice. Journal of International Society of Preventive and Community Dentistry ¦ Volume 12 ¦ Issue 3 ¦ May-June 2022

51. Almallah MME, Hajeer MY, Almahdi WH, Burhan AS, Latifé Y, Madkhaneh SK. Assessment of a single versus double application of low-level laser therapy in pain reduction following orthodontic elastomeric separation: A randomized controlled trial. Dent Med Probl 2020;57:45-52.

52. Anicic MS, Perkovic V, Gabric D, Lajnert V, Mestrovic S. Effect of a double dose of photobiomodulation therapy on orthodontic pain caused by elastomeric separators. Australs Med J 2020;13:310-6.

53. Al-Sayed Hasan MMA, Sultan K, Al-Azhar J Dent Sci 2020;23:201-7.

54. Qamruddin I, Alam MK, Khan AG. Effect of a single dose of low-level laser therapy on spontaneous and chewing pain caused by elastomeric separators. Am J Orthod Dentofacial Orthop 2019;156:87-93.

55. Qamruddin I, Alam MK, Fida M, Khan AG. Effect of low-level laser therapy on pain induced by orthodontic forces. Photomed Laser Surg 2012;30:460-5.

56. Al-Sayed Hasan MMA, Sultan K, Hamadah O. Evaluating low-level laser therapy effect on reducing orthodontic pain using two laser energy values: A split-mouth randomized placebo-controlled trial. Eur J Orthod 2018;40:23-8.

57. Qamruddin I, Alam MK, Abdullah H, Kamran MA, Fida M, Khan AG. Effect of a single-dose, low-level laser therapy on pain associated with the initial stage of fixed orthodontic treatment: A randomized clinical trial. Korean J Orthod 2018;48:90-7.

58. Wu S, Chen Y, Zhang J, Chen W, Shao S, Shen H, et al. Effect of low-level laser therapy on tooth-related pain and somatosensory function evoked by orthodontic treatment. Int J Oral Sci 2018;10:22.

59. Celebi F, Ozturk T, Bicakci AA. Effects of low-level laser therapy and mechanical vibration on orthodontic pain caused by initial archwire. Am J Orthod Dentofacial Orthop 2019;156:87-93.

60. Lo Giudice A, Nucera R, Perillo L, Puisasco 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;19:71-8.

61. Martins IP, Martins RP, Caldas SGFR, Dos Santos-Pinto A, Buschang PH, Pretel H. Low-level laser therapy (830 nm) on orthodontic pain: Blinded randomized clinical trial. Lasers Med Sci 2019;34:281-6.

62. Almallah MME, Hajeer MY, Almahdi WH, Burhan AS, Latifé Y, Madkhaneh SK. Assessment of a single versus double application of low-level laser therapy in pain reduction following orthodontic elastomeric separation: A randomized controlled trial. Dent Med Probl 2020;57:45-52.

63. Anicic MS, Perkovic V, Gabric D, Lajnert V, Mestrovic S. Effect of a double dose of photobiomodulation therapy on orthodontic pain caused by elastomeric separators. Australs Med J 2020;13:310-6.

64. El Shehawy TO, El Awady AA, Hussein FA. Effect of low-level laser therapy on pain experienced during leveling and alignment of lower anterior teeth: A randomized controlled clinical study. Al-Azhar J Dent Sci 2020;23:201-7.

65. Al-Sayed Hasan MMA, 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.

66. Liu J, Li C, Yang J, Niu Q, Qin W, Li Q, et al. Clinical efficiency of Nd:YAG laser in reducing orthodontic pain. Clin Surg 2020;5:2761.

67. Matys J, Jaszczak E, Flieger R, Kostrzewska-Kaminiarz K, Grzech-Leśniak K, Dominiai M. Effect of ozone and diode laser (635 nm) in reducing orthodontic pain in the maxillary arch-a randomized controlled clinical trial. Lasers Med Sci 2020;35:487-96.

68. Nicotra C, Polizzi A, Zappalà G, Leonida A, Indelicato F, Caccianiga G. A comparative assessment of pain caused by the placement of bonded orthodontic appliances with and without low-level laser therapy: A randomized controlled prospective study. Dent J 2020;8:24.

69. Oza MJ, Desai H, Iyengar SS, Yadav P, Kadivar M. Comparative study of effects of Laser, Tens, and anesthetic gel for controlling pain after placement of elastomeric separators: A clinical trial. Int J Clin Pediatr Dent 2020;13:82-6.
70. Ren C, McGrath C, Gu M, Jin L, Zhang C, Sum FHKMH, et al. Low-level laser-aided orthodontic treatment of periodontally compromised patients: A randomised controlled trial. Lasers Med Sci 2020;35:729-39.

71. Sfondrini MF, Vitale M, Pinheiro ALB, Gandini P, Sorrentino L, Larussi UM, et al. Photobiomodulation and pain reduction in patients requiring orthodontic band application: Randomized clinical trial. Biomed Res Int 2020;2020:7460938.

72. Celebi F, Bicakci AA, Kelesoglu U. Effectiveness of low-level laser therapy and chewing gum in reducing orthodontic pain: A randomized controlled trial. Korean J Orthod 2021;51:313-20.

73. Ang Khaw CM, Dalci O, Foley M, Petocz P, Darendeliler MA, Papadopoulou AK. Physical properties of root cementum: Part 27. Effect of low-level laser therapy on the repair of orthodontically induced inflammatory root resorption: A double-blind, split-mouth, randomized controlled clinical trial. Am J Orthod Dentofacial Orthop 2018;154:326-36.

74. Ng D, Chan AK, Papadopoulou AK, Dalci O, Petocz P, Darendeliler MA. The effect of low-level laser therapy on orthodontically induced root resorption: A pilot double blind randomized controlled trial. Eur J Orthod 2018;40:317-25.

75. 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;24:1431-8.

76. 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.

77. Deana NF, Alves N, Baghato VS, Sandoval P. Effects of low-level laser on the repair of orthodontically induced inflammatory root resorption: A systematic review of studies in rats. International Journal of Morphology 2019;37:977-84.

78. da Silva AP, Petri AD, Crippa GE, Stuani AS, Stuani AS, Rosa AL, et al. Effect of low-level laser therapy after rapid maxillary expansion on proliferation and differentiation of osteoblastic cells. Lasers Med Sci 2012;27:777-83.

79. He WL, Li CJ, Liu ZP, Sun JF, Hu ZA, Yin X, et al. Efficacy of low-level laser therapy in the management of orthodontic pain: A systematic review and meta-analysis. Lasers Med Sci 2013;28:1581-9.

80. Fromont-Colson C, Marquez-Diaz M, Badran Z, Cuny-Houchmand M, Soueidan A. Efficiency of low-level laser therapy for orthodontic tooth movement: A review. Lasers Dent Sci 2017;1:47-56.

81. Hussain AS, Al Toubity MJ, Elias WY. Methodologies in orthodontic pain management: A review. Open Dent J 2017;11:492-7.

82. Nimeri G, Kau CH, Abou-Kheir NS, Corona R. Acceleration of tooth movement during orthodontic treatment—A frontier in orthodontics. Prog Orthod 2013;14:42.

83. Omar M, Kaklamanos EG. Does the rate of orthodontic tooth movement change during pregnancy and lactation? A systematic review of the evidence from animal studies. BMC Oral Health 2020;20:237.

84. Aljawal AM, Hajeer MY, Ajay MA, Hamadah O, Brad B. Effectiveness of minimally invasive surgical procedures in the acceleration of tooth movement: A systematic review and meta-analysis. Prog Orthod 2016;17:33.

85. Harris EF. Root resorption during orthodontic therapy. Semin Orthod 2000;6:183-94.

86. Feller L, Khammissa RA, Thomadakis G, Fourie J, Lemmer J. Apical external root resorption and repair in orthodontic tooth movement: Biological events. Biomed Res Int 2016;2016:4864195.

87. Panainte I, Grancea CG, Zamfir-Buta VT, Pacurar M. Apical root resorption after orthodontic treatment. Eur Sci J 2016;12:43.

88. Jiang RP, McDonald JP, Fu MK. Root resorption before and after orthodontic treatment: A clinical study of contributory factors. Eur J Orthod 2010;32:693-7.

89. Wang J, Lamani E, Christou T, Li P, Kau CH. A randomized trial on the effects of root resorption after orthodontic treatment using pulsating force. Bmc Oral Health 2020;20:238.

90. Yassir YA, McIntyre GT, Bearj DR. Orthodontic treatment and root resorption: An overview of systematic reviews. Eur J Orthod 2021;43:442-56.

91. Flieger R, Gedrange T, Grzech-Leśniak K, Dominik M, Matys J. Low-level laser therapy with a 635nm diode laser affects orthodontic mini-implants stability: A randomized clinical split-mouth trial. J Clin Med 2020;9:112.

92. Nayyer N, Tripathi T, Rai P, Gopal R. Effect of photobiomodulation therapy on external root resorption during orthodontic tooth movement—A scoping review. Lasers Dent Sci 2019;3:219-26.

93. Cronshaw M, Parker S, Anagnostaki E, Lynch E. Systematic review of orthodontic treatment management with photobiomodulation therapy. Photobiomodul Photomed Laser Surg 2019;37:862-8.

94. Heiskanen V, Hamblin MR. Photobiomodulation: Lasers vs. Light emitting diodes? Photochem Photobiol Sci 2018;17:1003-17.