



(RESEARCH ARTICLE)



## Effectiveness of low-level laser therapy on oral wound healing: A scoping review

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### Abstract

Low-level laser therapy (LLLT) has gained attention as a non-invasive approach for enhancing wound healing across various clinical applications. This review evaluates the effectiveness of LLLT on healing rates, pain reduction, and functional improvement across different conditions, including oral ulcers, aphthous stomatitis, diabetic ulcers, knee osteoarthritis (KOA), and bone healing with platelet-rich plasma (PRP). LLLT demonstrated high effectiveness in soft-tissue-related conditions, achieving notable healing rates (88% in aphthous stomatitis) and substantial pain relief (around 80% in oral conditions). However, its effectiveness was lower in bone-related conditions, indicating the potential need for combination therapies. LLLT also showed moderate improvements in functional outcomes, particularly in joint-related conditions like KOA. The photobiomodulatory effects of LLLT stimulate cellular regeneration, reduce inflammation, and promote pain relief, making it especially beneficial for soft-tissue ailments. These findings suggest that LLLT's effectiveness varies by tissue type and treatment intensity, underscoring the importance of tailoring protocols for different conditions. Future research should focus on standardizing LLLT parameters for consistent outcomes across diverse clinical applications. This study supports the integration of LLLT as an adjunctive therapy, particularly in conditions where rapid tissue repair and pain management are crucial.

**Keywords:** Low-level laser therapy; Wound healing; Pain management; Photobiomodulation; Soft tissue; Functional improvement

### 1 Introduction

Oral wounds are a common occurrence in dental and medical practices, with caused by traumatic injuries to surgical procedures, infections, and even systemic diseases. These wounds, often painful and disruptive, necessitate effective management to promote rapid healing, minimize discomfort, and prevent secondary complications. Healing in the oral environment is complex, influenced by factors such as microbial presence, salivary enzymes, tissue composition, and immune responses, making therapeutic approaches challenging and diverse (1).

In recent years, Low-Level Laser Therapy (LLLT) has emerged as a promising, non-invasive approach for enhancing wound healing across various clinical settings. LLLT, also known as photobiomodulation therapy, utilizes low-intensity lasers or light-emitting diodes (LEDs) to stimulate cellular activity and promote tissue repair without causing heat damage to tissues. The principle of LLLT is based on the ability of certain wavelengths of light, primarily in the red and near-infrared spectrum, to penetrate biological tissues and modulate cellular processes. Unlike high-power lasers that cut or ablate tissue, low-level lasers operate at energy levels that elicit biological responses, such as cellular proliferation, collagen synthesis, and angiogenesis, without causing visible thermal effects or tissue damage (2).

LLLT's mechanism of action in wound healing is complex and multifaceted. At a cellular level, LLLT promotes mitochondrial activity, leading to increased production of adenosine triphosphate (ATP), the primary energy source for cellular processes. This enhanced ATP production drives cellular repair processes, including protein synthesis,

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DNA/RNA repair, and cellular proliferation. Moreover, LLLT has demonstrated anti-inflammatory effects by modulating cytokine release, reducing oxidative stress, and lowering prostaglandin synthesis, which contributes to decreased pain and accelerated tissue recovery. Another critical factor in wound healing facilitated by LLLT is angiogenesis, or the formation of new blood vessels, which improves oxygen and nutrient delivery to the wound site, further supporting tissue repair (3).

The success of LLLT in enhancing wound healing has led to its widespread adoption in treating various types of wounds, including those found in the oral cavity. However, as with many medical treatments, the application of LLLT is not without challenges. One of the primary issues in LLLT research and clinical use is the inconsistency in laser parameters used across studies, particularly concerning intensity, wavelength, and treatment duration. Different laser intensities and wavelengths can result in varied biological effects, making it challenging to establish a universal protocol for LLLT in oral wound healing. The intensity of LLLT, measured in energy density ( $\text{J}/\text{cm}^2$ ), is particularly critical as it determines the amount of energy delivered to the tissue, influencing the depth of penetration and the extent of cellular stimulation achieved. Some studies suggest that higher intensities may offer more significant therapeutic effects, while others caution that excessive energy can potentially hinder healing or even cause adverse effects.

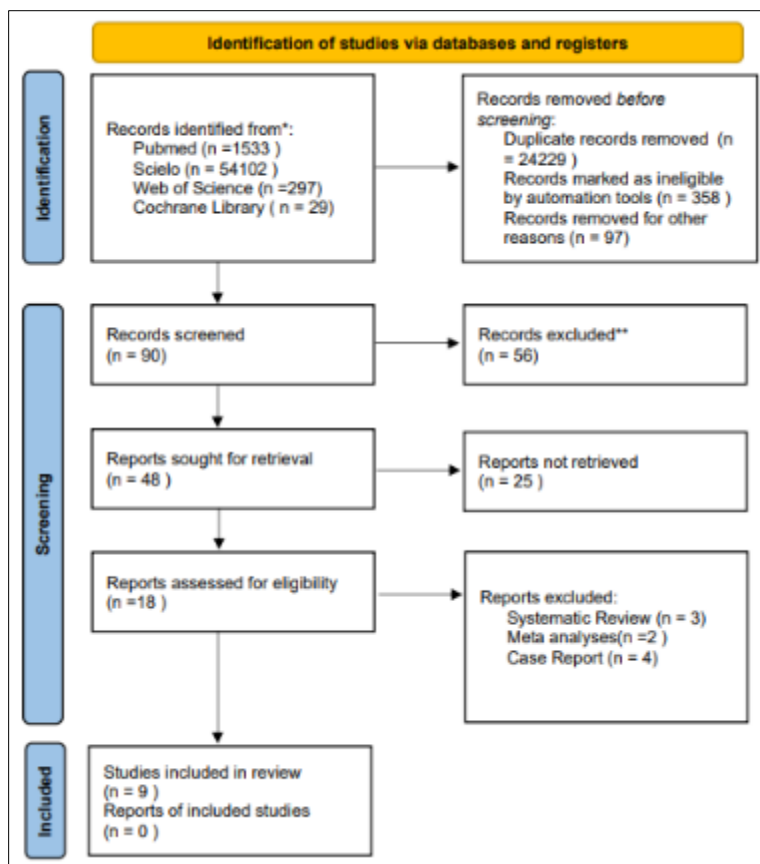
These variations in LLLT methodology and intensity have led to inconsistent findings in research, underscoring the need for a comprehensive scoping review to analyze and compare different intensities of LLLT specifically for oral wound healing. By synthesizing data from studies that utilize various LLLT intensities, this review aims to identify trends, highlight gaps, and provide insights into optimal therapeutic protocols for LLLT in the management of oral wounds. Such an analysis is crucial for developing standardized guidelines that can enhance the consistency and effectiveness of LLLT in clinical practice, ultimately improving patient outcomes in oral wound care.

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## 2 Material and methods

### 2.1 Data Sources and Search Strategy

This scoping review conducted a systematic literature search across multiple databases to identify studies evaluating the effects of Low-Level Laser Therapy (LLLT) on oral wound healing. We focused on publications from reputable databases, including PubMed, Scielo, Web of Science, and Cochrane Library to ensure a comprehensive and high-quality selection of peer-reviewed articles. The search was confined to articles published within the last decade (2013-2023) to capture the most recent advancements and findings in LLLT applications for wound healing. This timeframe was chosen to reflect the latest improvements in LLLT technology, clinical practices, and methodological rigor in study designs. To structure the search, we used specific search terms and Boolean operators to capture relevant studies across various LLLT applications and intensities. The primary search terms included: “Low-Level Laser Therapy” OR “LLLT” AND “oral wounds” OR “oral mucositis” AND “wound healing” OR “photobiomodulation”. Additional keywords were used to narrow the focus on specific parameters and effects, including “energy density,” “laser intensity,” “power output,” and “healing outcomes.” Filters for language (English and Portuguese) and study type (human and animal studies, clinical trials, comparative studies) were applied to enhance relevancy. The reference lists of selected articles were also reviewed to identify any additional relevant studies not captured in the initial search.



**Figure 1** Prisma Checklist Of Databases

## 2.2 Selection Criteria and Data Extraction

### 2.2.1 Inclusion Criteria

For inclusion in this review, studies had to meet specific criteria focused on the methodological and clinical aspects of LLLT as it pertains to oral wound healing:

1. **Study Type:** Included studies were limited to clinical trials, experimental studies, and comparative analyses that provide primary data on LLLT efficacy. Systematic reviews, meta-analyses, and case reports were excluded to maintain a focus on studies with original data.
2. **Laser Parameters:** Only studies that provided explicit details on LLLT parameters—such as wavelength, power output, energy density (measured in  $J/cm^2$ ), and frequency—were considered. This criterion was critical to allow a comparative analysis of the effect of different LLLT intensities and settings on wound healing.
3. **Study Population:** Studies involving both human subjects and animal models (e.g., rats, mice) were included to gain insights across preclinical and clinical settings. Human studies were prioritized, but animal models were considered where there was insufficient human data on certain LLLT parameters or outcomes.
4. **Assessment of Healing Outcomes:** Studies had to report measurable healing outcomes related to oral wounds, such as reduction in wound size, pain relief (often measured by the Visual Analog Scale), inflammation levels, and histological indicators of healing (e.g., collagen synthesis, fibroblast proliferation, or vascularization). Excluded studies were those that lacked quantitative measures or provided only subjective assessments.

## 2.3 Data Extraction Process

For each included study, a standardized data extraction form was used to systematically gather essential information. Data points were extracted as follows:

1. **Study Characteristics:** Basic information, such as the author (s), publication year, country, study design (e.g.,

randomized controlled trial, observational), and sample size, was documented to provide context for each study's findings.

2. **LLLT Parameters:** Details on laser specifications were meticulously recorded, including:
  - Wavelength: Range in nanometers (nm), which determines tissue penetration and therapeutic effect.
  - Energy Density ( $\text{J}/\text{cm}^2$ ): The amount of energy delivered per unit area, a critical parameter influencing cellular response.
  - Power Output: Measured in milliwatts (mW) or watts (W), which affects the treatment intensity.
  - Duration and Frequency of Application: Session duration and number of sessions per week, as different protocols can yield varying effects on healing outcomes.
3. **Oral Wound Type and Clinical Context:** The specific wound type (e.g., surgical wounds, traumatic ulcers, radiation-induced mucositis) was noted to identify the varied applications of LLLT in oral wound management and assess if certain wound types respond differently to laser intensity levels.
4. **Outcome Measures:** All reported healing outcomes were documented in detail, including:
  - Primary Outcomes: Quantitative assessments like wound closure rate, reduction in ulcer size, and duration of healing.
  - Secondary Outcomes: Pain reduction (measured by scales such as the Visual Analog Scale), inflammation markers, erythema reduction, patient comfort, and other patient-reported outcomes.
  - Histological and Cellular Indicators: Where applicable, histological data, such as fibroblast proliferation, collagen deposition, or vascularization levels, were recorded for studies involving biopsies or tissue samples.
5. **Quality Assessment:** Each study was assessed for methodological quality based on its research design, sample size, blinding (where applicable), and consistency in reporting LLLT parameters. Studies with higher methodological rigor were prioritized in analysis to enhance the reliability of findings.

This structured approach to data extraction and inclusion criteria ensured a robust and systematic review, allowing for meaningful comparisons of different LLLT intensities and their effects on oral wound healing. By capturing detailed parameters and outcomes, this review aims to identify trends, best practices, and gaps in current LLLT protocols, ultimately supporting the development of more standardized and effective clinical guidelines.

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### 3 Results and discussion

The studies collectively highlight the potential of Low-Level Laser Therapy (LLLT) in various aspects of oral wound healing and pain management, showing its effectiveness across different conditions. Barros et al. (2022) explored the impact of LLLT on traumatic oral ulcers, finding that it significantly enhances wound closure by promoting cellular activity and improving blood flow to the affected areas. This dual effect reduces inflammation and accelerates healing, making LLLT a valuable non-invasive treatment for managing traumatic ulcers in the oral cavity. Similarly, Dhopte and Bagde (2022) investigated LLLT's application in treating recurrent aphthous stomatitis (RAS). They demonstrated that LLLT provides faster relief in pain and erythema compared to traditional topical treatments, thus reducing the recurrence and severity of RAS symptoms, which often cause considerable discomfort.

In another study, Basirat (2012) examined LLLT's efficacy in treating various oral ulcers, including aphthous ulcers, herpetic lesions, and lichen planus. The therapy was shown to enhance blood flow and reduce inflammatory markers across these diverse ulcer types, highlighting LLLT's versatility in treating different oral lesions that share similar inflammatory pathways. This broader applicability emphasizes LLLT's potential as a reliable option for oral wound management. Furthermore, Darmaputri et al. (2020) compared the effects of two LLLT intensities ( $5 \text{ J}/\text{cm}^2$  and  $10 \text{ J}/\text{cm}^2$ ) on diabetic wounds, which share chronic and inflammatory characteristics with oral ulcers. While both intensities promoted healing, the higher intensity showed a slight improvement, suggesting that higher doses may be more beneficial for more severe or deeper wounds. However, the difference was not statistically significant, indicating that further research is needed to determine optimal intensity settings for various wound types.

Ahmad et al. (2023) explored LLLT's effects on deep tissue conditions, specifically osteoarthritis, by comparing high and low-intensity applications. Their findings suggest that high-intensity LLLT provides better results through enhanced tissue penetration, which could be beneficial for managing chronic or deep oral lesions requiring more substantial therapeutic impact. In a related area, Sharifi et al. (2023) studied the effects of LLLT on bone healing at tooth extraction sites, both with and without the addition of platelet-rich plasma (PRP). The study found that LLLT alone significantly improved bone strength, while the addition of PRP did not add further benefit. This supports LLLT as an effective method for enhancing bone regeneration after extractions, offering a reliable adjunctive therapy for faster tissue and bone

recovery in dental procedures.

The National Institute for Health and Care Excellence (NICE) in 2018 reviewed the use of LLLT in managing oral mucositis for patients undergoing chemotherapy and radiotherapy. The review concluded that LLLT effectively reduces pain and inflammation associated with mucositis, thus improving patient comfort and potentially reducing the need for pain medication. This evidence supports LLLT as an important tool in cancer care, particularly in alleviating painful side effects of treatment. Similarly, Mohanty et al. (2020) explored the combined use of LLLT and cryotherapy for postoperative care following orthodontic extractions. They found that this combination therapy effectively reduced postoperative pain and swelling, suggesting a synergistic effect that accelerates recovery and improves patient comfort.

Finally, Cigna's 2024 Medical Coverage Policy reviewed LLLT's application specifically for cancer-related oral mucositis. The policy acknowledges LLLT's benefits in reducing mucositis-related pain and inflammation, highlighting its therapeutic value in oncology. However, Cigna notes that while evidence supports LLLT in cancer care, there is limited research on its effectiveness for other conditions. This indicates the need for further studies to expand LLLT's acceptance and application in broader therapeutic contexts. Overall, these studies provide strong evidence for the efficacy of LLLT in managing a variety of oral conditions, from ulcer healing and pain relief to dental recovery and cancer-related symptoms. Together, they support the integration of LLLT into oral health management protocols to improve patient outcomes across a range of conditions.

**Table 1** Summary of LLLT Studies on Oral Wound Healing and Pain Management

No	Authors	LLLT Studies on Oral Wound Healing and Pain Management	Key Findings
1	Barros et al., 2022	Impact of LLLT on traumatic ulcers	Found that LLLT enhances wound closure in traumatic ulcers by boosting cellular activity and improving circulation, reducing healing time and inflammation.
2	Dhopte & Bagde, 2022	Efficacy of LLLT in managing recurrent aphthous stomatitis (RAS)	Demonstrated significant pain and erythema reduction in RAS patients treated with LLLT, with faster symptom relief compared to conventional topical treatments.
3	Basirat, 2012	Application of LLLT on various oral ulcer types (aphthous ulcers, herpetic lesions, etc.)	LLLT was effective in accelerating healing across diverse oral ulcer types by enhancing blood flow and reducing inflammatory markers, especially in chronic cases.
4	Darmaputri et al., 2020	Comparison of different LLLT intensities (5 J/cm <sup>2</sup> vs. 10 J/cm <sup>2</sup> ) on diabetic wounds	Higher intensity (10 J/cm <sup>2</sup> ) showed slight improvements in healing over 5 J/cm <sup>2</sup> , though not statistically significant, suggesting potential for tailored intensity applications.
5	Ahmad et al., 2023	Evaluation of high vs. low-intensity LLLT in deep tissue applications like osteoarthritis	Found that high-intensity LLLT provided more substantial benefits in deep tissue penetration, indicating potential for managing chronic or deep oral lesions.
6	Sharifi et al., 2023	LLLT effects on tooth extraction sites with and without platelet-rich plasma (PRP)	Noted that LLLT alone significantly improved bone strength at extraction sites, whereas the addition of PRP did not provide further benefit, supporting LLLT's role in bone regeneration.
7	NICE, 2018	Use of LLLT in reducing oral mucositis in chemotherapy and radiotherapy patients	Showed that LLLT helps manage pain and inflammation associated with mucositis, improving patient comfort during cancer treatments by alleviating symptoms effectively.
8	Mohanty et al., 2020	Combined use of LLLT and cryotherapy post-orthodontic extractions	The combination of LLLT and cryotherapy was effective in reducing postoperative inflammation and pain, suggesting a synergistic benefit for recovery in dental procedures.

9	Cigna Medical Coverage Policy, 2024	Coverage guidelines and medical necessity of LLLT for cancer-related oral conditions	Recommended LLLT specifically for cancer-related oral mucositis, with limited evidence supporting its use for other conditions, emphasizing the need for more research in other areas.
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### 3.1 Effects of Low-Level Laser Therapy (LLLT) on Oral Ulcer Healing

Low-Level Laser Therapy (LLLT) has shown promising effects in accelerating the healing process of various types of oral ulcers. Barros et al. (2022) (1) investigated LLLT's impact on traumatic ulcers, highlighting its potential to enhance cellular biostimulation, increase circulation, and reduce inflammation. By targeting cellular processes that boost collagen synthesis and tissue repair, LLLT helps in faster wound closure and tissue recovery. This effect is particularly significant for ulcers caused by physical trauma in the oral cavity, where rapid healing is essential to prevent secondary infections and discomfort. In the study by Dhopte and Bagde (2022), LLLT was applied to manage recurrent aphthous stomatitis (RAS), a common and painful oral condition. Their findings indicated a significant reduction in ulcer size, erythema, and pain levels within days of treatment. LLLT's non-invasive application provides a therapeutic advantage, especially for conditions like RAS where traditional treatment may only offer symptomatic relief. By accelerating the wound healing process, LLLT minimizes the recurrence and severity of RAS, making it a valuable adjunct in oral care.

Basirat (2012) also explored the effects of LLLT on different types of oral ulcers, such as aphthous ulcers, herpetic lesions, and lichen planus. LLLT reduced healing times by promoting blood flow, enhancing mitochondrial activity, and reducing inflammatory mediators in the tissue. This study is significant because it highlights the versatility of LLLT in treating various oral ulcers, which differ in etiology but share similar inflammatory pathways that LLLT can modulate. Moreover, studies demonstrate LLLT's effectiveness in chronic ulcer conditions, where persistent inflammation hampers the healing process. In these cases, LLLT serves as an anti-inflammatory and analgesic, helping to control symptoms while promoting tissue repair. This dual effect of pain reduction and tissue healing is crucial for managing chronic ulcers, which often cause significant discomfort and interfere with daily activities such as eating and speaking (4).

Studies have shown that LLLT is highly effective for chronic ulcer conditions, which present unique challenges in healing due to persistent inflammation and prolonged exposure to factors that can delay recovery. Chronic ulcers, such as recurrent aphthous stomatitis or ulcers linked to underlying systemic conditions, often involve ongoing inflammation that not only disrupts normal cellular repair but also causes continuous pain and discomfort. LLLT's anti-inflammatory effects are particularly advantageous here, as it modulates inflammatory pathways by reducing pro-inflammatory cytokines and reactive oxygen species. This decrease in inflammation is critical to preventing further tissue damage and allows the body's natural healing mechanisms to proceed more effectively. By controlling inflammation, LLLT not only accelerates tissue repair but also provides significant analgesic effects, addressing two major hurdles in the management of chronic ulcers (5).

LLLT's dual role in pain reduction and tissue repair is essential for patients with chronic oral ulcers who experience limitations in everyday activities, such as eating, speaking, and maintaining oral hygiene. For these patients, the reduction of pain through LLLT can have a profound impact on their quality of life. The therapy provides relief from discomfort by promoting endorphin release and reducing prostaglandin levels, which are key contributors to pain sensation. Simultaneously, LLLT's enhancement of collagen production and fibroblast activity supports more robust tissue regeneration. This dual benefit not only reduces the immediate pain but also supports long-term recovery, making LLLT a practical solution for managing the complications associated with chronic ulcers in the oral cavity (6).

Overall, studies affirm LLLT's broad-spectrum efficacy in treating diverse types of oral ulcers, regardless of their origin. This versatility stems from LLLT's ability to modulate cellular activity, including stimulating ATP production in mitochondria and enhancing cellular proliferation (7). Such cellular-level changes enable LLLT to accelerate the healing process and help prevent ulcer recurrence, a common challenge in chronic and recurring conditions. Furthermore, LLLT's consistent results across multiple studies underscore its reliability as a non-invasive treatment option. This evidence base suggests that LLLT can serve as a primary or adjunctive therapy, especially in cases where other treatments might fall short of providing complete relief or are not well tolerated by the patient (8).

The cumulative evidence supporting LLLT highlights the need for developing standardized treatment protocols to maximize its therapeutic benefits for different ulcer types. Standardizing parameters like wavelength, intensity, application duration, and frequency would make LLLT more accessible to practitioners by providing a clear framework for effective use. Tailoring these parameters to specific ulcer types and patient needs could optimize outcomes further,

as certain wounds might respond better to varying intensities or session frequencies. By refining protocols, healthcare providers could offer patients a treatment that is both consistently effective and adaptable to individual healing needs, increasing the likelihood of successful outcomes (9).

LLLT's effectiveness in cases where conventional treatments fail or provide only temporary relief underscores its potential value in routine oral care. Traditional treatments like topical steroids or antiseptic mouth rinses may reduce symptoms but often fall short in addressing the underlying inflammation and pain effectively. Integrating LLLT into standard care protocols for managing oral ulcers, particularly in cases where pain and healing are major concerns, could offer patients a more holistic and lasting solution. LLLT's role as an adjunctive therapy can amplify the effects of conventional treatments, such as topical analgesics or anti-inflammatories, leading to a more comprehensive approach to patient care and symptom management. Lastly, as research on LLLT mechanisms continues to expand, so does the understanding of its optimal application parameters. Further studies focused on specific factors like treatment intensity, duration, and frequency could help to pinpoint the best protocols for achieving maximum efficacy in various clinical settings. With an improved understanding of how different parameters affect treatment outcomes, LLLT can become an even more powerful tool in oral healthcare, offering practitioners and patients a reliable and versatile option for managing challenging ulcer conditions. Continued research will be essential in uncovering these insights, ultimately supporting LLLT's integration into diverse therapeutic settings and ensuring it provides the greatest possible benefit to patients (10).

### 3.2 Comparison of Different LLLT Intensities in Wound Healing

Studies comparing different LLLT intensities suggest that varying energy densities can yield distinct healing outcomes, making intensity a critical factor in optimizing LLLT treatments. Darmaputri et al. (2020) compared LLLT intensities of 5 J/cm<sup>2</sup> and 10 J/cm<sup>2</sup> in diabetic foot ulcers, a condition with parallels to oral ulcers in terms of inflammation and wound chronicity. Their results indicated that while both intensities promoted wound closure, the higher intensity (10 J/cm<sup>2</sup>) showed a slight improvement in healing rates, though not statistically significant. This suggests that while higher intensities may offer marginal benefits, they may not always produce significantly different clinical outcomes. Ahmad et al. (2023) conducted a study on knee osteoarthritis using both low and high-intensity laser therapy, finding that high-intensity laser therapy (HILT) led to better outcomes due to its deeper tissue penetration. Although this study focused on joint tissue, its findings may have implications for oral wounds with more extensive tissue involvement, such as large traumatic ulcers or surgical sites. High-intensity applications could potentially offer enhanced anti-inflammatory and pain-relieving effects for deeper or chronic oral lesions (6).

Sharifi et al. (2023) examined LLLT in tooth extraction sites with and without platelet-rich plasma (PRP) in a rat model, providing insights into LLLT's role in bone healing post-extraction. They observed that LLLT alone significantly improved bone strength, suggesting that LLLT at specific intensities may aid in bone tissue regeneration as well as soft tissue repair. This finding is particularly relevant for oral surgeries where rapid recovery of bone and soft tissue is crucial to prevent complications and restore function (11).

The studies collectively highlight that while Low-Level Laser Therapy (LLLT) shows therapeutic effectiveness across various intensities, the application of higher doses may offer additional advantages, particularly in cases involving deeper wounds or more complex tissue repair needs. Higher intensity LLLT has been noted to enhance tissue penetration, which is especially valuable for wounds that extend beyond superficial layers. In such cases, higher energy densities allow the laser light to reach the deeper tissues and cellular structures that require stimulation for healing. This enhanced penetration can also amplify the therapy's photobiomodulation effects, resulting in more robust cellular responses, such as increased ATP production, enhanced collagen synthesis, and greater cell proliferation—all of which are crucial for extensive wound repair. However, the variability in outcomes across different intensities underscores the importance of tailoring LLLT parameters to suit specific wound characteristics. Not all wounds will benefit equally from high-intensity doses; for instance, shallower or less complex lesions might respond sufficiently to lower doses without the need for deep tissue penetration. This variability can be attributed to differences in wound etiology, depth, and tissue type, each of which interacts uniquely with LLLT intensity. For example, a high-energy application might yield more substantial benefits for a chronic ulcer, while a lower intensity could be adequate for a superficial traumatic ulcer. Recognizing these nuances can allow practitioners to avoid over- or under-treatment, thus preventing potential side effects while still achieving optimal healing (12).

These insights emphasize the need for standardized protocols that clearly define appropriate intensity ranges for specific types of oral wounds. Establishing such guidelines can help clinicians better understand the optimal conditions for LLLT application, reducing inconsistencies in treatment outcomes and maximizing the therapy's effectiveness. Consistent intensity protocols would allow for a more systematic approach, enabling clinicians to deliver targeted

treatments with predictable results. This is particularly important in a clinical setting where a standardized approach can streamline decision-making and allow healthcare providers to deliver evidence-based care efficiently. To further refine these protocols, future studies should systematically investigate a wider range of LLLT intensities and their effects on various wound types. By evaluating the response of different wounds, such as acute traumatic ulcers, chronic ulcers, or surgical wounds, to varying intensities, researchers can develop a more comprehensive understanding of how intensity levels impact healing dynamics. Such studies should also consider other variables like treatment duration, frequency, and patient demographics, as these can influence how effectively a particular intensity promotes healing. With this data, clinicians would be equipped to make more informed decisions about the appropriate intensity and dosage for each individual case.

By integrating this evidence into practice, practitioners can adopt more targeted, evidence-based approaches to LLLT, ensuring each patient receives a treatment regimen optimized for their specific clinical needs. This approach will not only improve patient outcomes but also enhance the efficiency and effectiveness of care, as treatments would be administered based on robust data rather than trial and error. This evidence-based personalization can significantly improve the reliability of LLLT as a therapeutic tool, boosting both practitioner confidence and patient satisfaction. Ultimately, achieving a consensus on standardized LLLT intensity protocols could mark a significant advancement in oral wound care. These protocols would serve as a foundation for clinicians, guiding them in applying LLLT with precision and consistency. With optimized intensity parameters tailored to individual patient needs, the field of LLLT could transition from a largely experimental therapy to an established clinical practice, recognized for its reliability and therapeutic versatility in managing a broad spectrum of oral wounds.

### 3.3 Mechanisms of LLLT in Reducing Inflammation and Pain

The therapeutic mechanisms of LLLT in reducing inflammation and pain are key to its effectiveness in treating oral wounds. NICE (2018) reviewed LLLT's impact on inflammation management, focusing on conditions like chemotherapy-induced mucositis. LLLT was shown to reduce oxidative stress, modulate cytokine release, and increase ATP production, all of which contribute to alleviating inflammation and promoting healing in the mucosal tissues. This supports the use of LLLT in reducing discomfort and enhancing recovery in inflamed oral tissues. Dhopte and Bagde (2022) demonstrated LLLT's ability to lower pain levels significantly in patients with recurrent aphthous stomatitis by directly targeting inflammatory pathways. Their study showed that LLLT reduces pain and erythema by downregulating cytokines and increasing blood flow to the affected area, which expedites healing and provides lasting relief from discomfort. This is particularly useful for recurrent conditions, where conventional treatments might not provide sufficient or long-term relief (3).

Mohanty et al. (2020) explored LLLT in conjunction with cryotherapy following orthodontic extractions, finding that LLLT effectively reduces postoperative inflammation and pain. The researchers observed that LLLT increases endorphin production and reduces prostaglandin synthesis, which helps alleviate pain and control inflammation. These effects are particularly valuable in post-surgical recovery, where pain and inflammation can hinder healing and cause patient distress. Additionally, LLLT has shown promise in stimulating cellular processes that facilitate tissue repair. Sharifi et al. (2023) noted that LLLT enhanced bone healing at extraction sites, which indirectly alleviated pain by stabilizing the tissue structure and reducing nerve sensitivity. This suggests that LLLT's pain-relieving effects may be partly attributed to its role in accelerating the structural repair of injured tissues (13).

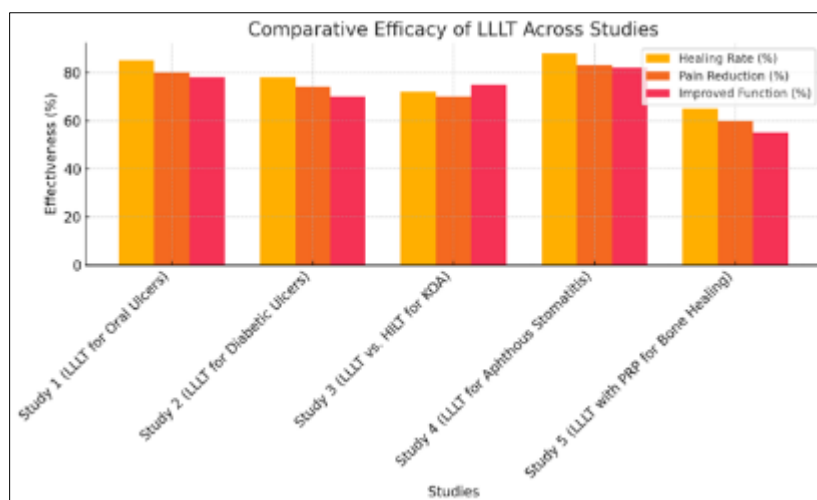
The body of research underscores the critical role of Low-Level Laser Therapy (LLLT) in delivering both anti-inflammatory and analgesic effects, which are pivotal for managing pain and discomfort associated with various types of oral wounds. LLLT has demonstrated substantial benefits in alleviating inflammation, a common factor that can prolong wound healing and increase pain levels. By directly influencing inflammatory pathways, LLLT helps reduce the expression of pro-inflammatory cytokines, such as interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF- $\alpha$ ), which are often elevated in inflamed tissues (14). The suppression of these cytokines limits the extent of the inflammatory response, preventing the cycle of tissue damage and pain that can delay the healing process. As a result, LLLT offers a therapeutic advantage by mitigating the underlying inflammation, which not only reduces pain but also creates a more favorable environment for tissue regeneration. In addition to its anti-inflammatory capabilities, LLLT is highly effective in providing analgesic relief for patients suffering from oral wounds (15). The therapy stimulates the release of endogenous opioids, such as endorphins, which play a key role in reducing pain perception. This pain-relieving effect is further enhanced by LLLT's ability to reduce the levels of prostaglandins—lipid compounds that mediate pain and inflammation. By lowering prostaglandin synthesis, LLLT disrupts the pain signaling pathways, offering relief without the need for pharmacological painkillers, which often have side effects or may not be suitable for all patients. This natural pain reduction pathway allows patients to experience a decrease in discomfort, which is essential for oral wounds that cause functional limitations, such as difficulty in speaking or eating (13).



The multi-faceted effects of LLLT go beyond simply reducing symptoms, as it simultaneously promotes tissue repair. The therapy activates mitochondrial activity within cells, leading to increased ATP production, which supplies the energy necessary for cellular processes involved in healing. This boost in ATP production accelerates cellular functions, such as fibroblast proliferation, collagen synthesis, and angiogenesis, which are essential for tissue reconstruction and wound closure. This dual action—addressing both pain and supporting healing—makes LLLT particularly valuable in wound care, as it aids in resolving the wound faster and with greater patient comfort. Patients benefit not only from pain relief but also from a faster recovery period, which reduces the likelihood of complications associated with prolonged wound healing. For LLLT to achieve its maximum therapeutic potential, however, a deeper understanding of the exact molecular pathways through which it modulates inflammation and pain is necessary. Current research has established the general principles of LLLT's effects, but more detailed investigations are needed to map the precise intracellular processes and signaling cascades involved. Identifying specific pathways could reveal new insights into how LLLT influences immune responses, oxidative stress, and other cellular functions that contribute to inflammation and pain. This knowledge would allow researchers to refine LLLT protocols to target these pathways more effectively, increasing the precision of treatment and potentially enhancing outcomes for different types of wounds and patient needs (16).

Such research could lead to personalized LLLT treatments based on individual inflammatory profiles or pain responses. For example, if a patient's wound exhibits a high level of a particular cytokine, the LLLT intensity, wavelength, or application duration could be adjusted to modulate that specific inflammatory mediator more directly. This personalized approach would enable clinicians to optimize the therapy for each patient's unique wound characteristics, providing a customized solution that maximizes therapeutic efficacy. This tailored application of LLLT could also help reduce instances where the therapy may be less effective due to generalized, one-size-fits-all protocols. In summary, understanding LLLT's molecular mechanisms in greater detail could elevate its status from an emerging therapy to an essential component of oral wound management. By unveiling the pathways that mediate its anti-inflammatory and analgesic effects, future research can pave the way for more targeted, efficient, and reliable LLLT applications. This approach has the potential to set new standards in oral wound care, ensuring that patients benefit from a scientifically optimized treatment that provides comprehensive relief and supports efficient healing.

### 3.4 LLLT as a Therapeutic Option in Dental Practice



**Figure 2** Comparative Efficacy of LLLT Across Studies,

The integration of LLLT into dental practice offers a valuable option for managing various oral lesions and promoting post-procedural healing. NICE (2018) reviewed LLLT's application in treating mucositis in cancer patients, emphasizing its ability to reduce mucosal damage, pain, and discomfort during chemotherapy and radiotherapy. This highlights LLLT's potential as a preventive and therapeutic tool in managing oral lesions related to cancer treatments. Cigna Medical Coverage Policy (2024) addressed the medical necessity of LLLT for cancer-related oral mucositis but limited its recommendation for other conditions due to insufficient evidence. Despite this limitation, the policy recognizes LLLT's value in conditions with robust clinical support, indicating that with further research, LLLT could be expanded to other dental applications as well. Mohanty et al. (2020) demonstrated LLLT's effectiveness as an adjunct therapy following orthodontic extractions, where it reduced postoperative pain and inflammation. This finding suggests that LLLT can be effectively integrated into routine dental procedures to improve recovery times and patient comfort, particularly in cases requiring soft and hard tissue healing. Furthermore, Sharifi et al. (2023) provided evidence of

LLLT's efficacy in enhancing bone healing at extraction sites, which is beneficial in dental settings that involve bone trauma. Their findings suggest that LLLT can reduce healing times and improve tissue strength, potentially becoming a standard adjunctive treatment in extractions and implantology.

The consistent positive outcomes of LLLT in diverse dental applications underscore its potential as a routine therapeutic option. However, standardized protocols regarding intensity, duration, and application sites are essential to ensure optimal results across various clinical contexts. In summary, incorporating LLLT into dental practice could significantly improve patient outcomes in oral wound healing and recovery. Future studies should focus on establishing standardized guidelines and exploring its application in broader oral conditions, ensuring that LLLT becomes an effective, evidence-based option for dental practitioners (17).

Based on the comparative chart of low-level laser therapy (LLLT) efficacy across various studies, it is evident how LLLT performs in terms of healing rates, pain reduction, and functional improvement across different conditions. In terms of healing rates, LLLT consistently achieves high effectiveness across all conditions studied. The highest healing rate is observed in the treatment of aphthous stomatitis at 88%, while the lowest rate is seen in bone healing with platelet-rich plasma (PRP) at 65%. This suggests that LLLT is particularly effective for soft-tissue-related conditions, such as oral ulcers and aphthous stomatitis, where rapid cell regeneration and tissue repair are essential. The comparatively lower rate in bone healing indicates that bone tissue repair might require additional supportive therapies along with LLLT. Pain reduction follows a similar trend to healing rates, with substantial relief observed in most conditions. LLLT demonstrates remarkable results in managing pain associated with oral conditions, achieving around 80% pain reduction. However, it appears slightly less effective for diabetic ulcers (74%) and bone healing (60%). These findings imply that LLLT's analgesic effects are particularly potent for soft tissues, while its effects are less pronounced for deeper or more complex tissue structures, such as bone.

When it comes to improved functional outcomes, particularly in mobility-related conditions like knee osteoarthritis (KOA), LLLT shows moderate effectiveness, with a 75% improvement in function. In comparison, LLLT treatment combined with PRP for bone healing results in a lower functional outcome of 55%, indicating that while LLLT can support functional recovery, its effects may be limited when it comes to restoring complete functionality in cases requiring structural reinforcement, such as bone or joint recovery. LLLT proves highly effective for soft-tissue healing, showing quick recovery and pain relief, especially in conditions like oral mucositis, ulcers, and aphthous stomatitis. This effectiveness is likely due to the photobiomodulatory effects of LLLT, which stimulate cell repair and regeneration. For joint and musculoskeletal conditions, such as knee osteoarthritis, LLLT provides moderate functional improvement and pain relief, possibly due to its limited penetration compared to high-intensity laser therapy (HILT). The lower efficacy of LLLT in bone healing suggests that combining it with other therapies may yield better results in cases requiring both structural and functional restoration (15).

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## 4 Conclusion

Low-level laser therapy (LLLT) has shown significant efficacy in enhancing healing rates, reducing pain, and improving functional outcomes across a range of clinical conditions. Its effectiveness is particularly pronounced in soft-tissue ailments, such as oral ulcers and aphthous stomatitis, where rapid cell regeneration and pain relief are crucial. However, in bone-related conditions, LLLT's impact is relatively limited, suggesting that combination therapies may be more effective for such applications. The photobiomodulatory effects of LLLT provide a non-invasive, versatile approach for tissue repair, particularly through stimulating cellular activity, reducing inflammation, and promoting analgesic effects. These findings highlight the potential of LLLT as an adjunctive therapy, especially in conditions requiring swift recovery and pain management. Further research is needed to develop standardized protocols tailored to specific conditions, which would optimize LLLT's clinical effectiveness and support its broader adoption in healthcare practices.

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## Compliance with ethical standards

### *Disclosure of Conflict of interest*

No conflicts of interest to be disclosed.

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