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Review article

The impact of low-level laser therapy (photobiomodulation) on the complications associated with conventional dental treatments and oral disorders: A literature review

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Abstract Oral health-related quality of life (OHRQoL) refers to how oral conditions impact an individual's social interactions and positive perception of their dental and facial appearance. OHRQoL is a crucial patient-reported outcome in dentistry and typically includes four key dimensions: Oral Function, orofacial pain, orofacial appearance, and Psychosocial impact. The Oral Health Impact Profile (OHIP) is a widely used tool for evaluating OHRQoL due to its strong psychometric properties. It focuses on how individuals perceive the repercussions of oral health issues. Complications arising from oral disorders and dental procedures can significantly disrupt a patient's daily routine, affecting aspects such as diet, sleep, physical activities, and work immediately following the intervention, thereby impacting their overall OHRQoL. Low-level laser therapy (LLLT), also known as "photobiomodulation," has emerged as a promising adjunctive treatment option to reduce inflammation, expedite the healing process, and

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enhance patients' OHRQoL. LLLT influences various cellular functions, including adenosine triphosphate production, protein and prostaglandin synthesis, neurotransmitter release, cellular growth, differentiation, and phagocytosis. Considering the significance of how oral health issues and associated treatment complications affect patients' OHRQoL, this study aimed to review patient-centered outcome measures in the context of LLLT to evaluate its impact on the complications associated with conventional dental treatments and oral disorders and patients' OHRQoL.

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Introduction

Oral health-related quality of life (OHRQoL) is essential in understanding how oral diseases or dental interventions can affect an individual's well-being and quality of life.¹ OHRQoL includes various dimensions, such as oral function, orofacial pain, appearance, and psychosocial impact. These dimensions aim to quantify the patient's experience.^{2,3} Common dental treatments like dental surgery, root canal therapy, and maxillofacial surgery, as well as orofacial diseases such as burning mouth syndrome (BMS), oral cancer, dental caries, and pericoronitis, can lead to complications like pain, sleep disorders, swelling, limited mouth opening, and difficulty eating. Conventional treatments like analgesics, antibiotics, and sedatives have helped alleviate these complications.^{4–6} However, these treatments come with their own set of issues, including addiction potential, digestive problems, drug resistance, high costs, and the need for patient compliance.^{7,8} Therefore, clinicians and researchers are actively exploring adjunctive treatment methods with minimal side effects that can reduce the complications associated with conventional dental treatments. These new approaches aim to reduce complications from conventional dental treatments and oral diseases.

One innovative approach is low-level laser therapy (LLLT), also known as low-intensity laser therapy, low-power laser therapy, cold laser, soft laser, photobiostimulation, and photobiomodulation (PBM).⁹ This therapy uses non-invasive specific light wavelengths between 650 and 1000 nm to promote tissue repair, reduce inflammation, and alleviate pain and discomfort.¹⁰ Typically, lasers, light-emitting diodes (LEDs), and broadband light within the visible, red, and near-infrared spectrum with power under 500 mW (mW) are used to produce therapeutic benefits without causing a noticeable temperature increase in the treated tissue or significant changes in the tissue structure.^{11–13}

Recent research suggests that LLLT or PBM can positively impact patients' OHRQoL without causing any adverse side effects.^{9,13} LLLT works by affecting various cellular activities, such as increasing the production of adenosine triphosphate (ATP), promoting protein and prostaglandin synthesis, regulating neurotransmitter release, promoting cellular growth and differentiation, facilitating phagocytosis, and ultimately reducing inflammation while expediting natural healing processes.^{14,15} Due to its ability to

modify cellular functions, LLLT can be considered a complementary treatment method that has the potential to significantly reduce the complications often associated with conventional dental procedures and oral conditions. OHRQoL is essential in the patient-centered evaluation of oral health issues and related treatment complications.¹⁶ Therefore, the current study aims to assess the impact of LLLT (PBM) on patients' OHRQoL.

Low-level laser therapy

LLLT works by activating cellular mechanisms through interactions with light. When cells absorb light energy, the molecular structure of the light receptor changes due to photon absorption, leading to alterations in cellular signaling. Initially, primary reactions involve changes in the photoreceptor's function, resulting in secondary modifications in cellular functions. At the cellular level, LLLT speeds up intracellular metabolic processes, promoting the synthesis of matrix, movement of fibroblasts, and cell proliferation.^{17,18} The effectiveness of laser stimulation depends on the amount of absorbed light energy, which is influenced by factors such as wavelength, optics, temperature, power, exposure duration, and tissue properties.¹³ Three essential parameters of LLLT are described as follows:

- 1 **Light source:** Various light sources are used in LLLT, and they can be categorized into two main groups: LEDs and lasers.¹³ There are several differences between LEDs and lasers. Firstly, LEDs produce light through electroluminescence, which involves electron movement in a semiconductor material that releases photons without thermal radiation. On the other hand, lasers generate light via stimulated emission, amplifying and focusing photons into a coherent beam by stimulating atoms or molecules.^{19,20} Secondly, LEDs typically emit light across a broader range of wavelengths, resulting in a wider bandwidth. In contrast, laser light is known for its narrow bandwidth, often emitting light in a specific wavelength or within a limited range of wavelengths.¹⁹ Thirdly, LEDs are generally more cost-effective than laser devices. The cost per milliwatt of optical power is notably lower for LEDs than lasers. This cost-effectiveness has increased LED use in applications like LLLT and healthcare.¹⁹ LEDs also produce heat during operation, which can degrade the semiconductor

material if not appropriately managed. Heat sinks or fans are commonly used to dissipate this heat. Laser devices also generate heat, but their heat management methods vary depending on the type of laser.¹⁹ Additionally, multiple LEDs can be arranged into planar arrays, enabling the treatment of larger body areas more conveniently.¹⁹ In contrast, lasers typically have smaller spot sizes, limiting the area they can efficiently treat. Finally, LEDs pose no risk of retinal damage, eliminating the need for eye protection.²⁰ In summary, LEDs and lasers each have unique advantages and applications; the key characteristic of lasers is their narrow bandwidth, as they typically emit light at a specific wavelength or within a limited range of wavelengths, making lasers increasingly popular in healthcare settings and most of the studies have used lasers and considering the lower the cost per milliwatt of optical power of LEDs than lasers, the relevant literature on LEDs is recommended.¹⁹

2 Power: Laser power refers to the energy delivered by a laser beam per unit of time and area, and it is typically measured in watts (W) or mW.²¹ Lasers are divided into three groups based on their power output: high power (exceeding 500 mW), moderate power (ranging from 250 to 500 mW), and low power (less than 250 mW). High-power lasers are often called “warm,” “hard,” or “surgical” lasers, and their therapeutic effectiveness depends on the temperature and the tissue’s response to heat. Different temperature ranges elicit distinct tissue reactions:²²

- Hyperthermia occurs at 37–43 °C
- Collagen damage and effects on cell membranes occur at 70–80 °C
- Molecular destruction occurs at 80–100 °C
- Carbonization, evaporation, and desquamation occur at 100–140 °C, 140–400 °C, and 500–800 °C, respectively.

Moderate-power lasers have a tissue-stimulating effect without generating excessive heat. On the other hand, low-power lasers, also known as “cold” lasers, produce gentle stimulation and gradual tissue responses without causing thermal effects.²² In LLLT or PBM, low-intensity light sources with power below 500 mW are used to avoid tissue heating and related issues like necrosis and damage, ensuring safe and effective treatment.^{13,22}

3 Wavelength: Low-level lasers typically emit light in the visible spectrum, particularly red light (600–700 nm) and near-infrared light (700–1200 nm), due to their low output power.^{20,22,23} These longer wavelengths can penetrate several centimeters into soft and hard tissues without causing excessive heat or tissue damage.²² Regarding light spectra, LLLT is effective in healing processes, particularly regeneration and anti-inflammatory signaling. This effectiveness is most notable within the red and infrared spectrum, with wavelengths ranging between 630 and 850 nm. These clinical benefits are precious in the oro-maxillofacial region and other anatomical areas of the body.^{20,23}

Mechanism of low-level laser therapy

LLLT is a new technique used to reduce complications from conventional dental procedures and oral health issues (Table 1). The main idea behind LLLT is biostimulation.⁵² When low-energy light in the visible and infrared spectrum is applied, it stimulates cellular activity and metabolism. This happens when photons are absorbed by a chromophore called cytochrome C oxidase (Cox), which increases mitochondrial membrane potential and initiates signaling in the mitochondria.¹³ This results in changes in ATP synthesis, the production of reactive oxygen species (ROS), and the release of nitric oxide (NO). ATP levels control cyclic adenosine monophosphate (cAMP), which affects various cellular functions like cell growth, differentiation, and gene transcription.⁵² After LLLT, increased cAMP levels activate the activator protein-1 (AP-1), a regulator that promotes cell proliferation. Under normal conditions, ROS are produced in low amounts during mitochondrial metabolism. However, when exposed to light, if the mitochondrial membrane potential in normal cells is altered, ROS production increases, which can be harmful. ROS generated during mitochondrial signaling can activate nuclear factor-kB (NF-kB), which responds to oxidative stress.⁵³ In therapeutic use, cells are in an abnormal state with low mitochondrial membrane potential due to existing abnormalities. Light absorption raises the mitochondrial membrane potential towards normal levels, reducing ROS production.^{54,55} These mechanisms contribute to *tissue repair, anti-inflammatory effects, pain relief, and nerve regeneration* (please see Fig. 1), ultimately improving OHRQoL.^{13,56} This focus on enhancing OHRQoL is important as it emphasizes the goal of improving patients’ overall well-being and satisfaction, a primary objective in treatment strategies.⁵⁷

Tissue repair

LLLT has been shown to enhance tissue repair and wound healing, which can be beneficial after conventional dental treatments such as dental extractions and root canal therapy. LLLT can reduce symptoms, improve patient comfort, and enhance their OHRQoL by speeding up the repair process. Initially, LLLT increases microcirculation by promoting the growth of new capillaries (angiogenesis). This increased blood flow delivers oxygen and nutrients to tissues, prompting cell mitochondria to produce more ATP, the cell’s energy source.^{13,14} This enhanced energy production regulates the proliferation of various cell types crucial for healing, such as keratinocytes and fibroblasts. Fibroblasts play a key role in collagen production, vital for tissue repair and wound healing. LLLT stimulates fibroblast activity, enhancing collagen synthesis and faster wound closure. Moreover, exposure to LLLT prompts fibroblasts to replicate and mature more rapidly, transitioning to myofibroblasts, which reduces E2 prostaglandin production and increases basic fibroblast growth factors (bFGF).^{13,58} This modulation helps balance cell growth and death, facilitating optimal tissue repair. Additionally, LLLT can regulate

Table 1 Summary of key characteristics of clinical studies assessing the impact of low-level laser therapy (photobiomodulation) on complications associated with traditional dental treatments and oral disorders.

Oral disorder/dental procedure	Patients			Low-level laser therapy				Questionnaire	Oral health related quality of life	Refs
	Groups (n = sample size)	Gender (male/ female)	Age (mean $\pm$ SD)	Type of laser	Time of exposure	Irradiation parameters	Sessions			
Endodontic treatment	PBM (35) Control (35)	27/43	over 18 years of age	InGaAlP	90 s	660 $\pm$ 10 nm 100 mW 9 J 3.33 W/cm ²	1	OHIP-14	Root canal treatment with or without PBM significantly improved the participants quality of life.	24
Extraction of lower molars	Without any adjunctive treatment (10)	15/25	41.25 $\pm$ 13.97	—	—	—	—	OHIP-14	After lower molar extraction, the aPDT and LLLT protocols positively affected the participants' quality of life.	25
	aPDT (10)			InGaAlP	90 s	660 $\pm$ 10 nm 100 mW 9 J 300 J/cm ² 3.33 W/cm ²	1			
	LLLT (10)			GaAlAs	40 s	808 nm 100 mW 133 J/cm ² 3.33 W/cm ²	1			
Cervical dentin hypersensitivity with the non-carious cervical lesion	aPDT + LLLT (10)	38/36	22–54 years	Use of both mentioned sources	Use of both mentioned sources	Use of both mentioned sources	1	OHIP-14	LLLT needs more time to effectively reduce CDH. This longer duration may be reflected in the OHIP-14 questionnaire results, as it indicates more limitations on daily activities due to more prolonged CDH symptoms.	26
	Potassium oxalate (24) LLLT (24) Potassium oxalate + LLLT (27)			AsGaAl	16 s	100 mW 808 nm 60 J/cm ²	4			
Xerostomia and hyposalivation	PBM (30) Control (Laser was turned off, 30)	2/58	65.4 68.4	Diode laser	Parotid gland: 144 s Submandibular gland: 72 s	810 nm 1 W 6 J/cm ²	6	VAS OHIP-14 HAD PSQI ESS	PBM with the diode laser is effective in patients with xerostomia and hyposalivation and should thus be considered a treatment option.	27
Neurotmesis following trauma and mandibular fracture	PBM (30) Control (Laser was turned off, 30)	54/6	35.69 $\pm$ 13.44 36.23 $\pm$ 11.51	GaAlAs	30 s	810 nm 200 mW 12–14 J/cm ²	12	OHIP-14	PBM could be an effective treatment for late post-traumatic nerve neurotmesis following a traumatic mandibular fracture.	28
Burning mouth syndrome	LLLT (21) Control (no intervention, 21)	8/34	51.69	Nd:YAG	30 s	1064 nm 100 mW 3 J/cm ² 10 Hz	4	VAS	PBM was influential in the reduction of pain in BMS.	29
Head and neck radiotherapy- induced oral mucositis	PBM (25) Control	41/7	59.75 $\pm$ 11.69	Diode laser	10 s	660 nm 25 mW 50 Hz 625 mW/cm ²	5	PROMS OHIP-14	PBM was effective in treating and preventing oral mucositis.	30

Burning mouth syndrome	PBM (20) Control (Laser was turned off, 20)	0/40	62.06 ± 3.1	Diode laser	300 s	6.2 j/cm ² 805 nm 4 W 60 mW 50 J/cm ² 166.7 mW/cm ²	8	VAS NSR	The improvement in the symptoms of BMS could be related to PBM.	31
Burning mouth syndrome	PBM (10) Control (Laser was turned off, 10)	4/16	60.30 ± 15.19 67.60 ± 10.68	Diode laser	10 s	810 nm 12 J/cm ² 0.6 W 1.2 W/cm ²	10	VAS OHIP-14 Epworth McGill	Pain reduction has been shown in patients with BMS by using PBM.	32
Burning mouth syndrome	LLLT (12) Control (Laser was turned off, 11)	3/20	61.5	GaAIs	381 s	685 nm 2 J/cm ² 30 mW 0.003 W/cm ²	10	VAS	LLLT is helpful in the reduction of burning symptoms and salivary cortisol levels in BMS patients.	33
Gingivectomy and Gingivoplasty	PBM (12) Control (no intervention, 12) Ozone group (12)	N/A	14–27	GaAIs	60 s	810 nm 300 mW 300 mW/cm ² 4 j/cm ²	3	VAS OHIP-14	PBM and ozone applications after gingivectomy and gingivoplasty reduce the pain and improve quality of life.	34
Head and neck radiotherapy-induced oral mucositis	PBM (10) Control (sham, 11)	16/5	64.05 ± 8.33	InGaAlP	17.5 s	810 nm 40 mW 25 J/cm ²	3	VAS TESS UW-QOL	PBM may help in preserving salivary PH. No difference between groups was noted in quality of life.	35
Burning mouth syndrome	PBM (43) Control (sham, 42)	0/85	59.76 ± 9.51 60.86 ± 10.02	K Laser Cube	3 min 51 s	660–970 nm 3.2 W	10	VAS OHIP-14 QLROH	Positive effects in BMS symptoms and improvement of quality of life have been shown in PBM.	36
Burning mouth syndrome	LLLT (12) Control (Laser was turned off, 9)	1/20	66.3 ± 6.99	GaAIs	15 s	808 ± 5 nm 200 mW 1.97 W/cm ²	8	VAS HADS	LLLT can relieve oral burning in BMS.	37
Temporomandibular disorder	Sample size: 13	3/10	Male: 50 ± 15.52 Female: 37.2 ± 11.44	Diode laser	120 s	808 nm 100 mW 684 J/cm ² 5.7 W/cm ²	8	OHIP-14	LLLT was effective in the treatment of TMD.	38
Extraction of retained lower third molars	LLLT (19) Control (Laser was turned off, 19)	N/A	N/A	LED	7 min (intraoral) 10 min (extraoral)	660 nm (intraoral) 850 nm (extraoral) 5 mW 6.4 mW/cm ² 2.7 J/cm ² (intraoral) 3.8 J/cm ² (extraoral)	3	OHIP-14 BAI	LLLT has shown promising results in the control of postoperative sequelae.	39
Burning mouth syndrome	LLLT (10) ALA (5)	6/9	60.2	Low level class 3B laser	10 s	660 nm 3 J/cm ² 30 mW	4	VAS	LLLT was effective in reducing burning mouth syndromes even more than ALA.	40
Burning mouth syndrome	LLLT (22) Control (sham, 22)	1/43	67.56	GaAIs	Switched on: 800 ms Switched off: 1 ms	830 nm 100 mW 12 J/cm ²	10	VAS OHIP-14	Both switched on and off decreased pain symptoms and improved OHIP-14.	41
Spastic cerebral palsy	PBM (26) Positive control group (26) Negative control group (26)	40/38	9.5 ± 2.2	GaAIs	20 s	808 ± 3 nm 120 mW 3 j/cm ² 3 W/cm ²	6	P-CPQ	PBM reduces the impact of spastic cerebral palsy.	42

(continued on next page)

Table 1 (continued)

Oral disorder/dental procedure	Patients			Low-level laser therapy				Questionnaire	Oral health related quality of life	Refs
	Groups (n = sample size)	Gender (male/ female)	Age (mean $\pm$ SD)	Type of laser	Time of exposure	Irradiation parameters	Sessions			
Burning mouth syndrome	LLLT- A (16) LLLT- B (16) Control (sham, 12)	3/41	65.5 $\pm$ 10.6	GaAlAs diode laser (A) GaAlAs infrared laser (B)	A: 4 s B: 6 s	815 nm 1 W 133.3 J/cm ² (A) 200 J/cm ² (B)	4	VAS OHIP-14 HAD PGI-1	LLLT application decreases symptoms slightly in BMS patients.	43
Burning mouth syndrome	LLLT (13) Control (sham, 10)	2/21	59.7	GaAlAs diode laser	50 s	790 nm 120 mW 4 W/cm ² 6 J/cm ²	4	VAS	LLLT group shows similar benefits to those of the control group.	33
Burning mouth syndrome	LLLT (18) Control (sham, 15)	8/25	67.12 $\pm$ 8.58	GaAlAs diode laser	10 s	980 nm 300 mW 1 W/cm ² 10 J/cm ²	10	VAS McGill OHIP-14 HADS PPI	Patients treated with LLLT experienced a decrease in pain sensation.	44
Burning mouth syndrome	LLLT (10) Control (sham, 10)	0/20	47.2 $\pm$ 5.3 46.6 $\pm$ 4.6	Iodine-Gallium- Arsenide laser	10 s	630 nm 30 mW 1 J/cm ²	4	OHIP-14 NSR	LLLT might reduce the severity of BMS.	45
Hematopoietic Stem cell transplantation chemotherapy-induced oral mucositis	LLLT (20) Control (no intervention, 19)	17/22	39	InGaAlP diode laser	4 s	660 nm 40 mW 4 J/cm ²	+7	OHIP-14 FACT-BMT	LLLT did not influence the quality of life of HSCT, although it was clinically effective in reducing oral mucositis.	46
Burning mouth syndrome	IR1W (20)	11/67	62.82 $\pm$ 7.54	GaAlAs (IR1W & IR3W) InGaAlP (red laser)	50 s	830 nm 100 mW 3.57 W/cm ² 176 J/cm ²	10	OHIP-14 VAS VNS	LLLT reduces the symptoms of BMS.	47
	IR3W (20)			Diode laser	50 s	830 nm 100 mW 3.57 W/cm ² 176 J/cm ²	9			
	Red laser (19)				58 s	685 nm 35 mW 1.25 W/cm ² 72 J/cm ²	9			
	Control (sham, 19)				—	—	—			
Sagittal split ramus osteotomy that presents neurosensory impairment of mandibular nerve	LLLT (17) Control (Laser was turned off, 14)	10/21	23 21.5: 23	GaAlAs diode laser	90 s	810 $\pm$ 20 nm 100 mW 32 J/cm ²	8	VAS	LLLT was beneficial for the recovery of neurosensory impairment.	48
Head and neck chemoradiotherapy-induced oral mucositis	LLLT (110) Control (no intervention, 110)	189/31	55 $\pm$ 11.52 56 $\pm$ 11.80	He-Ne laser	125 s	632.8 nm 24 mW/cm ² 36–40 J/cm ²	33 (five fractions/ week for 6.5 weeks)	OMWQ-HN FACT-HN	LLLT effectively improved the life and oral mucositis of HNC patients receiving chemoradiotherapy.	49
Burning mouth syndrome	LLLT (20) Control (Laser was turned off, 20)	13/27	60.2 $\pm$ 6.3 61.1 $\pm$ 2.2	GaAlAs diode laser	100 s	685 nm 30 mW 3 J/cm ²	20	VAS	There was no significant difference in the experimental group.	50

Acute pericoronitis	LLLT-A (20)	39/41	23.65	ND:YAG	10 s	1064 nm 0.25 W 10 Hz 8 J/cm ²	1	OHIP-14 VAS	LLLT has biostimulatory effects and improves the quality of life.	51
	LLLT-B (20)			GaAlAs diode laser	60 s	660 nm 0.04 W 8 J/cm ²				
	LLLT-C (20)			GaAlAs diode laser	10 s	808 nm 0.25 W 8 J/cm ²				
	Control (sham, 20)									

Abbreviation: ALA, alpha-lipoic acid; aPDT, antimicrobial photodynamic therapy; BAI, beck anxiety inventor; BMS, burning mouth syndrome; CDH, cervical dentin hypersensitivity; EG, experimental cp group; ESS, epworth sleepiness scale; HAD, hospital anxiety-depression scale; FACT-BMT, functional assessment of cancer therapy-bone marrow transplantation; FACT-HN, functional assessment of cancer treatment head and neck; GaAlAs, Gallium-aluminum-arsenide; HSCT, Hematopoietic Stem cell transplantation; HNC, Head and neck chemo-radiotherapy; He-Ne laser, Helium–neon laser; IR1W, infrared laser weekly group; IR3W, infrared laser three times a week; InGaAlP, Indium-gallium-aluminum phosphide; J, Joule; J/cm², Joules per square centimeter; LED, Light-emitting diode; LLLT, low level laser therapy; Ms, Millisecond; Min, Minute; mW, Milliwatt; mW/cm², Milliwatt per square centimeter; NSR, numeric rating scale; N/A, Not applicable; Nd:YAG, Neodymium-doped yttrium aluminum garnet; Nm, Nanometer; OHIP-14, oral health impact profile-14; PBM, photobiomodulation; CPQ, parental-caregiver perception questionnaire; PROMS, patient-reported oral mucositis symptoms scale; PPI, present pain intensity; PO, potassium oxalate; POLL, potassium oxalate associated with low-power laser irradiation; PSQJ, pittsburgh sleep quality index; PGI-1, patient global impression of improvement; OMWQ-HN, oral mucositis weekly questionnaire head and neck; QLROH, quality of life related to oral health; Sec, Second; TESS, treatment-emergent symptom scale; TMD, Temporomandibular disorder; UW-QOL, university of Washington quality of life assessment; VAS, visual analogue scale; VNS, visual numeric scale; W/cm², watt per square centimeter.

oxidative stress by boosting antioxidant production and reducing ROS. By balancing oxidative stress levels, LLLT supports healing and protects cells from damage.¹³

Anti-inflammatory effect

Inflammation and its association with pain are common issues that can significantly impact one’s quality of life. LLLT is a promising approach to reducing inflammation, especially in conditions like pericoronitis and oral mucositis post-cancer treatment. This therapy operates through multiple mechanisms, including reducing inflammatory mediators, modulating immune responses, and enhancing blood circulation.¹³ To start, LLLT plays a crucial role in reducing the production of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α), interleukin 1 beta (IL-1β), and IL-6. By diminishing the levels of these inflammatory mediators, LLLT effectively mitigates the intensity of the inflammatory response, thereby aiding in managing associated symptoms.^{56,59,60} Moreover, LLLT can modulate the activity of immune cells, such as macrophages and lymphocytes, which play a key role in the inflammatory process. LLLT helps regulate immune responses through this modulation, curbing inflammation and facilitating healing.^{13,61} LLLT’s ability to enhance blood flow to the target area is instrumental in combating inflammation. Improved circulation facilitates the removal of inflammatory substances and ensures the efficient delivery of oxygen and nutrients essential for resolving inflammation effectively.^{13,56}

Pain relief

The impact of pain on both physical and mental well-being can lead to a decline in an individual’s OHRQoL. LLLT is showing promise in managing pain associated with conditions such as temporomandibular joint disorders, oral mucositis, dentin hypersensitivity, and postoperative pain. This non-invasive treatment method uses its analgesic, anti-inflammatory, and modulatory effects to alleviate discomfort with minimal contraindications, ultimately improving the quality of life for patients.^{9,13,62} LLLT targets pain nerve endings, modulating nociception and reducing pain signals by leveraging mitochondrial photoreceptors that absorb laser light, initiating energy transduction processes that lead to intracellular events. This cascade of reactions culminates analgesia by impeding nerve impulse conduction velocity, particularly inhibiting delta A and type C nerve fibers.^{63,64} Additionally, LLLT functions similarly to non-steroidal anti-inflammatory drugs by mitigating inflammation. It achieves this by reducing prostaglandin levels, altering the arachidonic acid pathway, and ultimately diminishing pain sensations, thus exhibiting anti-inflammatory properties crucial for pain management.^{56,65} Furthermore, LLLT accelerates the healing process of wounds and damaged tissues by promoting the release of growth factors and enhancing cellular energy production (ATP).^{56,58,66} This stimulation fosters cellular proliferation, maturation, and functionality, contributing to pain reduction and the restoration of proper tissue function.

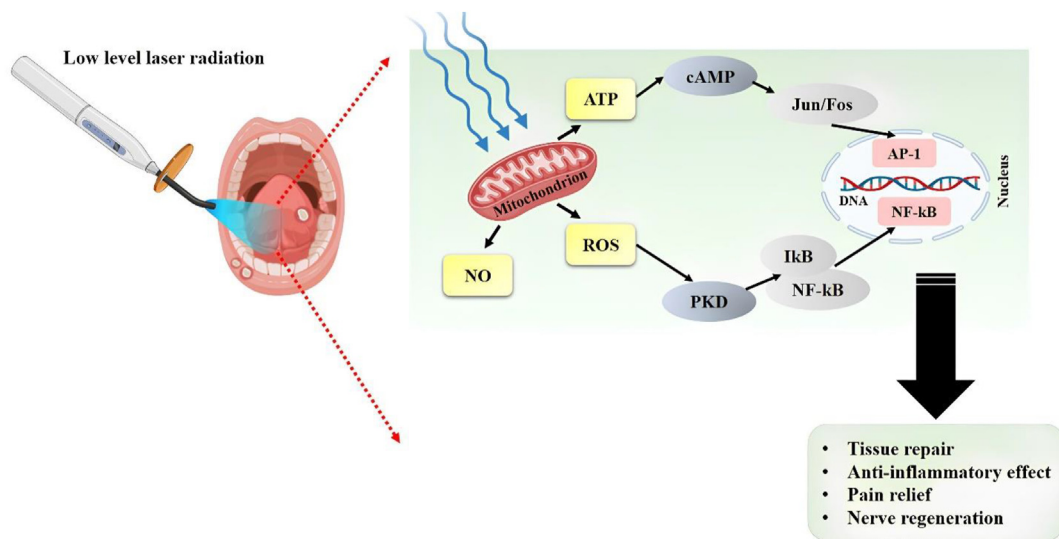


Figure 1 Mechanism of low-level laser therapy. ATP: Adenosine triphosphate, AP-1: activator protein-1, cAMP: Cyclic adenosine monophosphate, NO: Nitric oxide, ROS: Reactive oxygen species, PKD: Protein kinase D, NF-κB: Nuclear factor-κB, IκB: Inhibitor of κB.

Nerve regeneration

Nerve injuries, particularly to the inferior alveolar nerve, can occur due to significant facial trauma such as mandibular fractures or complex maxillofacial procedures such as bilateral sagittal split osteotomy, can have detrimental effects on individuals.^{28,48} These injuries can lead to neurosensory issues like paraesthesia or dysesthesia in the affected area, potentially causing long-lasting or permanent numbness in the lower lip, chin, and lower incisors.^{67,68} Damage to peripheral nerves triggers a repair and regeneration process, while damage to central nervous system cells results in irreversible nerve damage. Incomplete nerve lesions often do not spontaneously recover, leading to axon degeneration.^{69–71} Treatment for nerve injuries ranges from non-surgical approaches like corticosteroids and vitamin B12 supplementation to surgical interventions such as nerve microsurgery and grafting. The time and cost involved, patient cooperation, potential complications, and the necessity of a skilled surgeon for surgical procedures have led to the proposal of a new method to aid in nerve repair.⁷² LLLT has been proposed as a method to aid in nerve repair,⁷³ as it may assist in nerve regeneration and alleviate neuropathic pain without the need for surgery.⁷⁴ LLLT can help stabilize neuron membranes, reduce pain transmission, decrease the production of inflammatory mediators, facilitate the peripheral release of opioids, promote the release of local beta-endorphin, and enhance the synthesis of adenosine triphosphate.¹⁵

In conclusion, based on patient-reported outcomes and outcome measures, LLLT, also known as PBM, is a promising and noninvasive technique. It can improve patients' OHR-QoL by reducing the complications associated with conventional dental treatments and oral disorders. This improvement is primarily achieved through faster wound healing, anti-inflammatory properties, pain relief, and nerve regeneration facilitated by LLLT. While the benefits

of LLLT are becoming increasingly evident, its potential risks still need to be better understood. Ensuring the safety of both patients and healthcare practitioners is crucial. Therefore, a comprehensive evaluation of the safety profile of LLLT is essential, including a meticulous examination of any potential risks associated with its application. It is imperative to conduct further randomized and controlled studies over extended periods to gain deeper insights into the long-term efficacy and safety of LLLT. Research into the effects of LLLT over prolonged periods can enhance understanding of its potential risks and benefits, guiding its more informed and responsible integration into clinical practice.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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