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# *Applications of Oral Photomedicine in Dentistry: A Comprehensive Review of Visible Light Lasers, Photobiomodulation, and Photodynamic Therapy*

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***Abstract.*** Visible light lasers in the 400–700 nm range are used in dentistry for two main types of treatment, photobiomodulation (PBM) and photodynamic therapy (PDT). In PBM, low levels of light energy stimulate mitochondrial cytochrome c oxidase (CcOx); this increases adenosine triphosphate (ATP) production, changes reactive oxygen species (ROS) levels, and promotes nitric oxide (NO) release, helping to reduce pain and inflammation and support tissue repair. In PDT, light activates a photosensitizer to produce ROS that damage cells; this treatment is used to kill periodontal pathogens, remove root canal biofilms, and support the treatment of oral precancerous lesions and tumors. This review examines evidence on ultraviolet, blue/violet, green, yellow, red, and near-infrared light, comparing how deeply they enter tissues, how they act on biological processes, and how they are used in dental care. These applications include pain control, wound healing, nerve repair, periodontal and peri-implant treatment, caries detection, and oral surgery; the review also discusses power density, energy density, exposure time, and the biphasic dose-response principle, which describes how treatment effects vary with dose. Contraindications, safety measures, and gaps in dental research are considered, with particular attention to the limited evidence on yellow light. Finally, the review presents an evidence-based framework for clinical use based on the WALT 2026 guidelines and suggests further research on wavelengths that have received less attention in oral medicine.

***Keywords:*** photobiomodulation, photodynamic therapy, oral photomedicine, laser dentistry, wavelength

## 1. Introduction

Light-based therapies are developing rapidly in clinical dentistry and are becoming an important part of oral medicine. Medical lasers with wavelengths in the visible range (400–700 nm) are now used for more purposes than cutting and removing tissue; they can also change cell activity through the effects of light and produce chemical reactions that target microorganisms. The main clinical uses can be divided into four groups: (1) photobiomodulation (PBM), used to reduce pain and swelling and help wounds heal faster; (2) photodynamic therapy (PDT), used for precancerous lesions,

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tumors, and periodontal treatment; (3) hard tissue applications, including tooth whitening and light curing; and (4) soft tissue surgery, including gingival reshaping and frenectomy.

Interactions between lasers and tissues are generally divided into five classical categories: photochemical interactions, photothermal interactions, photoablation, plasma-induced ablation, and photodisruption; the main differences between these types depend on how long the laser acts on the tissue and its power density. According to established dental laser literature, the duration of this interaction is more important than power density when identifying the interaction type. Understanding these differences helps clinicians choose a suitable laser by considering three questions: which biological target needs treatment, what type of interaction is needed, and how strong the treatment effect should be.

The answers to these questions determine wavelength, interaction time, and power density respectively.

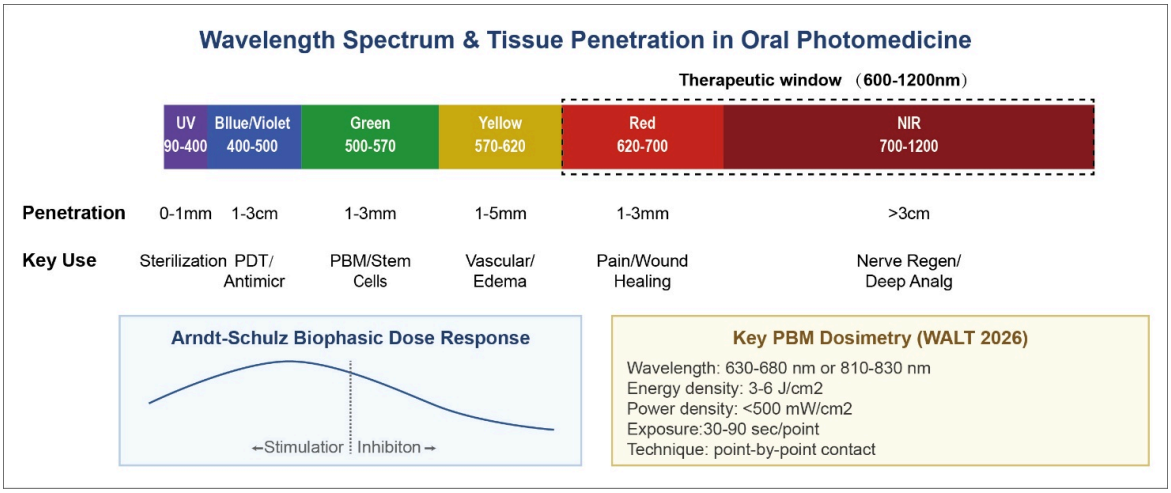



Figure 1. Wavelength spectrum of visible and near-infrared light in oral photomedicine

Notes: It *shows tissue penetration depth, primary therapeutic applications, the therapeutic window (600–1200 nm), the Arndt-Schulz biphasic dose-response curve, and key PBM dosimetry parameters (WALT 2026).*

Figure 1 above illustrates the complete visible and near-infrared spectrum, indicating tissue penetration depth and key dental applications by wavelength band, and includes the Arndt-Schulz biphasic dose-response curve and current WALT 2026 dosimetry parameters for quick clinical reference.

## 2. Background

### 2.1. Laser–tissue interaction

Understanding how light interacts with biological tissue is necessary before using it for treatment. Five main interaction types are determined by power density and exposure time. Photochemical interactions, including PBM and PDT, generally occur at low power densities over longer periods. Photothermal interactions include coagulation, vaporization, and carbonization. Higher power densities and shorter exposures are used in photoablation, plasma-induced ablation, and photodisruption.

Absorption and scattering determine how deeply light enters tissue. The approximate range of 600–1200 nm is often described as a therapeutic window. Relatively low absorption within this

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range allows deeper penetration. The actual depth depends on wavelength and tissue properties. Water strongly absorbs far-infrared light from $CO_2$ lasers. These lasers are used to remove or vaporize soft tissue. UV light has applications in photoablation and instrument disinfection. Its potential to damage tissue limits its therapeutic use.

### 2.2. Photobiomodulation: core mechanisms

PBM is a noninvasive treatment that uses light; it has been studied for immune and inflammatory conditions, neurological and musculoskeletal disorders, and the healing of oral and chronic skin wounds. One proposed main mechanism involves light absorption by mitochondrial cytochrome c oxidase (CcOx), which promotes electron transfer, increases mitochondrial membrane potential, and supports ATP production [1]. Three related processes are commonly described: (1) increased mitochondrial activity and ATP production; (2) a controlled rise in ROS that activates transcription factors involved in cell repair, with effects depending on dose, as described by the Arndt–Schulz principle [2]; and (3) the release of nitric oxide (NO) from CcOx following light absorption, which may help widen blood vessels and improve local blood flow and oxygen delivery [3]. PBM can also influence cytokine activity by reducing pro-inflammatory signals and increasing anti-inflammatory signals; it may support bone cell activity and the production of bone matrix [1].

### 2.3. Photodynamic therapy: core mechanisms

PDT requires a photosensitizer (PS), light, and oxygen. Reactive oxygen species (ROS) are produced through their interaction. Light at a suitable wavelength activates the photosensitizer. The activated photosensitizer then generates ROS, including singlet oxygen. These molecules can irreversibly damage bacterial structures, cancer cell membranes, and intracellular components through oxidation.

A 1993 study found no significant bacterial killing when either the photosensitizer or laser was used alone. Bacterial survival was substantially reduced when both were used together. Clinical applications include periodontal treatment, root canal disinfection, and treatment of oral mucosal diseases. PDT is also used as an additional treatment for oral tumors and precancerous lesions [4].

## 3. Wavelength comparison: mechanisms and applications

Table 1. Comparative overview of wavelength bands in oral photomedicine: spectral range, tissue penetration, primary mechanism, key dental applications, and evidence sources

| Wavelength | Range | Penetration | Primary Mechanism | Key Dental Applications | Ref. |
|---|---|---|---|---|---|
| UV (Ultraviolet) | 190–400 nm | ~0.1 mm | Photochemical / photoablation | Sterilization of instruments; not used for treatment | [1] |
| Blue / Violet | 400–500 nm | 1–3 mm | PDT-mediated ROS; fluorescence excitation | PDT (periodontal, root canal); caries fluorescence detection; osteosarcoma ferroptosis | [4] |

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Table 1. (continued)

| | | | | | |
|---|---|---|---|---|---|
| Green | 500–570 nm | 1–3 mm | Cytoskeletal reorganization; cytokine modulation (IL-6, IL-1β) | Dental pulp stem cell proliferation; periodontal bone remodeling; anti-inflammation | [5, 6] |
| Yellow | 570–620 nm | 1–5 mm | VEGF/SCF inhibition; AKT/PI3K/mTOR downregulation; NO release | Postoperative erythema/edema control; vascular regulation; lymphatic drainage | [7, 8] |
| Red | 620–700 nm | 1–3 cm | CcOx activation → ATP ↑; BDNF/NGF upregulation; ROS modulation | Pain management; wound healing; nerve regeneration; implant stability; orthodontics | [8, 9] |
| Near-Infrared | 700–1200 nm | >3 cm | Deep mitochondrial stimulation; NO/ROS signaling; angiogenesis | Deep analgesia; nerve repair; lymphatic drainage; peri-implant healing (dual-wavelength) | [10] |

Table 1 provides a structured comparison of all major wavelength bands used in oral photomedicine.

## 4. Discussion

### 4.1. Blue and violet light (400-500 nm)

Blue and violet light have attracted substantial research interest for antimicrobial properties in PDT. High-power blue LEDs directly inhibit Porphyromonas gingivalis. Synergistic bacterial killing is achieved when blue light is combined with a red dye, outperforming either treatment alone. Evidence suggests that blue light selectively inhibits periodontal pathogens while supporting the growth of beneficial denitrifying bacteria. This effect is selective rather than broad-spectrum.

Under blue/violet light, healthy enamel and dentin show strong green fluorescence. Much weaker fluorescence is observed at carious sites, allowing fluorescence-guided caries detection.

In cancer research, blue light can trigger cell death through ferroptosis in osteosarcoma cells. Photodynamic antimicrobial chemotherapy (PACT) for root canals was examined in a review of 62 articles. Most articles concluded that PDT was more effective than sodium hypochlorite alone [4].

### 4.2. Green light (520-540 nm)

Green light shows anti-inflammatory effects and supports tissue repair through mechanisms different from those of red and near-infrared light. Significant collagen maturation and deposition were reported 21 days after treatment in burn wound models, according to a 2014 review. Wound contraction was greater than in controls at 14 days [6].

A 2024 review reported that green light accelerated diabetic wound healing and increased local blood flow by modulating IL-6 and IL-1β [5]. In dental pulp stem cells, proliferation and migration were significantly increased following 520 nm irradiation. These effects involved actin cytoskeleton reorganization and cell softening, with improved wound healing observed at 24 hours.

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A 2025 rat study examined 540 nm irradiation during orthodontic retention. Osteoblast differentiation was promoted, while BMP-2 expression and bone mineral density increased. These findings helped address an important gap in the literature. Multiple studies reported no cytotoxic effects on fibroblasts or osteoblasts.

### 4.3. Yellow light (590 nm)

Yellow light uniquely reduces VEGF and SCF expression and suppresses angiogenesis through the AKT/PI3K/mTOR pathway. Facial erythema and abnormal vasodilation are also improved, with effects opposite to those of red light. A split-face controlled clinical trial examined immediate yellow light treatment after fractional laser surgery. Erythema and edema were significantly less severe on the treated side at 24 and 48 hours than the untreated side [7]. Yellow light also reduces inflammation in burn wounds, speeds up re-epithelialization, and increases collagen deposition.

Despite these skin-related findings, almost no research specifically addresses yellow light in oral tissues. Three main research questions are proposed. Can intraoral application of 590 nm light resolve post-extraction edema by accelerating macrophage return? Can excessive granulation during oral soft tissue grafting be inhibited without affecting healing? Do human gingival endothelial cells and fibroblasts show the same reduction in VEGF as skin cells?

### 4.4. Red light (620-700 nm)

Red light PBM at 660 nm is the most extensively studied wavelength in dental practice. A triple-blind RCT in the Journal of Periodontology confirmed 660 nm red light significantly accelerated palatal donor site epithelialization and influenced pain VAS scores.

A systematic review confirmed reduced pain and trismus within 1–3 days post-third molar extraction, with dual-wavelength protocols outperforming single-wavelength. A 2025 study in the Journal of Laser Medical Sciences showed both red and NIR light significantly relieved orthodontic pain and accelerated tooth movement.

Red light has also demonstrated efficacy in recurrent stomatitis, shortening healing time and reducing lesion size. For nerve regeneration, a direct rat study comparison of 660 nm and 808 nm for inferior alveolar nerve crush injury confirmed both wavelengths promote remyelination; PBM upregulates BDNF and NGF and downregulates inflammatory factors including NF-κB, TNF-α, and IL-1β [11]. A two-year follow-up study confirmed accelerated sensory recovery in orthognathic surgery patients receiving continuous PBM.

### 4.5. Near-infrared light (700-1200 nm)

NIR light penetrates beyond 3 cm into tissue, offering superior access to deep structures including the inferior alveolar nerve, deep periodontal bone, and temporomandibular joint. It increases mitochondrial metabolism and ATP production, provides notable post-surgical analgesic and anti-edema effects, and promotes angiogenesis. NIR at 808 nm outperformed 660 nm red light for deep inferior alveolar nerve remyelination. Most clinical protocols for dental implants and nerve regeneration recommend combined red + NIR dual-wavelength application to leverage complementary superficial and deep tissue effects. NIR also demonstrates a positive role in lymphatic drainage and clearance, relevant to postoperative edema management.

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## 5. Dosimetry, safety, and contraindications

### 5.1. Core dosimetry parameters

Effective PBM requires precise control of four interdependent parameters. The 2026 WALT position paper on orofacial neuropathic pain specifically recommends wavelengths of 630–680 nm or 810–830 nm, an energy density of 3–6 J/cm² (strictly adhering to low-dose stimulation), and point-by-point stationary contact technique with the probe applied vertically under light pressure to minimize photon reflection.

Table 2. Core PBM dosimetry parameters: definitions, clinical ranges, and clinical notes

| Parameter | Definition | Clinical Range | Clinical Note |
|---|---|---|---|
| Power / Power Density (Irradiance) | Energy emitted per second (W or mW); power per unit area (W/cm² or mW/cm²) | ≤500 mW/cm² per point | Higher power needed for deeper tissue targets; exceeding limit causes thermal damage |
| Energy Density (Fluence) | Total energy delivered per unit area — the most critical PBM parameter (J/cm²) | Superficial: 1–10 J/cm²<br>Deep tissues: 10–60 J/point | Low-dose stimulation (3–6 J/cm²) recommended for neuropathic pain (WALT 2026) |
| Exposure Time | Duration light remains on a specific target point (seconds) | 30–90 sec/point (typical) | Primary variable for adjusting total energy; combines with power to set fluence |
| Wavelength | Determines chromophore absorption and tissue penetration depth | PBM: 630–680 nm or 810–830 nm<br>PDT: photosensitizer-matched | Wavelength selection governs which tissue structures absorb photons and to what depth |
| Biphasic Dose Response | Arndt-Schulz Law: low doses stimulate healing; high doses inhibit and damage | Stimulatory range varies by tissue type | Always use the minimum effective dose; overdosing negates therapeutic effect |
| Application Technique | Contact vs. non-contact; scanning vs. point-by-point | Point-by-point stationary contact (WALT 2026) | Vertical probe contact minimizes photon reflection; avoids tattooed/pigmented skin |

Table 2 summarizes all core dosimetry parameters and their clinical ranges.

### 5.2. Contraindications and safety protocols

Table 3. Contraindications and safety protocols for PBM and PDT in oral photomedicine

| Contraindication / Precaution | Clinical Risk | Clinical Protocol / Safety Baseline |
|---|---|---|
| Active Primary Tumor (unresected) | Theoretical risk of promoting tumor cell activity under direct irradiation | PBM is safe for supportive/palliative cancer care (MASCC/ISOO). Direct irradiation over unexcised active tumors is STRICTLY PROHIBITED. |
| Photosensitizing Medications | Exponentially increased tissue photosensitivity; risk of phototoxic burns, blistering, or hyperpigmentation | Mandatory medication history before treatment. Significantly reduce energy density or postpone. Drugs include: isotretinoin, tetracyclines, certain antidepressants, chemotherapy agents. |

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Table 3. (continued)

| | | |
|---|---|---|
| Photosensitive Epilepsy | Pulsed visible light at 5–30 Hz can trigger seizures in photosensitive patients | Disable pulsed visible light modes; switch to Continuous Wave (CW) mode or exclusive NIR (invisible) light. |
| Tattooed / High-Melanin Areas | Dark pigments absorb photons as intense heat, causing instant thermal burns under contact irradiation | Bypass tattooed areas or use non-contact hovering technique at a safe distance for high-power (Class IV) devices. |
| Ocular Exposure | Blue light and high-power lasers cause irreversible photochemical retinal damage | Both operator and patient must wear wavelength-specific certified protective goggles for the entire procedure. |
| PDT: Post-Photosensitizer Systemic Exposure | Circulating photosensitizer causes phototoxic skin/eye reactions on exposure to ambient light | Patients must observe strict light-avoidance protocols following photosensitizer injection (duration varies by agent). |
| Thermal Risk: Soft Tissue Burns | Light energy raises intraoral tissue temperature; risk of gingival or mucosal burns | Use three-way syringe air cooling during light curing; monitor exposure time carefully in confined intraoral areas. |

Table 3 consolidates all contraindications and safety protocols relevant to PBM and PDT in dental practice.

### 5.3. Limitations of PDT

PDT has several limitations. Both the photosensitizer and activating light have limited tissue penetration, restricting treatment of deep infections or tumors. Extended light avoidance is required after photosensitizer injection to prevent systemic phototoxic reactions.

Treatment protocols differ in photosensitizer type, wavelength, energy density, and irradiation time. Standardization is made more difficult by these differences, which also limit the availability of high-quality clinical trial evidence.

## 6. Conclusion

Oral photomedicine includes several light-based treatments, each with different mechanisms and clinical uses. PBM activates mitochondrial CcOx, increases ATP production, regulates ROS, and releases NO; these processes reduce pain and inflammation, supporting tissue repair. Its effects are used in pain management, wound healing, nerve regeneration, periodontal treatment, and dental implantology. PDT produces targeted antimicrobial and anticancer effects through ROS generation mediated by photosensitizers. Evidence indicates better results than conventional methods in root canal disinfection and periodontal pathogen removal.

Specific wavelengths have established therapeutic uses; blue/violet light supports antimicrobial PDT and fluorescence-based caries detection. Stem cell support and periodontal bone remodeling are associated with green light [5]. Red light helps reduce pain, heal wounds, and repair nerves; NIR supports pain relief in deeper tissues and nerve regeneration.

Yellow light shows promise for vascular regulation and postoperative swelling control in dentistry, but research remains limited. Dedicated intraoral clinical studies are needed to examine these potential uses. Clinical practice requires careful attention to dosimetry, particularly the biphasic dose-response relationship; contraindications must be checked systematically. The 2026

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WALT guidelines [12] provide the latest evidence-based framework for standardizing clinical protocols. Further studies on less explored wavelengths will help extend the clinical uses of oral photomedicine.

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