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Laser Technology in Dentistry: A Narrative Review of Classification and Clinical Applications

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Abstract

Introduction: Lasers were developed in the mid-20th century and became an accepted dental treatment modality by the 1990s. They are now used across most dental specialties. Compared with conventional instruments, dental lasers are reported to cut more precisely, cause less collateral damage and bleeding, and speed healing in several indications, though the strength of that evidence differs by application. These effects are photothermal, photochemical, and photomechanical, and depend on wavelength and irradiation parameters.

Methods: This narrative review draws on peer-reviewed literature from PubMed, Scopus, and Web of Science (1990–2026). It covers the principles of laser–tissue interaction and presents dental laser systems by active medium and wavelength, adding a wavelength-oriented clinical classification of dental diode lasers (violet, blue, red, and near-infrared subtypes; Section 4).

Results: The classes reviewed are erbium-family systems (Er: YAG, Er, Cr: YSGG), diode lasers from violet and blue through the near-infrared, CO_2 lasers (the conventional 10,600 nm system and the newer 9,300 nm all-tissue platform), and argon lasers, across diagnostic, surgical, and therapeutic uses. Laser-based techniques are also applied in dental materials science to improve prosthetic biocompatibility.

Conclusion: Evidence is most consistent for erbium-family hard-tissue ablation and for diode and CO_2 soft-tissue surgery. Antimicrobial photodynamic therapy is similarly well supported, though its clinical data still lag behind in vitro findings. Fluorescence-based diagnostics rest on a reasonably established base, but performance varies with device, lesion type, and reference standard. Far more uncertainty surrounds photobiomodulation, oncologic photodynamic therapy, and the 9,300 nm CO_2 platform. Realizing the full potential of the field will require rigorous comparative trials and standardized treatment protocols.

Keywords: Lasers, Dental, Dental materials, Low-level light therapy, Dentistry

Introduction

Lasers entered dentistry in the mid-20th century, shortly after the first working laser was built in 1960 (Section 2), but only became an established treatment modality in the 1990s .[1] Their use has since spread across most dental specialties, in both clinical and industrial dentistry,[2] reaching caries removal, soft-tissue procedures, hemostasis, antimicrobial treatment, and other therapeutic indications,[3,4] as well as more complex settings such as implant-supported prosthetics and peri-implant complications.[5,6]

These specialties include periodontics, endodontics, prosthodontics, aesthetic dentistry, pediatric dentistry, and orthodontics.[2,7] Pediatric dentistry adopted lasers particularly quickly since minimally invasive treatment causes less anxiety in children than conventional instruments.[8,9] Orthodontics shows a similar pattern: lasers are used for soft-tissue work such as exposing impacted teeth, gingival contouring, and frenectomy, and for photobiomodulation (PBM), which has been studied for accelerating tooth movement and easing orthodontic pain.[10-12]

Lasers are not confined to chairside care: dental materials science and industrial dentistry use them to modify materials, altering surface topography, hydrophilicity, and antibacterial behavior, and fine-tuning components such as implant fixtures and zirconia restorations.[13,14]

Across these settings, laser treatment tends to raise patient satisfaction, lower anxiety and stress, and improve cooperation.[8] Yet dental laser classification remains inconsistent: diode lasers especially are usually treated as a single category even though these wavelengths interact with tissue very differently, and few reviews link that interaction to a wavelength-based classification. This review therefore aims to examine the principles of laser–tissue interaction, to present dental laser systems by wavelength and tissue-interaction classification, updated with a wavelength-

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oriented clinical classification of dental diode lasers, and to review their diagnostic, surgical, and therapeutic applications in contemporary dentistry.

Methods

Review design: This is a narrative review rather than a systematic or scoping one, covering laser physics, classification, and diagnostic, surgical, and therapeutic applications. These are distinct questions resting on different evidence types, too broad for one review. Narrower sub-questions that could support their own systematic review, such as diagnostic accuracy of fluorescence-based caries detection or PBM dose–response, are flagged where they arise.

Information sources: PubMed/MEDLINE, Scopus, and Web of Science served as the primary databases. Manufacturer white papers and regulatory databases were not systematically searched, though selected clearances are cited where relevant (Section 4).

Search strategy: Search concepts were built as separate blocks: device and wavelength; clinical applications, including fluorescence diagnostics, Doppler flowmetry, soft-tissue surgery, and implants; and newer terms such as "9,300 nm." One combination ran: ("dental laser" OR "laser dentistry") AND ("Erbium" OR "Er: YAG" OR "diode laser" OR "CO_2 laser" OR "Nd: YAG" OR "argon laser") AND ("photobiomodulation" OR "photodynamic therapy" OR "caries detection" OR "periodontal" OR "dental materials"). The searches were run in PubMed, Scopus, and Web of Science on June 21, 2026, covered 1990–2026, and were limited to English-language publications. Reference lists of retrieved articles were hand-searched as well.

Eligibility: Every study type retrieved was eligible, including RCTs, systematic reviews and meta-analyses, non-randomized studies, case series, in vitro and animal studies, and technical reports, spanning diagnostic, surgical, therapeutic, and materials-science applications. Non-English articles were excluded because translation resources were unavailable, as were abstracts whose full text could not be obtained.

Study selection: The author team screened titles and abstracts for relevance and retrieved full texts as needed. This was not a formal dual-reviewer process; single-reviewer screening of this kind is standard practice for narrative reviews. Disagreements about inclusion were settled by discussion, with final inclusion decided jointly.

Evidence synthesis: The evidence is organized first by laser type and wavelength (Section 4), then by clinical indication (Section 5), with mechanistic, laboratory, and clinical evidence kept apart throughout (Sections 5.3, 6, 7).

Critical appraisal: Where possible, the quality and limitations of cited systematic reviews and trials (heterogeneity, risk of bias, certainty) are flagged next to the claims they support, most consistently in Sections 5.3 and 7.

Reporting: No PRISMA-style flow diagram is included, typical of narrative reviews.

Words such as "effective" report study findings and should be read against the evidence level noted beside them, not as author certainty. Unless stated otherwise, "laser" means a device generating light through stimulated emission (Section 3). Non-laser optical technologies, such as LED-based fluorescence and photobiomodulation, are identified as such and included where clinically comparable to laser systems at the same wavelength (Sections 5.1.1, 5.3.1).

Historical Development of Laser Technology

Albert Einstein laid the theoretical groundwork in 1917 with his description of stimulated emission of radiation.[15] Theodore Maiman built the first practical laser in 1960 using a flashlamp-pumped ruby crystal, followed by the Nd: YAG laser in 1962 and the argon laser (Patel, Bell Laboratories) in 1964 .[16,17] Dental applications accumulated through the 1990s, along with the clinical evidence that gradually made lasers an accepted treatment option.[1,2,4] Sections 4 and 5 cover their present-day clinical use.

Fundamental Principles and Laser–Tissue Interaction

A dental laser emits electromagnetic radiation with three characteristic beam properties: a relatively narrow spectral bandwidth rather than a single wavelength, high coherence, and low divergence, letting clinical systems approximate these ideals and deliver energy precisely to the target tissue.[18,19] That energy interacts with tissue in three ways: photothermally (coagulation, vaporization, carbonization), photomechanically (acoustic micro-explosions from rapid vaporization), and photochemically (generation of reactive oxygen species [ROS], as in photodynamic therapy).[20]

Wavelength alone does not settle the clinical result; dosimetric and delivery parameters decide how it behaves.[18,19] Penetration depth, the distance light travels before absorption, varies inversely with the absorption coefficient of the tissue: strongly absorbed wavelengths such as Er: YAG deposit energy superficially, while weakly absorbed ones such as Nd: YAG travel further before absorption occurs. Fluence (J/cm^2) must clear a tissue-specific ablation threshold before cutting or vaporization occurs; below threshold, red and near-infrared wavelengths (Section 5.3.1) instead produce the non-ablative effects exploited in photobiomodulation, though the response depends on the full set of irradiation parameters, not fluence alone. Power density (W/cm^2) shapes the outcome further: a given fluence packed into a short, high-power pulse yields precise ablation with little thermal spread, while continuous low-power delivery coagulates rather than cuts.

Pulse duration and repetition rate work against the tissue's thermal relaxation time (TRT), the interval for half the absorbed heat to dissipate. A pulse shorter than the TRT keeps heat confined to the target. Longer pulses, or repetition rates too rapid for the tissue to cool between pulses, let heat accumulate and raise the risk of carbonization and necrosis.[20] Spot size also matters since power density scales inversely with irradiated area, so a smaller spot sharply raises power density and ablation efficiency. Air-water cooling, standard with erbium-family and CO_2 systems, limits residual heat and clears debris, protecting surrounding tissue.[21,22] This is why two lasers

of an identical wavelength can be tuned, through fluence, power density, pulse duration, repetition rate, spot size, and cooling, toward anything from photobiomodulation to precise hard-tissue ablation (representative parameters for each modality are listed in Table 3)

In enamel and dentin, the erbium-family lasers (Er: YAG at 2,940 nm and Er, Cr: YSGG at 2,780 nm) are absorbed extremely strongly by water, producing rapid vaporization and micro-explosion that ablates tissue while sparing surrounding structures from thermal damage.[21,22] The newer 9,300 nm CO_2 laser is likewise well absorbed by water and HAp, making it effective for both hard- and soft-tissue work.[23]

For soft-tissue and periodontal work, the CO_2 laser (10,600 nm) and near-infrared diodes (810–980 nm) are well established for incision and vaporization, with few postoperative complications.[24] The Nd: YAG laser (1,064 nm) penetrates deeper: in vitro and microbiological studies report bactericidal activity against periodontal pathogens, and clinical studies describe coagulation within the pocket, though bactericidal activity is not the same as a better periodontal outcome: probing-depth reduction and attachment-level gain depend on further factors (Section 7).[25]

Dental Laser Types (Wavelengths)

Dental lasers are classified, and clinically deployed, primarily by active medium and wavelength.[26] These properties govern how strongly the beam is absorbed by tissue chromophores such as water, melanin, hemoglobin, and HAp, and that selective absorption is what makes each laser type useful for particular tasks.[27] In some systems, notably the 9,300 nm CO_2 laser, pulse duration and repetition rate shape clinical utility alongside the wavelength (Section 4.3.2). Figure 1 and Table 1 summarize these wavelength-dependent absorption characteristics and their principal clinical indications, as discussed through Section 5, while Table 2 links the major clinical applications to their evidence level, benefits, limitations, and safety considerations. Table 3 reports laser parameters for each modality discussed in this review, following the journal's laser-parameter reporting items (type of laser, emission mode, time on/off, delivery system, energy distribution, peak/average power, spot size and focus-to-tissue distance, peak/average power density, beam divergence, and water/air cooling). The primary and review literature reports these device-level parameters inconsistently, or sometimes not at all, so the values shown reflect typical or representative settings from the cited literature rather than a single definitive specification. Parameters that are inherently device-, technique-, and operator-dependent (e.g., exact focus-to-tissue distance, power density, and beam divergence) are identified as such instead of being assigned a single value. Readers who need exact settings for a specific device should consult the manufacturer specifications and the cited primary studies

Erbium Family Lasers (Er: YAG and Er, Cr: YSGG)

Er: YAG (2,940 nm) and Er, Cr: YSGG (2,780 nm) were chosen for their high absorption in water and HAp, and

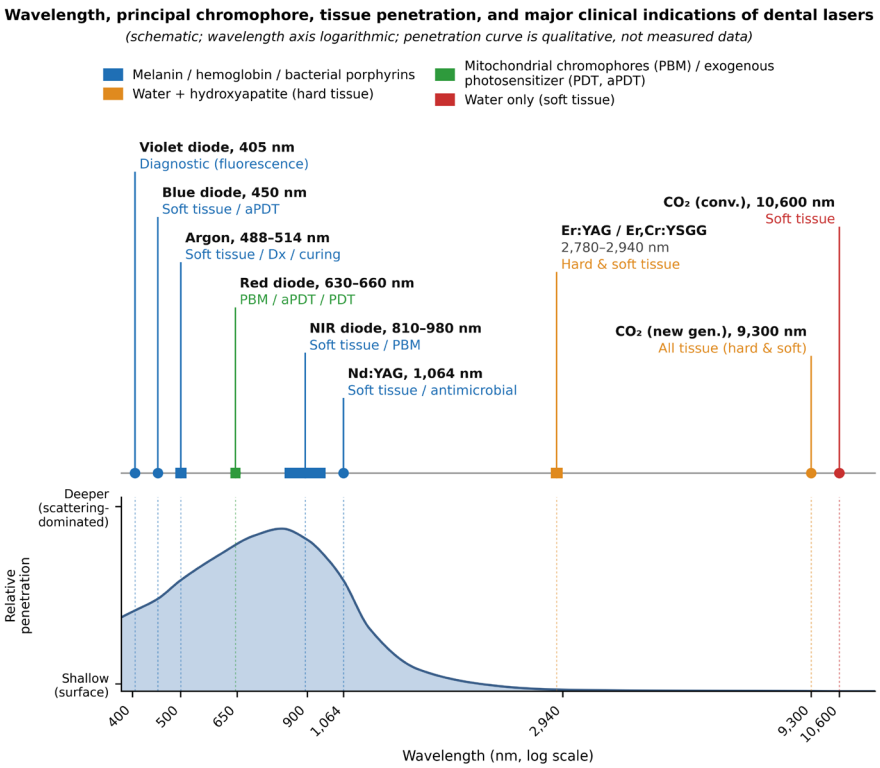


Figure 1. Schematic overview of dental laser wavelength, principal chromophore, relative tissue penetration, and major clinical indications, synthesizing the wavelength-dependent absorption principles and clinical applications discussed in Sections 3–5. Penetration depth is shown qualitatively and is not derived from measured data for a specific tissue; original figure prepared for this review (not adapted from another source, so no third-party copyright/attribution applies)

Table 1. Summary of dental laser types, wavelengths, tissue targets, principal chromophores, typical clinical roles, main clinical applications, key advantages, principal limitations, and representative parameters reported in the selected studies

Laser Type	Wavelength (nm)	Tissue Target	Major Absorbing Chromophores	Typical Clinical Role	Main Clinical Applications	Key Advantages	Principal Limitations	Representative Parameters Reported in Selected Studies
Er: YAG, Er, Cr: YSGG	2,780–2,940	Hard tissue (primary); soft tissue (secondary)	Water, HAp	Ablative / surgical	Hard tissue removal (enamel, dentin), caries removal, bone surgery, soft tissue procedures	High precision; minimal thermal damage when adequately water-cooled; may reduce or avoid anesthesia in selected superficial procedures (device- and protocol-dependent)	Slower than rotary instruments for larger preparations; high equipment cost; requires water/air cooling to avoid pulpal injury	Typically ~150–400 mJ/pulse at 10–20 Hz (e.g., ~300 mJ/20 Hz enamel, ~200 mJ/20 Hz dentin) with water/air cooling; fluence roughly 15–23 J/cm² for caries removal
Diode (Violet)	405	N/A (diagnostic; non-ablative)	Bacterial porphyrins	Diagnostic	Photodynamic diagnosis of oral mucosal lesions; related LED-based QLF technology (non-laser) operates near this wavelength for caries detection (Section 5.1.1)	Non-invasive; real-time; non-ionizing lesion assessment	Diagnostic accuracy (sensitivity/specificity) varies by lesion type, tooth surface, and device generation (Section 5.1)	Low-power diagnostic illumination (non-ablative); not typically reported as a therapeutic dose
Diode (Blue)	450	Soft tissue	Melanin, Hemoglobin, Proteins	Ablative / surgical (soft tissue) + antimicrobial PDT adjunct	Soft tissue surgery (no tip initiation needed), teeth whitening, antimicrobial PDT	High absorption in pigments; efficient cutting at low power; minimal thermal damage	Not suitable for hard-tissue ablation; efficacy depends on tissue pigmentation	Typically < 2 W continuous-wave for soft-tissue cutting; photosensitizer-based use follows aPDT dosimetry (Section 5.3.2.1)
Diode (Red)	630–660	N/A (sub-ablative; non-ablative biostimulation)	Mitochondrial chromophores	Biostimulatory / photodynamic / non-ablative	Photobiomodulation (PBM) and antimicrobial photodynamic therapy (aPDT); wound healing, pain management	Non-thermal; promotes cellular biostimulation	Highly dose-dependent; protocols heterogeneous across studies (Section 5.3.1); pooled efficacy estimates not well supported	See Section 5.3.1 for full parameter set; reported power roughly 10–500 mW, fluence roughly 2–10 J/cm² per site
Diode (Near-Infrared)	810–980	Soft tissue (ablative use); non-ablative tissue targets in PBM applications	Melanin, Hemoglobin	Ablative / surgical (soft tissue) + biostimulatory (PBM)	Soft tissue surgery, periodontal pocket disinfection, PBM, endodontic disinfection	Compact, cost-effective; deep tissue penetration; strong hemostatic effect	Not suitable for hard-tissue ablation; PBM efficacy at this wavelength is dose- and protocol-dependent	Typically ~0.5–2.5 W continuous-wave for soft-tissue surgery; PBM dosimetry as in Section 5.3.1
CO_2 (10,600 nm)	10,600	Soft tissue	Water	Ablative / surgical (soft tissue)	Soft tissue surgery, frenectomy, biopsy, treatment of benign and precancerous lesions	Precise cutting; suitable hemostasis; minimal postoperative pain	Not suitable for hard-tissue ablation; plume/aerosol hazard requires evacuation (Section 7.3.4)	Typically ~1–6 W continuous-wave (or pulsed equivalent) for intraoral soft-tissue surgery
CO_2 (9,300 nm) [New Generation]	9,300	Hard and soft tissue (all-tissue)	Water, HAp	Ablative / surgical (all-tissue)	Hard tissue removal (enamel/dentin/bone), cavity preparation, soft tissue surgery	All-tissue capability; may reduce or avoid anesthesia in selected superficial procedures (device- and protocol-dependent); minimal thermal damage; high HAp absorption	Newer platform; clinical evidence base still preliminary relative to Er: YAG, diode, and CO_2 10,600 nm (Section 8)	Manufacturer-specified pulsed parameters; published dosimetric detail more limited than for erbium systems

Table 1. Continued.

Laser Type	Wavelength (nm)	Tissue Target	Major Absorbing Chromophores	Typical Clinical Role	Main Clinical Applications	Key Advantages	Principal Limitations	Representative Parameters Reported in Selected Studies
Nd: YAG	1,064	Soft tissue (+periodontal pocket epithelium)	Melanin, Hemoglobin	Ablative / surgical + antimicrobial (periodontal)	Tissue coagulation, disinfection, periodontal therapies (LANAP), soft tissue surgery	Deep penetration; strong coagulative effect; bactericidal properties	Not suitable for hard-tissue ablation; higher risk of thermal injury if parameters not controlled (Section 7.3.3)	Typically pulsed, ~1–4 W average power; specific protocols (e.g., LANAP) use manufacturer-defined settings
Argon	488–514	Soft tissue (superficial) / resin curing (non-tissue)	Hemoglobin, Melanin	Ablative / surgical (limited) + diagnostic + curing	Coagulation, soft tissue procedures, caries detection, resin curing	Useful for fluorescence-based caries detection and composite-resin curing at low power	Limited to superficial soft-tissue procedures; largely superseded by diode lasers in contemporary practice	Typically low power (~150 mW–1 W) depending on application; curing/ diagnostic uses well below surgical thresholds
PBM	600–950 (varied)	N/A (non-ablative; various tissues via biostimulation)	Mitochondrial chromophores	Biostimulatory, non-ablative	Wound healing, TMJ disorders, orthodontic pain, mucositis, neuropathic pain	Sub-ablative; anti-inflammatory; no thermal damage when appropriately dosed	No standardized dosimetry; effect size and even direction of benefit vary by protocol (Section 5.3.1)	See Section 5.3.1 for full dosimetric framework (wavelength, irradiance, fluence, exposure time, spot size, pulsing, frequency, schedule)
PDT / aPDT	630–660	Microbial biofilm (aPDT) / dysplastic-malignant epithelium (oncologic PDT)	Photosensitizer (exogenous)	Antimicrobial / photodynamic, non-ablative	Periodontal/ endodontic disinfection, peri-implantitis, oral carcinoma adjunct therapy	Selective antimicrobial or antitumor effect; minimally invasive	Requires photosensitizer administration; protocols heterogeneous; long-term outcome data more limited than short-term microbial/ lesion response (Section 5.3.2)	aPDT: ~0.005–0.05% photosensitizer, ~1–5 min pre-irradiation, 630–660 nm, ~10–200 mW. Oncologic PDT: topical 5-ALA, ~1–4 h drug-light interval, ~630–635 nm, ~90–200 J/cm² (Section 5.3.2)

Note on 405-nm technologies: QLF (Section 5.1.1) uses an LED, not a laser, despite operating near the same ~405-nm wavelength as the violet diode laser in this table; DIAGNOdent, though also fluorescence-based, uses a 655-nm laser diode and is not a 405-nm technology. Wavelength proximity does not imply shared light-source type or device classification.

Abbreviations: HAp, hydroxyapatite; LANAP, laser-assisted new attachment procedure; PBM, photobiomodulation (also referred to in the literature as PBMT or LLLT); RCT, randomized controlled trial; TMJ, temporomandibular joint; aPDT, antimicrobial photodynamic therapy

for years they were the principal systems cleared for hard-tissue work: enamel and dentin ablation, cavity preparation, caries removal, and bone surgery. They handle soft tissue readily as well, with a minimal thermal effect.[21,22,28] Regulatory approval for hard-tissue indications is jurisdiction- and device-specific: at least one 9.3-micron CO_2 system (Section 4.3.2) reportedly carries U.S. clearance for hard-tissue use, so the erbium family should not be assumed the only approved class. This regulatory status was not independently verified; readers should confirm device-specific clearances locally. In pediatric dentistry, Er: YAG lasers have likewise proved effective for caries removal, with less anxiety and lower anesthesia requirements in children.[29]

Diode Lasers (450–980 nm)

Diode lasers cover a broad span of wavelengths and, being compact and inexpensive, are the family most often found in general practice.[30] Their applications sort naturally by the wavelength subgroup:

Blue Diode Laser (450 nm): Surgical Applications

This Newer-Generation Diode operates in the blue part of the visible spectrum. Proteins absorb 450-nm light far more strongly than near-infrared diode wavelengths, so the beam cuts soft tissue efficiently at low power without tip initiation. Clinically, it serves soft-tissue surgery (gingivectomy, frenectomy, operculectomy), gingival depigmentation, tooth whitening, and photodynamic therapy. Efficient chromophore absorption keeps collateral thermal damage

Table 2. Major clinical applications of dental lasers linked to evidence level/type, principal clinical benefit, limitations, and safety considerations

Clinical Application	Evidence Level / Type	Principal Clinical Benefit	Limitations	Safety Considerations
Hard-tissue ablation (Er: YAG, Er, Cr: YSGG; CO_2 9,300 nm)	Multiple RCTs / comparative trials (Er: YAG, Er, Cr: YSGG); CO_2 9,300 nm evidence still preliminary	Minimally invasive removal of caries/enamel/dentin with high precision; anesthesia may be reduced or, in selected cases, avoided, depending on device and protocol	Slower than rotary instruments for larger preparations; high equipment cost	Pulpal thermal-injury risk if energy/cooling inadequate (~5.5°C threshold); wavelength-specific eye protection required (Section 7.3)
Soft-tissue surgery (diode, CO_2 10,600 nm, Nd: YAG)	Comparative clinical studies and case series support hemostasis and visibility benefits; limited long-term RCT evidence vs. scalpel	Reduced intraoperative bleeding, improved visibility, often reduced postoperative pain/sutures	Wavelength determines tissue suitability; learning curve for optimal settings	Plume/aerosol hazard with CO_2/high-power ablation; fire risk near flammable agents (Section 7.3.4–7.3.5)
Fluorescence-based diagnostics (QLF, DIAGNOdent, PDD)	Validated diagnostic-accuracy studies for occlusal caries detection; systematic-review support for mucosal PDD more limited	Non-invasive, real-time, non-ionizing early lesion detection	Sensitivity/specificity vary by lesion type, tooth surface, and device generation; not a radiography replacement	Low-power diagnostic use; minimal direct hazard beyond standard eye protection
Laser Doppler flowmetry (pulp vitality)	Evidence suggests potential diagnostic advantages in selected populations, but robust head-to-head diagnostic-accuracy evidence remains limited	Objective, non-invasive functional assessment of pulp blood flow	Sensitive to probe movement and tissue thickness; equipment cost limits routine adoption	Low-power diagnostic use; minimal direct hazard
Photobiomodulation (PBM)	Multiple systematic reviews/meta-analyses, but substantial protocol heterogeneity (Section 5.3.1)	Reported reduction in orthodontic pain, acceleration of tooth movement, and support for wound healing/mucositis in some protocols	No standardized dosimetry; pooled efficacy estimates not well supported given heterogeneity	Non-ablative, generally low direct thermal/ocular risk at typical doses; wavelength-appropriate eyewear still recommended
Antimicrobial PDT (aPDT)	Systematic-review support for periodontal, endodontic, and peri-implant infection control	Selective bactericidal effect as adjunct to mechanical debridement, including antibiotic-resistant organisms	Requires photosensitizer administration; long-term clinical-attachment outcomes less consistently reported than short-term microbial reduction	Generally favorable safety profile; photosensitizer handling and wavelength matching required
Oncologic PDT (premalignant/malignant lesions)	Growing but more limited evidence base than aPDT; heterogeneous ALA protocols (Section 5.3.2.2)	Minimally invasive, tissue-sparing option for premalignant lesions and superficial oral carcinomas	Response rates vary across studies; not established as a first-line replacement for surgery/radiotherapy	Photosensitizer-related photosensitivity; substantially higher fluence than aPDT; drug-light interval timing is critical
Laser-assisted materials / surface modification	Laboratory / materials-science studies only (Section 6); no patient-level clinical outcome data identified	Improved surface wettability, protein adsorption, and bond strength in bench-top testing	Unclear translation to implant survival, restoration longevity, or other patient-centered outcomes	Not directly patient-facing in most applications; standard laser safety applies during manufacturing.

low at modest power, given the short contact times and small spot size typical of initiated-tip technique. Results still vary with tissue pigmentation, power, and operator technique, however, and no standardized comparison of hemostasis against other wavelengths has been published.[31,32]

Red Diode Lasers (630–660 nm)

These wavelengths sit inside the therapeutic optical window and are used for PBM and antimicrobial photodynamic therapy (aPDT) alongside photosensitizers such as methylene blue (MB) or toluidine blue O (TBO). PBM at these wavelengths is thought to act on mitochondrial and cellular signaling pathways, including cytochrome c oxidase, though how much each pathway contributes is still unsettled.[33-35]

Near-Infrared Diode Lasers (810–980 nm)

Melanin and hemoglobin absorb these wavelengths, but less strongly than shorter ones, so the beam reaches deeper. Typical uses are soft-tissue surgery, gingival contouring, periodontal pocket disinfection, and PBM, with hemostatic and bactericidal effects.[36-39]

CO_2 Lasers

10,600 nm CO_2 Laser (Traditional)

Strong water absorption makes this laser best suited to soft-tissue surgery, a standard choice for gingivectomy, frenectomy, biopsy, vestibuloplasty, and treatment of benign and premalignant oral lesions, with comparative studies reporting good postoperative pain control and hemostasis.[40,41]

9,300 nm CO_2 Laser (New Generation – All-Tissue)

Unlike the 10,600 nm system, the newer 9,300 nm CO_2 laser is strongly absorbed by both water and HAp at a single wavelength, letting it perform hard-tissue surgery (enamel ablation, dentin preparation, caries removal) as well as soft-tissue surgery. It may allow local anesthesia to be reduced or, in selected superficial to moderate procedures, omitted, though this depends on device, protocol, lesion depth, proximity to the pulp, and patient pain sensitivity, and comparative clinical data remain sparse.[23] That all-tissue capability makes it an innovative addition to minimally invasive dentistry.[23]

Whether a 9,300 nm system ablates dental hard tissue depends on more than wavelength-dependent absorption:

Table 3. Representative laser parameters by modality (per journal laser-parameter reporting requirements)

Laser Type (Wavelength)	Emission Mode & Duty Cycle (Time On/Off)	Delivery System	Peak / Average Power	Energy Distribution (Beam Profile)	Spot Size (Focus / Tissue) & Focus-to-Tissue Distance	Power Density (Peak & Average; Spot / Tissue)	Beam Divergence	Water Irrigation / Air-Aspirating Airflow
Er: YAG, Er, Cr: YSGG (2,780–2,940 nm)	Pulsed (free-running); typical pulse duration ~50–300 µs at 10–20 Hz (duty cycle < 1%)	Articulated arm or fiber with sapphire/ zirconium-oxide contact tip	Peak power several kW per pulse; average power typically ~1–8 W depending on energy/ pulse and repetition rate	Manufacturer-specific; near-Gaussian at fiber/tip output	Tip-defined (typically 0.6–1.3 mm contact-tip diameter); used mainly in contact mode (focus-to-tissue ≈ 0)	Calculated from tip diameter and pulse energy; device- and setting-specific, not a single value across studies	Low at contact-tip exit; manufacturer-specific	Water and air spray essential to safe hard-tissue ablation
Diode, Violet (405 nm) – diagnostic	Continuous-wave, low-power diagnostic illumination; non-ablative (not pulsed for ablation)	Fiber-optic diagnostic probe/ handpiece	Low power, typically < 5 mW (fluorescence excitation)	N/A (non-ablative diagnostic use)	Device-specific (imaging field, not a surgical spot)	N/A (non-ablative)	Device-specific	Not applicable (no thermal ablation)
Diode, Blue (450 nm)	Continuous-wave typically; gated/pulsed modes available on some devices	Flexible optical fiber, initiated or non-initiated tip	Typically < 2 W continuous-wave for soft-tissue cutting	Near-Gaussian, fiber-coupled	Tip diameter typically 200–400 µm; near-contact or contact mode	Device- and technique-dependent; not standardized across studies	Fiber-dependent; typically low at tip exit	Typically none (ambient/handpiece air only); no dedicated water spray
Diode, Red (630–660 nm) / PBM	Continuous-wave or pulsed, highly protocol-dependent (Section 5.3.1)	Fiber-optic probe or multi-diode array handpiece, typically non-contact	Typically 10–500 mW (sub-ablative)	Device-specific; often near-Gaussian single-fiber or array output	Variable; probe held at set distance or light contact; not standardized across studies	Highly variable across protocols; see Section 5.3.1 for full dosimetric framework	Device-specific	Not applicable (sub-ablative, no thermal ablation)
Diode, Near-Infrared (810–980 nm)	Continuous-wave typically for surgery; gated modes available; variable for PBM protocols	Flexible optical fiber, initiated contact tip	~0.5–2.5 W continuous-wave (soft-tissue surgery); lower, sub-ablative for PBM use	Near-Gaussian, fiber-coupled	Tip diameter typically 200–400 µm; contact mode	Device- and technique-dependent	Fiber-dependent	Typically none (ambient air only); no dedicated water spray
CO_2, 10,600 nm (traditional)	Continuous-wave (traditional) or superpulsed/ gated in newer systems	Historically articulated hollow mirror arm (silica fiber transmits this wavelength poorly); newer hollow-core waveguide delivery also used	~1–6 W for intraoral soft-tissue surgery	Near-Gaussian (TEM00) achievable with mirror-arm delivery	Operator-selected via focusing handpiece/ defocus; typically non-contact, working distance adjustable	Highly dependent on operator-selected focus/defocus; not a fixed value	Low when collimated; increases if intentionally defocused	Typically none (water strongly absorbs this wavelength and would block the beam); some systems air-cool the handpiece only
CO_2, 9,300 nm (new generation)	Pulsed; reported pulse duration ~3–20 µs at ~40–300 Hz repetition rate, designed to limit thermal accumulation for hard-tissue use (Section 4.3.2)	Hollow-core waveguide or articulated arm, manufacturer-specific	Manufacturer-specified; published dosimetric detail more limited than for erbium/ traditional CO_2 systems	Manufacturer-specific	Manufacturer-specific; both contact and non-contact handpieces reported	Manufacturer-specific; not yet standardized across published studies	Manufacturer-specific	Water and air spray used for hard-tissue applications (similar rationale to erbium systems)

Table 3. Continued.

Laser Type (Wavelength)	Emission Mode & Duty Cycle (Time On/Off)	Delivery System	Peak / Average Power	Energy Distribution (Beam Profile)	Spot Size (Focus / Tissue) & Focus-to-Tissue Distance	Power Density (Peak & Average; Spot / Tissue)	Beam Divergence	Water Irrigation / Air-Aspirating Airflow
Nd: YAG (1,064 nm)	Pulsed (free-running); typical pulse duration in the hundred-microsecond range	Flexible silica optical fiber, contact or near-contact tip	Pulsed, ~1–4 W average power; protocol-specific systems (e.g., LANAP) use manufacturer-defined settings	Near-Gaussian, fiber-coupled	Fiber-tip diameter typically 200–400 µm; contact mode	Device- and technique-dependent	Fiber-dependent	Typically none; coagulative effect relies on absorption/scattering rather than surface cooling
Argon (488–514 nm)	Continuous-wave	Fiber-optic delivery	Typically low power, ~150 mW–1 W depending on application	Near-Gaussian	Device-specific; largely superseded by diode lasers, less standardized in recent literature	Device-specific	Device-specific	Not typically used (low-power diagnostic/curing/superficial coagulation applications)
PDT / aPDT (630–660 nm activation)	Continuous-wave typically, low power (photosensitizer activation, not ablation)	Fiber-optic probe, often with a diffusing tip for periodontal pocket/root canal delivery	~10–200 mW (aPDT); oncologic PDT uses higher fluence but remains non-ablative (Section 5.3.2).	Device-specific; diffusing-tip fibers used for more uniform intracanal/pocket distribution	Variable by application (diffusing tip for pocket/canal vs. surface irradiation for mucosal lesions)	Not typically reported as a fixed value; fluence (J/cm²) is the dosimetric parameter usually reported (Section 5.3.2)	Device-specific	Not applicable (non-ablative, photochemical mechanism)

pulse duration, pulse energy, repetition rate, spot size, and heat dissipation all matter, and short pulses confine heat and limit its diffusion toward the pulp.[23] Reported pulse durations run roughly 3–20 µs, with repetition rates of about 40–300 Hz, varying with target tissue and irradiation protocol.[23,41] One commercial system is marketed as matching computer-controlled pulse energy, repetition rate, and spot size to the heat dissipation of enamel and dentin, ablating hard tissue without pulpal injury and, in selected cases, reducing or removing the need for anesthesia. These engineering and regulatory claims come from the manufacturer, were not verified independently here, and may differ by jurisdiction.[23] This pulse behavior, more than wavelength itself, distinguishes the 9,300 nm laser from the continuous-wave 10,600 nm system used on soft tissue.

Nd: YAG Laser (1,064 nm)

Deep penetration lets the Nd: YAG laser coagulate tissue, eradicate bacteria, and disinfect deep periodontal pockets. It is used in periodontal treatment, in laser-assisted new attachment procedures (LANAP), in soft-tissue surgery, and for endodontic disinfection.[39]

Argon Laser (488–514 nm)

The argon laser emits blue-green visible light that hemoglobin and melanin absorb strongly, and it has been used for blood coagulation, composite resin curing, caries detection, and soft-tissue procedures. Its shallow tissue penetration has since seen it largely displaced by more compact, versatile diode systems,[4,42] and today it is largely of historical interest.

Violet Diode Laser (405 nm): Diagnostic Applications

The 405 nm violet diode stands apart from other diode wavelengths (Section 4.2) in being used mostly for diagnosis, though non-diagnostic uses such as resin-curing activation have been reported. Its principal roles are fluorescence-based detection of carious lesions and photodynamic diagnosis of oral mucosal change (Section 5.1.1).[31,32]

Lasers in Dentistry: Diagnostic, Invasive Surgical, and Therapeutic Strategies

Diagnostic Applications

Light- and Laser-Based Fluorescence for Caries Detection

Fluorescence-based caries-detection systems are better classified as light-based or optical diagnostic technologies than as "laser" devices, since their light sources differ: QLF (Quantitative Light-induced Fluorescence) uses an LED at about 405 nm, while DIAGNOdent uses a 655-nm laser diode; both read fluorescence from bacterial by-products in carious lesions.[43,44] The ~405 nm QLF excitation coincides with the violet diode wavelength (Section 4.6), though the two play different roles: LED-delivered diagnosis versus therapeutic laser use. Both are non-invasive and give real-time information on lesion depth and activity. Reported accuracy depends on device, lesion location, and reference standard. One in vivo study of 332 occlusal surfaces in 240 patients, using post-operative caries extent as the reference standard, put DIAGNOdent sensitivity near 92% against 31–63% for visual inspection and bitewing radiography, at the cost of more false positives. An in vitro study of 100 extracted teeth with a histological reference standard found QLF-D sensitivity of 0.64–0.80 depending on lesion depth, comparable to visual (ICDAS II) and radiographic detection

rather than clearly better.[43,44] Bader et al.'s systematic review concluded the literature cannot support reliable point estimates for any single method since differences between methods were often smaller than variation within a method across studies.[45] Photodynamic diagnosis (PDD) extends the same principle, using photosensitizer-assisted fluorescence to detect dysplastic and neoplastic change in the oral mucosa.[46,47]

Laser Doppler Flowmetry for Pulp Vitality Assessment

Laser Doppler flowmetry (LDF) matters in endodontics because it measures pulpal microcirculation directly and non-invasively, reading the Doppler shift of coherent laser light (usually 780–830 nm) scattered by moving erythrocytes, where thermal and electric sensibility tests measure nerve response instead.[22,48] This makes LDF most valuable where nerve function is unreliable: recently traumatized or immature teeth, and teeth with calcified canals.[48,49] Luke et al. proposed that LDF may have advantages over electrical and thermal testing for pulp vitality in permanent teeth, though head-to-head accuracy data (sensitivity, specificity, an independent reference standard, a defined setting) remain scarce, so the claim warrants caution.[50] Afkhami et al. judged LDF reliable and promising in traumatology and pediatric endodontics[49]; its acknowledged drawbacks are sensitivity to probe movement, variable tissue thickness, and equipment cost.[51,52]

Invasive Surgical Applications

Hard Tissue Applications

Erbium lasers remain the main modality for hard tissue. Clinicians use Er: YAG (2,940 nm) and Er, Cr: YSGG (2,780 nm) for cavity preparation, caries excavation, enameloplasty, and selective dentin removal, with high precision and little thermal insult to the pulp-dentin complex.[21,22,28] The newer 9,300 nm CO_2 laser is emerging as an all-tissue alternative: clinical reports using its short-pulse, computer-controlled delivery (Section 4.3.2) describe cavity preparation and bone surgery with reduced or, in selected cases, no local anesthesia. Outcomes here remain device- and protocol-dependent.[23] A systematic review of controlled trials found erbium lasers compared favorably with conventional rotary instruments for caries removal.[28] In endodontics, erbium-family and Nd: YAG lasers also serve in pulpotomy, canal enlargement, smear layer removal, and periapical surgery,[39,53] and in pediatric dentistry, Er: YAG-assisted cavity preparation in primary and immature permanent teeth has been linked to less pain and better acceptance than rotary technique.[54,55]

Oral Soft-Tissue Surgery

Diode lasers (810–980 nm and 405–450 nm), CO_2 lasers (10,600 nm), and Nd: YAG lasers are the primary tools of oral soft-tissue surgery,[26,40,56] used in gingivectomy, gingivoplasty, frenectomy, operculectomy, fibroma removal, crown lengthening, gingival depigmentation, sulcular debridement, and management of oral mucosal lesions.[26,40] Compared with the scalpel, laser procedures have been reported to bleed less, hurt less afterward, and in some studies heal faster, often without suturing. These are findings from particular studies rather than universal properties. Their magnitude depends on wavelengths, power/energy settings, pulse mode, comparator technique, and the outcomes each study measured.[56,57]

Therapeutic Applications

Photobiomodulation Therapy

Photobiomodulation (PBM), called photobiomodulation therapy (PBMT) or low-level laser therapy (LLLT) in older work and PBM throughout this review, uses low-power laser or LED light, mostly red (600–700 nm) and near-infrared (780–950 nm), to stimulate cellular activity without damaging tissue.[34] One candidate mechanism is light-induced activation of cytochrome c oxidase, thought to raise mitochondrial ATP production, though its reproducibility is debated. ROS modulation and transcription-factor effects have also been proposed, with no unifying mechanism established.[35] PBM is also strongly dose-dependent: wavelength, irradiance, fluence, exposure time, spot size, delivery mode, and schedule all shape the outcome (Section 3). Pooling disparate protocols risks hiding real dose–response relationships, so these parameters are reported below where possible. Clinically, PBM is applied to temporomandibular joint disorders, mucositis, neuropathic pain, delayed wound healing, and orthodontic pain.[58-60] Several meta-analyses have asked whether it accelerates tooth movement; pooled findings deserve caution given the range of protocols combined. Olmedo-Hernández et al. reported that adjunctive PBM shortened overall treatment time, with benefit varying between trials.[10] Huang et al., restricted to the alignment phase, found the effect strongest at shorter wavelengths (~655–810 nm) and lower irradiance (~5–10 mW/cm²) rather than with longer-wavelength, higher-power protocols, so "PBM accelerates tooth movement" is not actionable without those parameters.[11] In pediatric soft-tissue procedures, PBM has likewise been reported to speed healing and reduce pain, again depending on wavelength and dose.[9,61] No standardized protocol yet exists for any single indication, which is reason enough to treat pooled efficacy claims with caution.[62]

Photodynamic Therapy

Photodynamic therapy (PDT) pairs a photosensitizing agent, such as methylene blue [MB] or toluidine blue [TBO], with irradiation at a laser wavelength of 630–660 nm; together they generate ROS that selectively destroy cells and microorganisms.[63,64] Dentistry puts PDT to work in two distinct ways.

Antimicrobial PDT (aPDT, Section 5.3.2.1) attacks microbial cell walls as an adjunct to debridement. Oncologic PDT (Section 5.3.2.2) relies on a photosensitizer, usually 5-aminolevulinic acid converted to protoporphyrin IX, that accumulates in dysplastic or malignant epithelium and kills tumor cells directly. Because the biology differs,

so does everything downstream of it: photosensitizer concentration, pre-irradiation interval, wavelength, fluence, and clinical endpoint. The two are therefore summarized separately below.

Antimicrobial Photodynamic Therapy

aPDT supplements mechanical debridement in treating pathogenic oral biofilms, with demonstrated efficacy in periodontitis, peri-implant mucositis, peri-implantitis, and endodontic infection.[65] Published protocols generally use methylene blue or toluidine blue at 0.005–0.05% (roughly 10–100 μM), allow 1–5 minutes of pre-irradiation, and then irradiate with a diode laser at 630–660 nm delivering about 10–200 mW. Endpoints are microbiological and periodontal rather than oncologic: colony-forming unit (CFU) counts, probing depth, bleeding on probing, and clinical attachment level. Jao et al.'s systematic review found that the evidence is weighted toward in vitro and microbiological work, that clinical data remain thinner, and that effectiveness is better established for some indications than others (Section 7).[66]

PDT for Premalignant and Malignant Oral Lesions

PDT is also drawing interest for oral premalignant lesions, such as leukoplakia and erythroplakia, and for superficial oral carcinomas, offering a minimally invasive alternative or complement to surgery and radiotherapy.[64,67] Dosimetrically, it shares almost nothing with aPDT: the photosensitizer is typically topical 5-ALA (10–20% gel), needing a much longer drug-light interval of roughly 1–4 hours to convert to protoporphyrin IX, with irradiation at about 630–635 nm and far higher fluences, on the order of 90–200 J/cm² per session. The endpoint is lesion or tumor response, not a microbiologic measure, and as with PBM, reported protocols vary widely, so read pooled response rates with that heterogeneity in mind.

Laser in the Dental Industry

Lasers also have a role in dental materials science and manufacturing: CO_2, Nd: YAG, and femtosecond lasers modify zirconia, titanium, and ceramic restoration surfaces so they adhere better and prove more biocompatible.[13]

Reported applications include surface texturing to improve implant osseointegration,[68] better wettability and protein adsorption on zirconia,[14] and stronger bonding in ceramic and resin-composite restorations.[69] This rests on laboratory rather than patient-level evidence, and whether such gains translate into longer implant survival or restoration lifespan remains unshown.

Overall Clinical Advantages and Limitations of Lasers in Dentistry

The advantages and limitations below are each tied to a specific indication and level of evidence, ranging from systematic reviews and randomized trials down to case series or laboratory data alone, and stating it plainly keeps the level of confidence visible rather than implied.

Clinical Advantages

Minimally Invasive Treatments

Lasers reportedly remove tissue precisely while sparing surrounding structures, often without mechanical instrumentation or local anesthesia.[70] Evidence is strongest for Er: YAG/Er, Cr: YSGG hard-tissue procedures, with several RCTs (Section 4.1); for soft-tissue diode/CO_2 procedures it rests largely on case series.

Accelerated Healing and Reduced Postoperative Pain and Bleeding

Photothermal effects provide hemostasis during soft-tissue procedures, and PBM has been studied for reducing postoperative pain and supporting healing, with results turning on laser type, irradiation parameters, and indication[56,57]; PBM dosimetry is covered in Section 5.3.1, while evidence for CO_2/diode hemostasis comes mainly from case series.

Antibacterial and Sterilizing Effects

Laser irradiation has shown antimicrobial effects in periodontal and endodontic settings, but clinical significance is not uniform, shaped by laser type, irradiation parameters, and protocol.[71] For aPDT (Section 5.3.2.1) the evidence reaches systematic-review level but supports short-term microbial reduction more than long-term outcomes. Direct bactericidal effects without a photosensitizer remain largely an in vitro finding.

Increased Patient Acceptance

Less noise, less vibration, and less pain are reported to improve comfort and compliance, particularly in children.[9,72] This comes mostly from patient-reported outcomes in case series rather than trials powered to measure acceptance, and it should not be confused with therapeutic efficacy (Section 5.3.1).

Applicability in Pediatric and Orthodontic Contexts

PBM may accelerate tooth movement and reduce pain and anxiety in these patients, although practical barriers limit its uptake.[10-12] Several meta-analyses (Section 5.3.1) support an effect, with considerable heterogeneity in its magnitude and in the optimal wavelength and dose.

Clinical Limitations

High Initial Cost

Acquisition, maintenance, and safety costs are all substantial.[7] That is a textbook observation rather than a quantified cost-effectiveness finding.

Need for Specialized Training

A safe operation calls for specific training and credentialing, which slows adoption.[73] This reflects consensus guidance, not comparative outcome data.

Tissue-Specific Limitations

Diode lasers cannot ablate hard tissue and must be paired with mechanical instrumentation.[74] This follows from

wavelength-dependent chromophore absorption (Sections 3–4) rather than from any clinical trial.

Lack of Standardized Protocols

Widely accepted clinical protocols are missing across many laser applications.[75] This matches the protocol heterogeneity documented throughout this review (Sections 5.3, 6) and formally set out in a recent WFLD report.

Safety Considerations

Hazard Classification and Regulatory Framework

Dental lasers fall under ANSI Z136.1, the American National Standards Institute laser safety standard,[76] and its health-care companion ANSI Z136.3 ,[77] usually Class 4 and sometimes Class 3B. A Class 4 beam can injure skin and eyes directly or by diffuse reflection, so a defined hazard zone, warning signage, and controlled access are required whenever the laser is running.

Ocular Hazards and Protective Eyewear

Ocular risk depends on the wavelength. Visible and near-infrared light, roughly 400–1400 nm, covering the diode wavelengths and Nd: YAG (Section 4), focuses onto the retina. Near-infrared light is invisible, so the blink reflex never fires, and a retinal burn can occur before anyone reacts. Longer wavelengths (Er: YAG, Er, Cr: YSGG, and CO_2 at 10,600/9,300 nm) are instead absorbed by the cornea, risking corneal and anterior-segment thermal injury and, with chronic exposure, cataract. Eyewear must be rated for the optical density of the operating wavelength since eyewear for one laser will not protect against another, and operators, assistants, and patients should all wear it.

Thermal Injury to Dental Hard and Soft Tissue

Excess energy density, power, or exposure time injures tissue thermally regardless of intended benefit, with the pulp-dentin complex most at risk. Zach and Cohen's histologic study found that an intrapulpal rise of 5.5°C sustained for 10 seconds produced irreversible pulpitis in about 15% of teeth, and 60–70% at 11.1°C ,[78] a benchmark for pulpal thermal risk ever since. Adequate water/air cooling, pulsed rather than continuous-wave emission, and conservative energy-density and power settings matter as much for safety as for efficacy. They are the same dosimetric parameters that govern PBM and PDT (Section 5.3), and should be reported alongside efficacy outcomes.

Plume and Aerosol Hazards

Ablative procedures, especially with CO_2 and other high-power wavelengths, produce a plume of carbonized tissue, water vapor, and sub-micron particulates. Viable microbial and viral genetic material, including HPV DNA, has been recovered from CO_2 plume in other surgical settings, a plausible inhalation risk during soft-tissue laser surgery. Since plume particles can be finer than a standard surgical mask filters, recommended controls include a high-filtration respirator (N95 or equivalent) plus dedicated smoke evacuation, though dentistry-specific evidence on plume composition and mitigation remains limited.

Additional Hazards and Training

Using a laser near supplemental oxygen, alcohol-based antiseptics, or other flammable materials creates a fire risk requiring standard perioperative precautions. As Section 7.2.2 notes, safe use also depends on training and credentialing specific to each laser and application. General clinical experience covers none of these hazards adequately.

Conclusion

Laser technology is a fast-moving set of diagnostic and therapeutic tools in dentistry, but the strength of the evidence behind it is uneven. Active medium and wavelength largely dictate what each system is good for: erbium lasers suit hard-tissue ablation, diode and CO_2 lasers carry most soft-tissue surgery, and PBM and aPDT work at sub-ablative levels toward therapeutic ends. The 9,300 nm CO_2 platform, PBM's widening role in orthodontics, and aPDT in infection control all show a field still in motion Laser-induced fluorescence and LDF extend the same technology into objective, non-invasive diagnosis. Evidence is most consistent where the link between physics and clinical effect is most direct: Er: YAG/Er, Cr: YSGG hard-tissue ablation and diode/CO_2 soft-tissue surgery each rest on multiple comparative or systematic-review-level studies; aPDT in periodontal and endodontic infection is similarly supported, though its clinical data still trail in vitro findings; and fluorescence-based caries detection has a reasonably established base whose performance varies by device, lesion type, and reference standard. Much more uncertainty remains around PBM, oncologic PDT, and the 9,300 nm platform, where protocols are heterogeneous and pooled estimates should not be read as settled; laser-assisted materials modification is supported almost entirely by laboratory rather than patient-level evidence (Section 6). Priorities from here are consistent dosimetric reporting across PBM and PDT studies, head-to-head trials with patient-centered endpoints, and longer follow-up for newer all-tissue CO_2 systems, rather than reliance on isolated case reports and small trials.

Authors' Contribution

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Competing Interests

The authors declare no conflicts of interest. For transparency, the authors note that the late Prof. Reza Fekrazad had previously served on the Editorial Team of JLMS; as he is no longer living, this affiliation has no bearing on the handling of this submission.

Ethical Approval

This study is a narrative review of previously published literature and did not involve the collection of new data from human participants or animals; formal ethics committee approval was therefore not required.

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