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Review Article

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Toward evidence-based laser dentistry: wavelength selection, parameter standardization and clinical outcomes

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ABSTRACT

Lasers in dentistry represent a range of wavelength-specific technologies and biological mechanisms rather than a uniform treatment category. This structured comprehensive narrative review examined the principal foundations and clinical domains of contemporary laser dentistry, including laser–tissue interaction, wavelength and parameter selection, periodontics and peri-implant therapy, endodontics, restorative dentistry, prosthodontics, oral surgery, pediatric dentistry, orthodontics, photobiomodulation, and antimicrobial photodynamic therapy. Literature from PubMed, Scopus, and Web of Science was reviewed and interpreted comparatively according to wavelength, target chromophore, emission characteristics, operating parameters, clinical indication, comparator, outcome measures, and degree of clinical support. The evidence showed considerable variation across applications. Selected soft-tissue surgical procedures and wavelength-matched ablative or debonding applications had the clearest clinically established roles, although superiority over conventional approaches was not universal. In periodontics, peri-implant therapy, and endodontics, lasers and antimicrobial photodynamic therapy were better supported as adjuncts to mechanical debridement or chemomechanical disinfection than as independent alternatives. Prosthodontic applications offered useful options for material-specific surface treatment and conservative restoration retrieval, although their effectiveness remained dependent on substrate characteristics and thermal control. Pediatric applications appeared relevant to minimally invasive care and patient acceptance. In orthodontics, evidence was stronger for selected soft-tissue procedures and ceramic bracket debonding than for accelerating tooth movement or consistently reducing pain. The available evidence indicates that lasers should not be considered a single therapeutic category or a universal replacement for conventional methods. Their clinical value is indication-specific and, in many applications, primarily adjunctive.

Keywords: Laser dentistry, Laser–tissue interaction, Photobiomodulation, Antimicrobial photodynamic therapy

INTRODUCTION

Laser technology has progressed from a limited adjunct for selected dental procedures into a diverse group of systems used for hard-tissue ablation, soft-tissue surgery, microbial control, irrigant activation, surface modification, restoration or bracket removal, and non-ablative biological modulation.[1,2] Its applications now extend across periodontics and peri-implant therapy, endodontics, restorative dentistry, prosthodontics, oral surgery, pediatric dentistry, and orthodontics. However, this breadth of use does not make laser dentistry a uniform therapeutic category. Different laser systems produce distinct tissue effects, and their value must be assessed according to the wavelength, target tissue, treatment objective, and clinical protocol rather than the general presence of a laser device.

The biological and clinical effects of laser irradiation begin with the interaction between the emitted wavelength and the optical and thermal properties of the target. Absorption by water, hydroxyapatite, hemoglobin, melanin, and other chromophores influences penetration depth, energy distribution, and the dominant tissue response.[3] Experimental evidence further demonstrates substantial differences in absorption, penetration, and thermal relaxation among wavelengths used for oral soft tissues.[4] Wavelength alone, nevertheless, provides an incomplete description of treatment. Power, energy per pulse, irradiance, radiant exposure, spot size, pulse duration, repetition rate, contact mode, exposure time, cooling, and operator movement can substantially alter the delivered dose and resulting tissue effect.[5] Accordingly, protocols using the same wavelength may produce different biological or clinical outcomes when their remaining parameters differ.[6]

Clinical interpretation is further complicated by the inclusion of interventions with fundamentally different therapeutic objectives under the broad designation of laser treatment. Ablative and surgical lasers are intended to remove, modify, coagulate, or disrupt tissue, whereas photobiomodulation aims to influence cellular signaling without deliberate ablation or coagulation.[7] Antimicrobial photodynamic therapy instead requires a photosensitizer, an activating wavelength, and molecular oxygen to generate reactive oxygen species capable of damaging microbial cellular components.[8] These modalities cannot be evaluated using interchangeable mechanisms, dose requirements, or outcome measures.

Despite the expanding literature, inconsistent parameter selection and incomplete reporting continue to restrict reproducibility and comparison. Parker et al found that essential information concerning power measurement, beam characteristics, radiant exposure, and dosimetry was frequently absent from dental photobiomodulation trials.[9] Cronshaw et al subsequently demonstrated that optical spot size, target depth, and delivery technique may influence clinical outcomes, indicating that apparently similar protocols may deliver substantially different energy to the intended tissue.[10] This variability complicates attempts to determine whether inconsistent findings reflect limitations of the modality itself or differences in treatment delivery. Accordingly, this structured comprehensive narrative review critically evaluates laser use in modern dentistry. Particular attention is given to how wavelength selection, target chromophores, emission characteristics, and operating parameters influence safety and clinical effectiveness. Laser-assisted and conventional approaches are compared where direct evidence permits, established applications are distinguished from those that remain promising or experimental, and deficiencies in parameter reporting and protocol standardization are identified.

METHODS

Review design and rationale

This article was developed as a structured narrative review to critically examine the biological basis, clinical effectiveness, safety, and evidence maturity of laser applications in contemporary dentistry. The analysis focused on how wavelength, laser medium, chromophore affinity, emission mode, pulse characteristics, power, irradiance, radiant exposure, exposure time, delivery technique, and thermal control influence tissue interactions and clinical outcomes. Rather than considering laser dentistry as a uniform technology, its applications were evaluated according to their specific indications across periodontics and peri-implant therapy, endodontics, restorative dentistry, prosthodontics, oral surgery, pediatric dentistry, and orthodontics. Photobiomodulation and antimicrobial photodynamic therapy were distinguished throughout the review because of their distinct biological targets and dose requirements. Laser-assisted approaches were compared with conventional care where direct evidence was available, with emphasis on distinguishing established applications from those that remain promising, inconsistent, or experimental.

Literature search strategy

A structured electronic search was conducted in PubMed/MEDLINE, Scopus, and Web of Science Core Collection from database inception through July 2026. Search terms were organized into three concept blocks covering dental specialties, laser or light-based interventions, and treatment parameters or clinical outcomes. Database-specific indexing, field tags, and proximity operators were applied as appropriate. No study-design restriction was imposed during retrieval to permit identification of clinical studies, evidence syntheses, and relevant mechanistic investigations. Reference lists of eligible journal articles and relevant reviews were also screened for additional publications. Only peer-reviewed journal articles were carried forward for eligibility assessment. The complete search strategies are presented in Table 1.

Eligibility and source selection

Peer-reviewed journal articles published in English were considered eligible when they directly examined laser–tissue interactions, wavelength or chromophore selection, operating parameters, safety, clinical effectiveness, or specialty-specific dental applications. Eligible evidence included systematic reviews, meta-analyses, randomized and nonrandomized clinical studies, observational investigations, and selected laboratory or preclinical studies required to explain biological mechanisms, dosimetry, thermal effects, or material interactions. Studies addressing periodontics and peri-implant therapy, endodontics, restorative dentistry, prosthodontics, oral surgery, pediatric dentistry, orthodontics, photobiomodulation, and antimicrobial photodynamic therapy were considered.

Articles were excluded when laser use was incidental to the study objective, the application was unrelated to dentistry, the report did not contribute relevant mechanistic or clinical information, or the primary topic belonged to oral medicine. Policy statements, books, book chapters, conference abstracts, theses, preprints, and other non-journal sources were excluded. Duplicate publications were removed, and the most complete report was retained when overlapping datasets were identified.

Table 1: Database-specific electronic search strategies

Database	Search strategy
PubMed/MEDLINE	(Dentistry[MeSH Terms] OR dental[Title/Abstract] OR dentistry[Title/Abstract] OR periodont*[Title/Abstract] OR (peri[Title/Abstract] AND implant*[Title/Abstract]) OR implant*[Title/Abstract] OR endodont*[Title/Abstract] OR restorativ*[Title/Abstract] OR prosthodont*[Title/Abstract] OR orthodont*[Title/Abstract] OR ((pediatric[Title/Abstract] OR paediatric[Title/Abstract]) AND dent*[Title/Abstract]) OR ((oral[Title/Abstract] OR maxillofacial[Title/Abstract]) AND surg*[Title/Abstract])) AND (Lasers[MeSH Terms] OR laser*[Title/Abstract] OR photobiomodulation[Title/Abstract] OR PBM[Title/Abstract] OR photodynamic[Title/Abstract] OR aPDT[Title/Abstract]) AND (wavelength*[Title/Abstract] OR chromophore*[Title/Abstract] OR parameter*[Title/Abstract] OR power[Title/Abstract] OR energy[Title/Abstract] OR irradiance[Title/Abstract] OR fluence[Title/Abstract] OR dosimetry[Title/Abstract] OR pulse*[Title/Abstract] OR thermal[Title/Abstract] OR safety[Title/Abstract] OR efficacy[Title/Abstract] OR effectiveness[Title/Abstract] OR outcome*[Title/Abstract] OR pain[Title/Abstract] OR healing[Title/Abstract] OR disinfection[Title/Abstract] OR decontamination[Title/Abstract] OR ablation[Title/Abstract] OR hemostasis[Title/Abstract])
Scopus	TITLE-ABS-KEY(dental OR dentistry OR periodont* OR peri W/1 implant* OR implant* OR endodont* OR restorativ* OR prosthodont* OR orthodont* OR pediatric W/1 dent* OR paediatric W/1 dent* OR oral W/3 surg* OR maxillofacial W/2 surg*) AND TITLE-ABS-KEY(laser* OR photobiomodulation OR PBM OR photodynamic W/1 therap* OR aPDT) AND TITLE-ABS-KEY(wavelength* OR chromophore* OR parameter* OR power OR energy OR irradiance OR radiant W/1 exposure OR fluence OR dosimetry OR pulse* OR thermal OR safety OR efficacy OR effectiveness OR clinical W/1 outcome* OR treatment W/1 outcome* OR pain OR healing OR disinfection OR decontamination OR ablation OR hemostasis)
Web of Science Core Collection	TS=(dental OR dentistry OR periodont* OR peri NEAR/1 implant* OR implant* OR endodont* OR restorativ* OR prosthodont* OR orthodont* OR pediatric NEAR/1 dent* OR paediatric NEAR/1 dent* OR oral NEAR/3 surg* OR maxillofacial NEAR/2 surg*) AND TS=(laser* OR photobiomodulation OR PBM OR photodynamic NEAR/1 therap* OR aPDT) AND TS=(wavelength* OR chromophore* OR parameter* OR power OR energy OR irradiance OR radiant NEAR/1 exposure OR fluence OR dosimetry OR pulse* OR thermal OR safety OR efficacy OR effectiveness OR clinical NEAR/1 outcome* OR treatment NEAR/1 outcome* OR pain OR healing OR disinfection OR decontamination OR ablation OR hemostasis)

REVIEW

Why laser therapy is a parameter-dependent intervention

Laser-assisted dentistry is not a single intervention. Wavelength, emission mode, pulse characteristics, spot size, exposure time, delivery technique, cooling, and tissue composition jointly determine the optical dose and biological response.[3,11] Average power alone is therefore insufficient to reproduce treatment, and the power selected on the device may differ from that delivered at the fiber or handpiece tip.[11,12] Accurate reporting should identify the target, wavelength, delivered output, pulse structure, irradiated area, exposure time, contact or non-contact mode, movement, cooling, and treatment repetition.[11,12]

This parameter dependence also explains part of the heterogeneity in clinical studies. Protocols described broadly as “diode”, “erbium”, or “photobiomodulation” may deliver substantially different exposures, even when the nominal wavelength is similar.[9-11] Clinical interpretation should therefore compare a fully specified laser protocol with the appropriate conventional treatment and distinguish mechanistic or surrogate outcomes, such as bacterial reduction or surface change, from patient-important outcomes such as pain, healing, disease control, restoration survival, or treatment success.[13-15] Throughout this review, evidence is interpreted according to the target, wavelength, operating parameters, comparator, clinical outcome, and safety rather than according to the presence of a laser device alone.[11]

Wavelengths, chromophores, and laser–tissue interactions

Wavelength determines which tissue components preferentially absorb incident energy, but does not independently determine the clinical effect.[3] Water, hemoglobin, melanin, proteins, and mineral components are important oral chromophores; their relative contribution varies with tissue hydration, vascularity, pigmentation, and mineralization.[3,4] Strongly absorbed wavelengths concentrate energy more superficially, whereas weaker absorption may permit greater penetration, although scattering and tissue structure modify the actual distribution.[3,4] Visible blue and green diode wavelengths interact strongly with blood pigments and can provide efficient soft-tissue cutting and hemostasis, while near-infrared diode wavelengths generally penetrate more deeply. Experimental and clinical observations nevertheless confirm that thermal alteration remains dependent on power, exposure time, fiber movement, and tissue margins.[16,17]

Er:YAG (2940 nm) and Er,Cr:YSGG (2780 nm) are strongly absorbed by water and are suited to hard-tissue and water-mediated ablation; effective water cooling is important for controlling heat accumulation.[3,18] The resulting interaction may be photothermal, photomechanical/photoacoustic, photochemical, or photobiomodulatory. Laser-activated endodontic irrigation relies mainly on rapid energy absorption in irrigants and cavitation, antimicrobial photodynamic therapy (aPDT) requires a photosensitizer, matched activating wavelength, and oxygen, while photobiomodulation (PBM) uses non-ablative optical exposure to modulate cellular signalling.[19-21] These modalities therefore require different dose descriptors and cannot be evaluated as interchangeable forms of “low-level laser therapy”. The principal mechanistic and protocol distinctions between PBM and aPDT are summarized in Figure 1.[10,20,21]

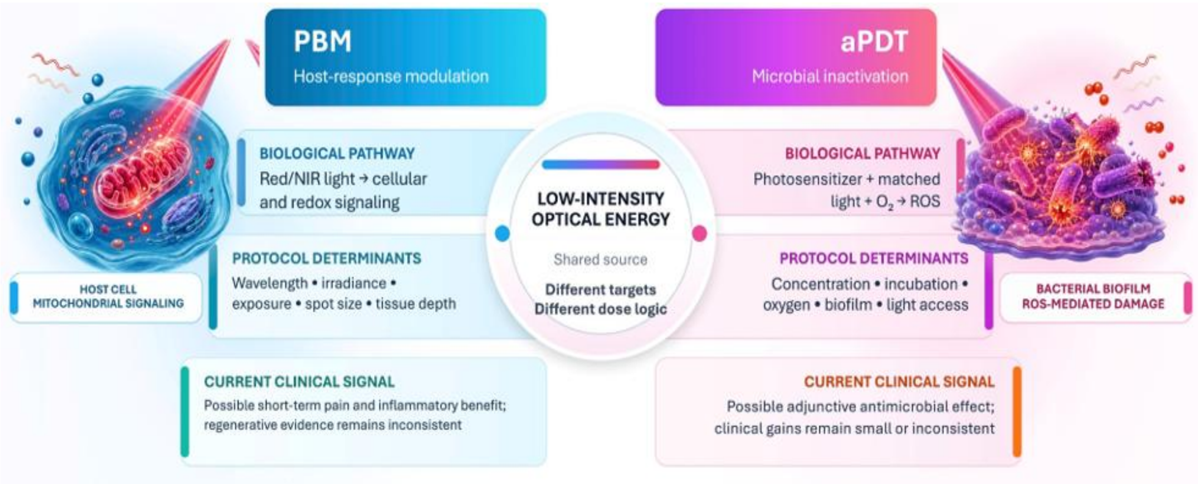

Figure 1: Mechanistic and protocol distinctions between photobiomodulation and antimicrobial photodynamic therapy in dentistry.

*PBM and aPDT both use low-intensity optical energy but act through different biological targets and require different protocol determinants. Abbreviations: aPDT, antimicrobial photodynamic therapy; NIR, near-infrared; O_2, molecular oxygen; PBM, photobiomodulation; ROS, reactive oxygen species.

Laser-assisted diagnosis and caries prevention

Laser fluorescence should be regarded as an adjunct to caries assessment rather than an independent diagnostic authority. Fluorescence-based readings can be influenced by plaque, staining, calculus, and restorative materials, and a meta-analysis of DIAGNOdent and VistaProof reported pooled sensitivity and specificity of approximately 0.77 and 0.75, respectively, indicating moderate rather than definitive discrimination.[22] Numerical readings should therefore be interpreted together with visual examination, radiographic findings when indicated, lesion activity, and patient-level caries risk.

Laser Doppler flowmetry assesses pulpal blood flow rather than sensory response. A meta-analysis of five pulp tests reported sensitivity and specificity of approximately 0.98 and 0.95 for laser Doppler flowmetry, but technique sensitivity, motion artifact, probe positioning, and the lack of universal vitality thresholds limit routine use.[23] Laser-based caries prevention is most developed for carbon-dioxide wavelengths that thermally modify enamel. A recent systematic review identified only a small group of clinical and ex vivo studies; pooled clinical findings favored laser treatment, but substantial heterogeneity limited certainty and transferability.[24] Evidence is particularly dependent on wavelength, fluence, pulse duration, cooling, and concomitant fluoride use. Current evidence therefore supports selective adjunctive use rather than replacement of established diagnostic, fluoride, and preventive strategies.

Periodontal and peri-implant applications of lasers

Periodontal applications depend on whether the target is calculus, root surface, pocket epithelium, granulation tissue, or microbial biofilm. Mechanical instrumentation remains the reference treatment. Systematic evidence indicates that adjunctive laser or aPDT protocols can produce short-term improvements in selected outcomes, but effects are inconsistent across wavelengths and treatment schedules.[25] A split-mouth trial found Er:YAG debridement broadly comparable with scaling and root planing, with less postoperative sensitivity and shorter treatment time but no superior short-term probing-depth or attachment outcome.[26]

More complex laser-assisted protocols may be useful in residual pockets or intrabony defects, although they evaluate complete treatment strategies rather than an isolated laser effect. A multicenter trial reported non-inferior 12-month outcomes for an Er,Cr:YSGG surgical protocol compared with minimally invasive periodontal surgery.[27] For peri-implantitis, a recent meta-analysis of 15 randomized trials showed that non-surgical laser therapy may reduce bleeding and probing depth from baseline but does not consistently outperform conventional treatment or prevent marginal bone loss.[28] Advanced disease should not be managed on the assumption that a minimally invasive laser protocol can replace surgical access; a recent randomized trial favored surgery over repeated diode-assisted non-surgical treatment in severe cases.[29] Lasers should therefore remain adjunctive or indication-specific tools within effective debridement, plaque control, and maintenance. In particular, improvements observed within laser-treated groups should not be interpreted as evidence of superiority unless the between-group effect is clinically meaningful and sustained. Peri-implant protocols also require caution because the implant surface, tip geometry, exposure duration, and cooling can influence both decontamination and the risk of surface or thermal damage.[28,29]

Laser-assisted endodontics: irrigation, disinfection, and clinical outcomes

Endodontic laser applications include direct intracanal irradiation, laser-activated irrigation, and aPDT, which act through different mechanisms.[19] Erbium laser activation of irrigants produces cavitation and fluid movement that may improve cleaning of fins, isthmuses, and other inaccessible anatomy, but efficacy depends on pulse energy, pulse duration, tip position, canal geometry, and irrigant replenishment.[19] Laboratory work confirms improved biofilm removal in difficult-to-reach areas compared with conventional needle irrigation in some models, while also demonstrating that complete disinfection is not achieved.[30]

Clinical evidence supports an adjunctive rather than substitutive role. Direct 445-nm diode irradiation reduced bacterial load less effectively than sodium hypochlorite alone, while the combination produced the greatest reduction in one randomized trial.[31] An umbrella review concluded that laser-assisted endodontic treatment remains heterogeneous and that evidence for improved long-term clinical outcomes is insufficient.[32] Meta-analysis of seven trials involving 490 teeth suggests that laser-activated irrigation may reduce early postoperative pain compared with ultrasonic activation, with the greatest effect within the first 24-48 hours; however, effects are technique-dependent, heterogeneous, and short-lived.[33] A randomized trial found no significant difference in 12-month periapical healing among advanced agitation methods despite numerical differences.[34] Thermal safety is also protocol-dependent; irrigant presence markedly limits temperature rise during Er:YAG activation.[35] Conventional chemomechanical preparation and irrigation therefore remain fundamental. Technique names such as PIPS or SWEEPS should not substitute for reporting pulse energy, repetition rate, pulse duration, tip position, irrigant volume, and activation time, because these variables determine the fluid-dynamic exposure delivered to the canal system.[19,32]

Laser applications in prosthodontics and restoration retrieval: material-specific benefits and unresolved clinical limits

Prosthodontic laser use should distinguish surface conditioning from restoration retrieval. For ceramic bonding, systematic evidence remains predominantly laboratory based. Laser conditioning can increase bond strength compared with untreated surfaces, but does not show a consistent advantage over established mechanical or chemical conditioning.[36] For silica-based ceramics, hydrofluoric-acid etching with silanization remains better supported than laser treatment alone.[37] Zirconia findings are similarly heterogeneous, with airborne-particle abrasion or tribochemical approaches generally outperforming most laser protocols.[38]

Erbium-laser-assisted ceramic retrieval has a stronger clinical rationale because transmitted energy can disrupt the resin-cement interface while potentially preserving the restoration and underlying tooth or implant abutment.[39] A scoping review found promising results but substantial reliance on laboratory and case-based evidence.[39] In a retrospective clinical series involving 46 ceramic prostheses, 44 were retrieved intact; retrieval was fastest for veneers and substantially longer for fixed partial dentures. Only 22 restorations were recemented at the same visit, and no conventional-removal control group was available.[40] Thermal safety depends on ceramic thickness, opacity, cement, irradiation parameters, cooling, and treatment duration; a single in vitro temperature threshold should not be treated as proof of clinical pulpal safety.[41] The most defensible current prosthodontic role is therefore selective erbium-assisted retrieval rather than routine replacement of material-specific bonding protocols. Retrieval settings should not be transferred directly between lithium disilicate, feldspathic ceramic, and zirconia, because optical transmission, thickness, opacity, cement composition, and restoration geometry alter both removal efficiency and heat generation.[39-41]

Laser-assisted caries removal and restorative dentistry

Er:YAG and Er,Cr:YSGG lasers are the principal systems used for enamel and dentin ablation because of their strong interaction with water-containing mineralized tissues.[42] Their use is not inherently minimally invasive: ablation efficiency and pulpal safety depend on pulse characteristics, water spray, beam movement, and the endpoint selected for caries removal.[18,42] A recent meta-analysis of 20 clinical studies found no clear advantage over rotary preparation for restoration survival or pulp vitality, but laser treatment was associated with less pain and a lower requirement for local anesthesia (risk ratios approximately 0.35 and 0.29, respectively). Preparation was about 2.2 minutes longer on average, and certainty for several outcomes was low or very low.[43]

Contemporary caries management prioritizes selective tissue removal and pulpal preservation rather than complete elimination of all altered dentin.[44] Adhesive performance after laser preparation remains protocol-sensitive; pooled evidence suggests that Er:YAG dentin pretreatment can alter bond strength and should not automatically replace conventional adhesive conditioning.[45] Evidence for dentin hypersensitivity is heterogeneous and does not establish reliable superiority of lasers over topical desensitizing agents.[46] Likewise, an umbrella review found no consistent improvement in final whitening efficacy from laser or light activation of in-office bleaching and no dependable reduction in sensitivity.[47] Restorative laser use is therefore best justified by selected patient-centered advantages rather than superior restoration longevity. Clinical protocols must also preserve the biological principles of contemporary selective caries removal - laser fluorescence, color, or a perceived ablation endpoint should not prompt unnecessary removal of caries-affected dentin near the pulp when a durable peripheral seal can be achieved.[44]

Laser applications in orthodontics: selective value in bracket debonding and uncertain biologic acceleration

Orthodontic laser applications include high-energy procedures at enamel, adhesive, bracket, or soft-tissue interfaces and low-energy PBM intended to influence pain or tooth movement. These uses require separate assessment.[48,49] The strongest mechanical rationale concerns ceramic bracket debonding, where laser energy can soften or ablate the adhesive and reduce the force required for removal. A systematic review found that carbon-dioxide and Er:YAG protocols generally reduced ceramic-bracket bond strength under selected conditions, but the evidence was dominated by heterogeneous laboratory studies.[48]

Experimental evidence also shows that diode, Er:YAG, and ultrasonic assistance can reduce ceramic-bracket debonding forces, with the Er:YAG protocol producing greater adhesive retention on enamel in one study.50 Thermal safety remains critical because energy transmitted through the bracket and adhesive can reach the pulp, and laboratory temperature thresholds cannot be transferred uncritically to clinical conditions.[41,48]

PBM has been investigated for accelerating orthodontic tooth movement and reducing pain. A meta-analysis of split-mouth trials suggested increased early tooth movement, but protocol variability and risk-of-bias concerns limited certainty.[51] A 2026 overview incorporating 40 systematic reviews, 134 primary studies, and 4,730 participants similarly concluded that most evidence was methodologically weak. Reanalysis of lower-bias studies suggested roughly 1 mm of additional movement over three months, but this did not establish shorter comprehensive treatment, and pain benefits were of limited clinical magnitude.[49] Accordingly, selective ceramic bracket debonding and soft-tissue procedures have a clearer current role than routine PBM for treatment acceleration. Routine laser enamel conditioning before bracket bonding is also difficult to justify when conventional acid etching is simpler and more extensively validated; any proposed laser protocol should demonstrate not only adequate bond strength but also acceptable enamel loss, pulpal temperature, bracket fracture risk, and adhesive-cleanup requirements.[48]

Laser applications in pediatric dentistry: behavioral advantages without established clinical superiority

Pediatric outcomes should include pain, anxiety, cooperation, anesthetic use, and treatment duration together with pulpal and restorative outcomes. Meta-analysis of seven randomized trials of Er:YAG caries removal in children found lower pain but longer preparation time, without clear improvement in restoration retention, marginal discoloration, or marginal adaptation.[52] A subsequent split-mouth study of 78 children aged 5-10 years similarly reported reduced pain, anxiety, hypersensitivity, and anesthetic use with Er:YAG treatment, while 12-month treatment success was comparable with conventional preparation.[53] The principal advantage is therefore improved treatment tolerance rather than superior disease control.

Laser pulpotomy has also been investigated in primary teeth. Meta-analyses show broadly similar clinical and radiographic success to conventional pulpotomy approaches, without consistent evidence of superiority. One 2025 synthesis included 17 randomized trials and 1,018 primary teeth and found essentially equivalent pooled clinical and radiographic success for diode-laser and conventional treatment.[54,55] For molar-incisor hypomineralization-associated hypersensitivity, a 2026 systematic review identified only three randomized trials and found no clear advantage of laser therapy over established desensitizing approaches.[56] Pediatric laser protocols should therefore be selected for specific behavioral or procedural benefits and should not be transferred directly from permanent-tooth protocols without attention to tooth type, remaining dentin, energy, repetition rate, working distance, and cooling. Trials should also compare laser excavation with contemporary selective caries-removal strategies rather than only with complete rotary excavation, because the relevant question is whether the child receives equivalent biological care with a meaningful improvement in comfort or cooperation.[52,53]

Laser-assisted oral surgery and soft-tissue management

High-power lasers can combine incision, ablation, and coagulation, but wavelength selection determines the balance between hemostasis and collateral thermal change. In comparative clinical and histological work, carbon-dioxide lasers provided stronger hemostasis, whereas Er:YAG produced less thermal alteration at specimen margins.[57] This trade-off is particularly important for excisional biopsy, where thermal artifact can compromise margin interpretation. A systematic review confirmed that all evaluated laser categories can produce histological thermal changes, with the extent depending on wavelength and operating parameters.[58] Scalpel excision remains the most predictable option when preservation of small or diagnostically critical margins is paramount.

Frenectomy and gingivectomy show more consistent perioperative benefits. Meta-analysis of 14 comparative studies indicates that diode frenectomy can reduce intraoperative bleeding and early postoperative pain compared with scalpel surgery, without clear evidence of superior later wound healing.[59] A systematic review of laser gingivectomy for orthodontic treatment-associated enlargement similarly found less bleeding and pain, but long-term stability and recurrence were inadequately studied.[60]

For bone surgery, a meta-analysis of six randomized trials involving 299 impacted mandibular third molars associated Er:YAG osteotomy with less edema and fewer reported complications, with only a small early pain advantage and no clear difference in trismus. Rotary surgery remained faster, and the evidence was limited by heterogeneous protocols and risk of bias.[61] Overall, lasers have clear technical value for selected soft-tissue procedures, particularly when hemostasis and operative visibility are important, but superiority in long-term healing, function, or recurrence is not universal. Specialty-specific applications and their current clinical interpretation are summarized in Table 2. When tissue is submitted for histopathology, the operative advantage of hemostasis must be balanced against specimen quality; adequate margins and conservative parameters are particularly important for small lesions in which a thermal zone may represent a substantial proportion of the-specimen.[57,58]

Table 2: Specialty-specific summary of laser applications in modern dentistry

Specialty or domain	Included clinical applications	Principal targets and representative modalities	Intended clinical outcomes	Current clinical interpretation
Periodontics	Subgingival debridement; pocket therapy; periodontal surgery; adjunctive aPDT	Calculus, root surface, biofilm and soft tissue; Er:YAG, Er,Cr:YSGG, diode, Nd:YAG, aPDT	Debridement, hemostasis, microbial and inflammatory control	Useful in selected protocols, but mechanical instrumentation remains fundamental; additional attachment gain is inconsistent.
Peri-implant therapy	Implant-surface decontamination; mucositis/peri-implantitis adjuncts	Biofilm and implant surfaces; Er:YAG, diode, CO_2, aPDT	Reduced inflammation and bleeding; decontamination	Benefits are generally small or inconsistent; advanced disease may still require surgical access and surface safety is parameter-dependent.
Endodontics	Laser-activated irrigation; intracanal disinfection; adjunctive aPDT	Irrigants and microbial targets; Er:YAG, Er,Cr:YSGG, diode; PIPS/SWEEPS	Irrigant movement, biofilm disruption, microbial reduction	Adjunctive role only; long-term healing or survival benefit remains unproven.
Restorative dentistry	Caries removal; cavity preparation; hypersensitivity; bleaching activation	Water/mineralized tissues; Er:YAG, Er,Cr:YSGG; selected diode/Nd:YAG protocols	Ablation, pain reduction, surface modification	Clinically feasible with less discomfort in selected patients, but not superior for restoration survival; bonding and thermal effects remain protocol-dependent.
Prosthodontics	Ceramic surface treatment; crown/veneer/restoration retrieval	Ceramic, resin cement and water; mainly erbium lasers	Conservative retrieval and substrate preservation	Retrieval is promising for selected restorations; laser surface conditioning does not replace established material-specific protocols.

Continued.

Specialty or domain	Included clinical applications	Principal targets and representative modalities	Intended clinical outcomes	Current clinical interpretation
Orthodontics	Ceramic bracket debonding; soft-tissue procedures; PBM	Bracket/adhesive interfaces and soft tissue; Er:YAG, CO2, diode; red/NIR PBM	Reduced debonding force, tissue management, possible pain/movement effects	Evidence is strongest for selected debonding/soft-tissue uses; routine PBM acceleration remains unsupported.
Pediatric dentistry	Caries removal; soft-tissue care; pulpotomy; hypersensitivity	Water/mineral and soft-tissue targets; Er:YAG, diode	Reduced pain/anesthetic need, hemostasis, treatment acceptance	Behavioral advantages are plausible, but treatment is often slower and biological superiority is not established.
Oral surgery	Incision/excision; frenectomy; gingivectomy; selected bone surgery	Water, hemoglobin and melanin; CO2, diode, Er:YAG, Er,Cr:YSGG	Hemostasis, visibility, tissue ablation, reduced early morbidity	Technical perioperative benefits are established for selected procedures; long-term superiority is not universal and biopsy margins require thermal caution.
PBM	Pain and inflammatory modulation; proposed healing/tooth-movement effects	Host cellular photoacceptors; low-intensity red/NIR light	Analgesic and biological modulation	Possible short-term benefits, but dose-response uncertainty and heterogeneous protocols limit routine transferability.
aPDT	Adjunctive periodontal, peri-implant and endodontic disinfection	Photosensitizer, matched light and oxygen	Reactive-oxygen-mediated microbial inactivation	May provide adjunctive antimicrobial effects but should not replace debridement, instrumentation, or irrigation.

*Legend: aPDT, antimicrobial photodynamic therapy; CO_2, carbon dioxide; Er:YAG, erbium-doped yttrium aluminum garnet; Er,Cr:YSGG, erbium, chromium-doped yttrium scandium gallium garnet; Nd:YAG, neodymium-doped yttrium aluminum garnet; NIR, near-infrared; PBM, photobiomodulation; PIPS, photon-induced photoacoustic streaming; SWEEPS, shock wave-enhanced emission photoacoustic streaming.

Laser safety, adverse effects, and economic feasibility

Laser safety requires wavelength-specific eye protection, controlled access to the treatment area, correct handling of fibers and tips, equipment checks, and attention to combustible materials and reflected radiation.[62] Thermal injury remains the principal tissue-level hazard and is determined by pulse structure, dwell time, movement, cooling, and the properties of adjacent tissues or materials rather than nominal power alone.[62,63]

Laser ablation also generates plume and aerosols. A randomized clinical trial found that Er:YAG caries removal with high-volume evacuation generated about 42% fewer aerosol particles and 79% fewer airborne aerobic bacteria than turbine preparation, but concentrations still increased above baseline; appropriate evacuation, ventilation, and personal protection remain necessary.[64] Safe adoption therefore depends on trained personnel, procedure-specific competence, validated parameters, and active adverse-event monitoring.[62,63] Economic value is likewise indication-specific: one decision model found several mechanical peri-implantitis strategies more cost-effective than Er:YAG monotherapy or aPDT, although the underlying evidence was uncertain.[65] Clinical benefit, safety, training requirements, procedure time, maintenance, and equipment costs should all be considered before routine implementation. Safety cannot be inferred from an absence of visible tissue damage: thermal injury may occur beneath the surface, and operator competence must include wavelength-specific eye protection, calibration, cooling, plume control, and response to adverse events.[62,63]

Evidence maturity and research priorities

Across specialties, evidence is stronger for technical feasibility and selected short-term outcomes than for durable superiority over conventional care.[11,63] The most persistent limitation is incomplete and inconsistent description of the intervention. At minimum, studies should report device and wavelength, verified output at the treatment site, emission mode, pulse energy and duration, repetition rate, spot size, irradiance or radiant exposure where relevant, irradiation time, delivery geometry, movement, cooling, and treatment frequency.[10-12] aPDT studies additionally require complete photosensitizer and illumination details.[20,63]

Future trials should define whether the laser is intended as an alternative or an adjunct, use an appropriate comparator, prespecify patient-important primary outcomes and adverse events, and follow participants long enough to evaluate recurrence, healing, treatment survival, and retreatment rather than relying mainly on bacterial reduction, surface modification, or other surrogate outcomes.[13-15] Prospective registration, adequate sample size, concealed allocation, blinded outcome assessment where feasible, complete participant accounting, and effect estimates with confidence intervals should follow contemporary trial-reporting standards.[66] Multicenter studies and economic evaluations are particularly important before technically promising protocols are promoted for routine care. Progress should be judged by reproducible, indication-specific protocols with demonstrated incremental clinical value, not by the availability of additional wavelengths or devices. Where the proposed advantage is comfort, reduced anesthetic need, or shorter recovery rather than better disease control, trials should preserve the accepted clinical outcome while separately testing superiority for the patient-centered benefit. This would prevent modest changes in surrogate or short-term outcomes from being interpreted as evidence that a laser has replaced a conventional standard of care.[14,15]

CONCLUSION

Laser dentistry comprises wavelength- and parameter-dependent interventions rather than a universal alternative to conventional care. The clearest current roles are selected soft-tissue procedures, patient-centered erbium-laser caries removal, and carefully controlled ceramic restoration or bracket retrieval. In periodontics, peri-implant therapy, and endodontics, laser- and aPDT-assisted approaches are better supported as selective adjuncts than as replacements for established mechanical or chemomechanical treatment. PBM may provide selected short-term biological or symptomatic benefits, but current evidence does not support its routine use for treatment acceleration. Across specialties, clinical value depends on complete parameter reporting, thermal and occupational safety, appropriate comparators, and evidence of meaningful patient benefit. Future research should prioritize standardized, reproducible protocols and long-term clinical outcomes over device-centered claims of superiority.

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