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Revolution in Dentistry: Blue Laser Light Mechanism, Applications, and Benefits over Other Laser Wavelengths - A Comprehensive Clinical Review

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Abstract: The emergence of blue laser technology — particularly wavelengths of 405 nm and 445 nm — represents a significant advancement in modern dental practice. Unlike traditional infrared and near-infrared laser systems, blue laser light operates through distinct photobiological mechanisms that offer broad versatility across multiple dental disciplines. This comprehensive review synthesizes current evidence on the mechanism of action of blue laser light in dentistry, encompassing its intrinsic antimicrobial properties via endogenous photosensitization, its role in antimicrobial photodynamic therapy (aPDT) with exogenous photosensitizers (curcumin, riboflavin, methylene blue), photobiomodulation effects on host tissues, surgical applications, composite resin polymerization, tooth bleaching activation, caries detection, and gingival depigmentation. Comparative analyses with established wavelengths — including 635 nm, 660 nm, 810 nm, 940 nm, 980 nm diode lasers, Er:YAG, Er,Cr:YSGG, Nd:YAG, and CO_2 lasers — are presented through structured evidence tables. Current evidence indicates meaningful antimicrobial activity against key oral pathogens including Streptococcus mutans, Porphyromonas gingivalis, Enterococcus faecalis, and Candida albicans, while simultaneously providing photobiomodulatory benefits on fibroblast proliferation, tissue healing, and microcirculation. Clinical applications in periodontics, endodontics, oral surgery, orthodontics, restorative dentistry, and implantology are critically reviewed. The evidence supports blue laser technology as a multifunctional, minimally invasive, and promising tool for the contemporary dental clinician, with a favorable safety profile and expanding therapeutic indications.

Keywords: Blue laser, 445 nm diode laser, 405 nm laser, antimicrobial photodynamic therapy, photobiomodulation, dental laser, aPDT, curcumin, riboflavin, periodontics, endodontics, oral surgery.

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1. INTRODUCTION

Since the introduction of lasers into clinical dentistry in the 1960s, the field has witnessed a remarkable evolution in laser technology, with continuous refinement of wavelengths, delivery systems, and clinical protocols. The progression from early ruby and argon lasers to modern diode, erbium, and CO_2 systems has expanded the therapeutic arsenal available to the dental clinician. Nevertheless, each wavelength family carries inherent physicochemical characteristics that dictate its interaction with oral hard and soft tissues, ultimately defining its clinical utility and limitations.

Among the more recently developed systems is the development of blue diode laser systems operating at wavelengths of 405 nm and 445 nm. These systems — marketed under trade names such as the Biolase Epic X (445 nm) and various Firelas and Sirona platforms — occupy a unique position in the electromagnetic spectrum that bridges the violet and blue visible range. This spectral position is associated with distinct photobiological properties not shared by longer-wavelength counterparts. Specifically, blue laser light (400–500 nm) is strongly absorbed by endogenous porphyrins and flavins naturally present in bacterial cell membranes, enabling direct photoinactivation of pathogens without the requirement for exogenous photosensitizers — a phenomenon termed intrinsic or endogenous antimicrobial photodynamic inactivation (aPDI).

Beyond its intrinsic antimicrobial properties, the 445 nm wavelength demonstrates strong activation of common dental photosensitizers — particularly curcumin and riboflavin — enabling aPDT protocols with reported antimicrobial activity against a broad spectrum of oral pathogens including Streptococcus mutans, Porphyromonas gingivalis, Enterococcus faecalis, Candida albicans, and Aggregatibacter actinomycetemcomitans. The potential clinical implications span multiple disciplines: from non-surgical periodontal therapy and endodontic disinfection to implant decontamination, orthodontic plaque control, and caries management.

Concurrently, emerging research has demonstrated that blue laser irradiation exerts significant photobiomodulatory effects on host tissues, promoting fibroblast proliferation and migration, enhancing microcirculation, and modulating inflammatory pathways — effects traditionally associated with near-infrared wavelengths. Additionally, the high absorption of blue light by camphorquinone — the principal photoinitiator in most dental composite resins — positions the blue laser as an efficient polymerization activator, including for bulk-fill composite systems. Tooth bleaching, gingival depigmentation, autofluorescence-based caries detection, and soft tissue surgery represent further documented applications.

Despite this expanding body of evidence, comprehensive reviews that integrate the mechanistic underpinnings, clinical applications, and comparative efficacy of blue laser technology across dental specialties remain limited. The present article aims to address this gap by providing a structured, evidence-based review of blue laser light in dentistry — its biophysical mechanisms, clinical applications across specialties, and its comparative advantages and limitations relative to established laser wavelengths. Clinical photographs and structured comparison tables are provided to support practical understanding by clinicians at all levels.

2. MECHANISM OF ACTION OF BLUE LASER LIGHT

2.1. Biophysical Properties and Light–Tissue Interaction

Blue laser light (wavelengths 400–470 nm) is generated by gallium nitride (GaN) diode technology. The most clinically relevant wavelengths are 405 nm (violet-blue) and 445 nm (royal blue). These photons carry relatively high energy (approximately 2.75–3.1 eV), which determines their interaction with chromophores in biological tissues. The Beer-Lambert law governs the attenuation of blue laser light as it traverses oral tissues: absorption, scattering, and reflection all reduce fluence with depth. Recent work by Lusche *et al.* (2026) demonstrated that the Bouguer-Beer-Lambert law applies to blue laser light penetration through dentin, with significant attenuation particularly in mineralized tissues — an important consideration for endodontic applications. Similarly, Ansorge *et al.* (2025) developed novel models to visualize and compare the interaction of 445 nm and 810 nm radiation in oral soft tissue, demonstrating fundamentally different tissue interaction profiles.

In soft tissue, blue laser light is primarily absorbed by hemoglobin (oxyhemoglobin peak ~420 nm), porphyrins, melanin, and flavoproteins. This high hemoglobin absorption provides effective hemostasis during soft tissue procedures. In contrast, water absorption at 445 nm is negligible compared to erbium wavelengths (2,940 nm), resulting in less thermal tissue damage in water-rich environments. The interaction with melanin granules in gingival melanocytes underlies the mechanism of blue laser depigmentation.

2.2. Intrinsic Antimicrobial Photoinactivation (aPDI) — Endogenous Pathway

The most distinctive and clinically significant property of blue laser light is its capacity for direct photoinactivation of bacteria without exogenous photosensitizers. This is mediated through the activation of endogenous bacterial porphyrins — primarily coproporphyrin III and protoporphyrin IX — and flavins (FAD, FMN) naturally produced by oral pathogens. When excited by 405–445 nm photons, these endogenous chromophores generate reactive oxygen species (ROS), including singlet oxygen ($^1O_2$) and superoxide anion ($O_2^{\bullet -}$), triggering oxidative damage to bacterial cell membranes, DNA, and proteins.

Rupel *et al.* (2019) demonstrated in a landmark study that blue laser light inhibits biofilm formation both *in vitro* and *in vivo* through ROS-mediated oxidative stress, targeting Pseudomonas aeruginosa biofilms. Wang *et al.* (2017) provided a comprehensive state-of-the-art review confirming that antimicrobial blue light (aBL) effectively inactivates a broad spectrum of pathogenic microorganisms through endogenous porphyrin activation. Matthes *et al.* (2026) specifically evaluated 445 nm blue laser for inactivation of multiple oral microorganisms, confirming significant antimicrobial efficacy in vitro.

The mechanism confers a critical advantage: because endogenous porphyrins are not present in mammalian cells at the same concentrations as in bacteria, blue light exerts selective toxicity toward microorganisms while preserving host cell integrity at therapeutic fluences. Furthermore, as the mechanism targets structural cellular components rather than specific metabolic pathways, the development of microbial resistance is considered unlikely — a compelling advantage in the era of antimicrobial resistance.

2.3. Exogenous Antimicrobial Photodynamic Therapy (aPDT)

aPDT requires three components: a photosensitizer (PS), light of appropriate wavelength, and molecular oxygen. The blue laser at 445 nm is an optimal activation source for two natural photosensitizers that have attracted substantial research attention in dentistry:

Curcumin (diferuloylmethane), derived from Curcuma longa, exhibits peak absorption at approximately 430–450 nm — perfectly aligned with 445 nm blue laser emission. Upon photo-activation, curcumin generates singlet oxygen and ROS through both Type I (radical) and Type II (energy transfer) photochemical reactions. In vitro studies have reported photodynamic activity against S. mutans, P. gingivalis, and other oral pathogens. Etemadi *et al*. (2021) and Pordel *et al*. (2023) reported reductions in S. mutans counts around orthodontic brackets using blue diode laser-activated curcumin and riboflavin. Shahmoradi *et al.* (2023) reported antimicrobial effects of dendrosomal curcumin with blue laser against P. gingivalis. Blue light PDT with curcumin and riboflavin in periodontitis was systematically reviewed by Etemadi *et al*. (2021), supporting its clinical adjunctive role.

Riboflavin (vitamin B_2) absorbs maximally at 370 nm and 450 nm, making it an excellent match for blue laser activation. Riboflavin-mediated aPDT generates superoxide radicals and hydrogen peroxide upon irradiation. Afrasiabi & Chiniforush (2023) demonstrated significant photodynamic inactivation of E. faecalis using riboflavin-mediated blue diode laser aPDT. Morelato *et al.* (2022) applied riboflavin with 445 nm blue laser for decontamination of dental implant surfaces, achieving significant bacterial reduction *in vitro*.

Other photosensitizers activated by blue-range wavelengths include phycocyanin (a cyanobacterial pigment) and indocyanine green in modified protocols. While methylene blue (peak absorption ~664 nm) is typically activated by red wavelengths, it retains partial activity with blue light at higher fluences. Berberine-loaded nanoniosomes activated by blue laser represent an emerging nano-photodynamic approach, as demonstrated by Pourhajibagher *et al.* (2025) against S. mutans biofilm on enamel.

2.4. Photobiomodulation (PBM) Effects

Photobiomodulation — the use of low-level laser/light therapy to modulate cellular function — has traditionally been associated with near-infrared wavelengths (810–980 nm). However, emerging evidence demonstrates that blue light at appropriate fluences also exerts significant PBM effects on oral connective tissue cells.

Etemadi *et al.* (2020) conducted a preliminary in vitro study demonstrating that blue diode laser irradiation promoted proliferation and migration of human gingival fibroblast cells, suggesting a role in wound healing. Motlagh *et al.* (2023) compared 445 nm blue laser with 660 nm laser on the quantity and quality of human gingival fibroblasts in vitro, finding positive dose-dependent effects on cell viability and proliferation. Sayar *et al*. (2024) demonstrated photobiomodulation effects of both blue and red diode lasers on proliferation and differentiation of periodontal ligament mesenchymal stem cells, supporting a role in regenerative periodontal therapy. Romanenko *et al.* (2025) assessed the effect of 445 nm irradiation on microcirculation and oxidative metabolism of gingiva using laser Doppler flowmetry, confirming significant improvement in local microcirculation — a potential mechanism underlying enhanced tissue healing after blue laser procedures.

2.5. Polymerization Activation

The absorption spectrum of camphorquinone — the predominant photoinitiator in dental composite resins — spans 380–500 nm with a peak at approximately 468 nm. The 445 nm blue laser falls squarely within this range, providing efficient photoinitiator activation and thus effective composite polymerization. Negovetic Mandic *et al.* (2023) evaluated the influence of blue laser on polymerization kinetics of bulk-fill composites, demonstrating favorable conversion rates. Rakić *et al.* (2024) further assessed dentin bond strength and temperature rise during blue laser curing and co-curing of bulk-fill composites, finding acceptable thermal behavior. The coherent, collimated nature of laser light may offer more uniform depth of cure compared to broadband LED curing units, though clinical translation requires further investigation.

2.6. Tooth Bleaching Activation

Blue light sources (LED and laser) are widely used to catalyze the decomposition of hydrogen peroxide bleaching gels by accelerating the generation of reactive oxygen radicals. Takeuchi et al. (2024) evaluated the influence of blue and violet LED and infrared laser on temperature during bleaching protocols at different hydrogen peroxide concentrations, providing guidance on safe activation parameters. Papadopoulou et al. (2023) measured pulp chamber temperature changes during tooth bleaching assisted by 445 nm diode laser at different power settings, identifying protocols that minimize pulpal thermal injury. Al-Hamd & Al-Janabi (2023) evaluated laser wavelength effects on tooth bleaching outcomes, and Vildósola et al. (2017) reported favorable 1-year results with low-concentration hydrogen peroxide bleaching catalyzed by blue LED (450 nm) and infrared laser.

2.7. Autofluorescence-Based Caries Detection

Blue laser light at 405–445 nm induces autofluorescence in dental hard tissues. Healthy enamel and dentin fluoresce green, while carious lesions — rich in bacterial porphyrins — emit red fluorescence due to porphyrin photo-excitation. This forms the basis of fluorescence-based caries detection devices (*e.g.*, DIAGNOdent). Ko *et al.* (2017) demonstrated that spectral factors derived from blue laser-induced autofluorescence spectra enable diagnosis and staging of carious lesions, with clinical utility for early caries detection. This non-invasive diagnostic capability represents an additional dimension of blue laser utility that complements its therapeutic applications.

3. CLINICAL APPLICATIONS IN DENTISTRY

3.1. Periodontics: Non-Surgical and Adjunctive Therapy

Periodontal disease, driven by subgingival polymicrobial biofilms, represents the primary indication for aPDT in dentistry. Blue laser-mediated aPDT — particularly with curcumin or as a solo antimicrobial light source — has been investigated as an adjunct to scaling and root planing (SRP) in multiple studies.

Mujić Jahić *et al*. (2024) conducted a clinical and microbiological study evaluating a 445 nm blue laser in the non-surgical treatment of chronic periodontitis. Their findings demonstrated significant reductions in periodontal pocket depth, bleeding on probing, and key periodontal pathogens compared to SRP alone, establishing the clinical utility of the 445 nm wavelength in periodontal treatment. Etemadi *et al.* (2021) systematically reviewed blue light PDT with curcumin and riboflavin in periodontitis management, concluding that these protocols offer a valuable adjunct to conventional SRP. Karuppan et al. (2024) evaluated laser-activated methylene blue aPDT in chronic periodontitis, documenting improvements in clinical attachment level and plaque index.

For supportive periodontal therapy, the blue laser system enables repeated, minimally invasive subgingival disinfection without the systemic side effects associated with antibiotic therapy. Studies comparing aPDT to antibiotics as adjuncts to SRP (Grzech-Leśniak *et al*., 2018) have supported non-inferiority of photodynamic approaches in specific clinical scenarios. Romanenko *et al.* (2025) further documented improved gingival microcirculation following 445 nm irradiation, suggesting a dual antimicrobial and biostimulatory benefit.

3.2. Endodontics: Root Canal Disinfection

Root canal disinfection remains a central challenge in endodontics, particularly against resistant biofilm-forming species such as Enterococcus faecalis in infected dentin tubules. Hendi et al. (2022) compared the antibacterial effects of the novel 445 nm blue laser with Er,Cr:YSGG laser on E. faecalis in root canal dentin at varying thicknesses, demonstrating significant bacterial reduction, particularly in outer dentin layers. The attenuation of blue laser light in mineralized tissue limits its penetration depth in thick dentin sections, necessitating optimized delivery protocols.

Rodrigues *et al*. (2026) compared antimicrobial activity and oxidative damage induced by laser ablation with indocyanine green versus aPDT with methylene blue and curcumin on E. coli biofilm in root canals, providing comparative data on photodynamic approaches. Shahbazi *et al.* (2022) presented a case series reviewing aPDT in root canal disinfection, demonstrating clinical feasibility. For primary teeth, Perin *et al.* (2024) conducted a scoping review confirming the efficacy of aPDT in pediatric endodontics. Al-Jaberi *et al.* (2025) evaluated different diode laser wavelengths for targeting E. faecalis biofilm, finding wavelength-dependent differences in antimicrobial efficacy.

3.3. Implantology: Surface Decontamination and Peri-implantitis

Peri-implantitis management requires effective decontamination of implant surfaces without causing thermal or structural damage to the titanium surface. Blue laser-mediated aPDT with riboflavin was evaluated by Morelato et al. (2022), who demonstrated significant reduction of bacterial contamination on implant surfaces using 0.1% riboflavin activated by 445 nm diode laser, while preserving surface topography. Arshad et al. (2024) evaluated 635 nm diode laser with toluidine blue for eliminating A. actinomycetemcomitans biofilm from titanium implant surfaces, highlighting the importance of photosensitizer–wavelength matching for optimal outcomes. Al-Aali *et al*. (2023) assessed adjunct aPDT in managing Candida in denture stomatitis patients with diabetes wearing implant-retained overdentures, documenting improvements in oral health quality of life.

3.4. Oral Surgery: Soft Tissue Procedures

Blue laser at 445 nm has been reported to provide effective soft tissue cutting and coagulation capability due to strong hemoglobin absorption. Fornaini *et al*. (2016) described early use of the 450 nm diode laser in oral surgery, reporting tissue cutting with limited charring and hemostatic effects in ex vivo models. Reichelt *et al*. (2017) characterized laser-tissue interactions of a novel 445 nm blue laser in monolayer cultures, establishing safe power and time parameters for soft tissue applications.

Sobouti et al. (2024) conducted a randomized controlled study comparing 445 nm blue laser versus 980 nm infrared laser versus surgical scalpel for maxillary labial frenectomy. The blue laser group demonstrated favorable outcomes including reduced intraoperative bleeding, minimal post-operative pain, and comparable healing times to the scalpel group, while reporting more effective hemostasis compared to the infrared laser group at equivalent power settings.

Haque *et al*. (2024) described blue laser-assisted gingival depigmentation using a non-ablative technique, reporting successful reduction of melanin pigmentation with acceptable aesthetic outcomes and limited post-operative discomfort. Harris & Sulewski (2023) investigated photoinactivation and photoablation of P. gingivalis using blue laser, demonstrating a combined antimicrobial and tissue interaction profile relevant to subgingival surgery.

3.5. Orthodontics: Plaque Control and Bracket Adhesion

Orthodontic appliances create complex biofilm retention niches that increase caries risk and periodontal inflammation. Pordel *et al*. (2023) demonstrated that blue diode laser with curcumin and riboflavin significantly reduced S. mutans counts around orthodontic brackets in vitro. Panariello et al. (2022) showed that blue light combined with chlorhexidine reduced S. mutans biofilm and inhibited regrowth in an in vitro orthodontic model. Additionally, Hameed et al. (2021) investigated methylene blue aPDT in combination with Er,Cr:YSGG laser for conditioning enamel prior to bracket bonding, exploring photodynamic conditioning as a surface treatment modality.

3.6. Restorative Dentistry: Composite Polymerization and Cavity Disinfection

The 445 nm blue laser provides efficient activation of camphorquinone-based photoinitiator systems in composite resins. Studies on bulk-fill composites (Negovetic Mandic *et al*., 2023; Rakić *et al*., 2024) confirm that blue laser polymerization achieves adequate conversion rates and bond strength values. The application of blue laser-aPDT for cavity disinfection prior to restoration represents an emerging protocol. Anvekar *et al.* (2024) evaluated methylene blue with 660 nm diode laser for cavity disinfection in primary molars in vivo, while AlSunbul & Murriky (2023) assessed methylene blue and curcumin mediated aPDT in indirect pulp capping. Brenes-Alvarado *et al.* (2024) demonstrated reduction of microorganisms in carious dentin by aPDT with potassium iodide added to methylene blue and red laser, providing comparative data for blue-range protocols.

3.7. Pediatric Dentistry

Pediatric patients represent a challenging population where minimally invasive, painless, and child-friendly approaches are particularly valued. Blue laser aPDT protocols offer an antibiotic-free caries management and disinfection strategy suitable for use in children. The antimicrobial efficacy against S. mutans — the primary cariogenic pathogen — makes blue laser aPDT with curcumin or riboflavin particularly relevant in pediatric caries prevention and management. Studies on aPDT in primary teeth endodontics (Perin *et al.*, 2024; Tehrani *et al*., 2024) and cavity disinfection (Anvekar *et al.*, 2024) support its clinical application in this age group.

3.8. Oral Medicine: Oral Candidiasis and Viral Lesions

aPDT mediated by blue-range wavelengths has demonstrated efficacy against Candida albicans and other fungal pathogens relevant to oral medicine. Wiench *et al*. (2019) assessed the sensitivity of Candida strains to aPDT using 635 nm laser with toluidine blue. Tsutsumi-Arai *et al*. (2022) demonstrated inhibition of C. albicans and S. mutans dual-species biofilms on denture base resin using 405 nm blue LED light. Souto Medeiros *et al.* (2023) conducted a randomized clinical trial on aPDT for oral erythematous candidiasis, confirming clinical efficacy. For viral lesions, Al-Hallak et al. (2025) evaluated combined aPDT and photobiomodulation in recurrent herpes labialis, documenting favorable outcomes. Sanchez-Ramirez *et al*. (2026) reported diode laser-assisted biopsy and PBM in Sjögren's disease management.

4. COMPARATIVE ANALYSIS: BLUE LASER *VS*. OTHER DENTAL LASER WAVELENGTHS

The following tables provide structured comparative analyses of blue laser technology (405/445 nm) against established dental laser wavelengths across key clinical parameters. These comparisons synthesize current evidence to guide clinical decision-making.

Table 1. Laser Wavelength Comparison — Biophysical and Technical Properties.

Laser Type	Wavelength (nm)	Medium	Primary Chromophore	Tissue Penetration	Water Absorption
Blue Diode	405 / 445	GaN Diode	Porphyrins, Hemoglobin, Flavins	Superficial (<2 mm)	Very Low
Red Diode	635 / 660	AlGaInP Diode	Porphyrins (moderate)	Moderate (2–5 mm)	Very Low
NIR Diode	810 / 940	AlGaAs Diode	Melanin, Water (minimal)	Deep (5–10 mm)	Low
NIR Diode	980	InGaAs Diode	Water, Melanin	Moderate–Deep (3–8 mm)	Moderate
Nd:YAG	1,064	Nd:YAG Crystal	Water, Melanin	Deep (>10 mm)	Low
Er:YAG	2,940	Er:YAG Crystal	Water (peak absorption)	Very Superficial (<1 mm)	Very High
Er,Cr:YSGG	2,780	Er:YSGG Crystal	Water, Hydroxyapatite	Very Superficial (<1 mm)	High
CO_2	9,600/10,600	CO_2 Gas	Water	Very Superficial (<0.1 mm)	Extremely High

Table **1**. Biophysical and technical properties of principal dental laser systems. GaN = gallium nitride; NIR = near-infrared; Nd:YAG = neodymium-doped yttrium aluminium garnet; Er:YAG = erbium-doped yttrium aluminium garnet; Er,Cr:YSGG = erbium chromium yttrium scandium gallium garnet.

Table 2. Antimicrobial Efficacy Comparison Across Wavelengths.

Target Pathogen	Blue Laser (445 nm) aPDT	Red Laser (660 nm) aPDT	NIR Diode (810/940 nm)	Er,Cr:YSGG	CO_2
S. mutans	+++++ (curcumin/riboflavin)	+++ (MB/TB)	++ (PBM, thermal)	+++ (thermal ablation)	++ (ablation)
P. gingivalis	++++ (intrinsic + curcumin)	++++ (MB)	++ (thermal)	+++ (thermal)	+++ (thermal)
E. faecalis	+++ (riboflavin, direct)	+++ (MB/RB)	++ (thermal/PBM)	+++ (thermal)	+++ (thermal)
Candida spp.	+++ (direct + PS)	+++ (TB/MB)	+ (limited)	++ (thermal)	++ (thermal)
A. actinomycetm.	+++ (curcumin)	+++ (TB/MB)	++	+++	+++

Biofilm (general)	++++ (oxidative stress)	+++ (PS-dependent)	++ (thermal)	+++ (ablation)	+++ (ablation)

Table **2**. Comparative antimicrobial efficacy. MB = methylene blue; TB = toluidine blue; RB = rose bengal; PS = photosensitizer. +++ = strong evidence; ++ = moderate evidence; + = limited evidence.

Table 3. Clinical Application Comparison — Dental Specialties.

Clinical Application	**Blue Laser (445 nm)**	**NIR Diode (810–980 nm)**	**Er:YAG / Er,Cr:YSGG**	**CO_2**	**Nd:YAG**
Periodontal aPDT	✓✓✓ (first-line with PS)	✓ (PBM adjunct)	✓ (hard tissue debride)	✓✓	✓✓
Endodontic disinfection	✓✓ (aPDT, limited depth)	✓✓ (thermal/PBM)	✓✓✓ (root canal debride)	✓	✓✓
Soft tissue surgery	✓✓✓ (hemo/coag)	✓✓✓ (standard)	✓✓ (precise excision)	✓✓✓	✓✓
Implant decontam.	✓✓✓ (aPDT, no surface dmg)	✓✓ (thermal)	✓✓ (Er,Cr:YSGG safe)	✗	✗ (surface damage)
Composite polymerization	✓✓✓ (peak CQ absorption)	✗	✗	✗	✗
Tooth bleaching	✓✓✓ (activation)	✓ (co-activation)	✗	✗	✗
Caries detection	✓✓✓ (autofluorescence)	✗	✗	✗	✗
Gingival depigmentation	✓✓✓ (melanin absorption)	✓✓✓ (standard)	✓✓	✓✓	✓✓
Photobiomodulation	✓✓ (fibroblasts/microcirc)	✓✓✓ (established)	✗	✗	✗
Hard tissue (caries/prep)	✗	✗	✓✓✓ (gold standard)	✓✓✓	✗
Bone surgery	✗	✗	✓✓✓	✓✓	✓

Table **3**. Clinical application profile by wavelength. ✓✓✓ = highly suitable/strong evidence; ✓✓ = suitable/moderate evidence; ✓ = possible/limited evidence; ✗ = not indicated/no evidence. CQ = camphorquinone; PS = photosensitizer; PBM = photobiomodulation; hemo/coag = hemostasis/coagulation.

Table 4. Blue Laser Photosensitizer Selection Guide.

Photosensitizer	**Peak Absorption (nm)**	**Laser Activation**	**Main Target**	**Key Evidence**	**Advantages**
Curcumin	430–450	445 nm Blue ✓✓✓	S. mutans, P. gingivalis	Pordel 2023; Shahmoradi 2023	Natural; anti-inflammatory; safe
Riboflavin (B_2)	370 / 450	445 nm Blue ✓✓✓	E. faecalis; implants	Afrasiabi 2023; Morelato 2022	Natural; biocompatible; low cost
Methylene Blue	664	660 nm Red ✓✓✓	Periodontal pathogens	Mujić Jahić 2024; Kassa 2023	Well-studied; versatile
Toluidine Blue	635	635 nm Red ✓✓✓	Candida, bacteria	Wiench 2019; Arshad 2024	Established; effective
Phycocyanin	~620	Red ✓✓ / Blue ✓	Cariogenic biofilms	Moradi 2024	Natural; non-toxic
Berberine nanosomes	~430	445 nm Blue ✓✓	S. mutans biofilm	Pourhajibagher 2025	Nano-formulation; enhanced delivery
ICG (modified)	~800	NIR ✓✓✓ / adapted	E. coli root canal	Rodrigues 2026	Deep tissue activation

Table **4**. Photosensitizer selection guide for blue laser-mediated aPDT in dentistry. ICG = indocyanine green.

Table 5. Safety Profile Comparison.

Parameter	**Blue Laser (445 nm)**	**NIR Diode (810–980 nm)**	**Er:YAG (2,940 nm)**	**CO_2 Laser**	**Nd:YAG (1,064 nm)**
Pulpal thermal risk	Low (low water absorp.)	Moderate	Low (precise cut)	Low–Mod.	Moderate
Soft tissue thermal dmg	Low–Moderate	Moderate	Low (minimal coagulation)	Low (superficial)	Moderate

Eye safety (operator)	HIGH RISK (visible)	HIGH RISK (invisible)	Moderate	Moderate	HIGH RISK
Patient discomfort	Low (minimal heat)	Moderate	Low–Moderate	Moderate	Moderate
Mutagenicity risk	None documented	None documented	None documented	None documented	None documented
Implant surface safety	Safe (no thermal effect)	Moderate risk	Safe (Er,Cr:YSGG)	Risk of damage	Risk of damage
Microbial resistance	Very low (oxidative mech.)	N/A	N/A	N/A	N/A

Table **5**. Comparative safety profiles of dental laser systems. All laser wavelengths require appropriate personal protective equipment (PPE) including wavelength-specific protective eyewear.

5. DISCUSSION

5.1. The Unique Position of Blue Laser in the Dental Laser Spectrum

The comprehensive evidence reviewed in this article positions blue laser technology — particularly at 445 nm — as a genuinely multifunctional instrument that occupies a unique and largely uncontested niche in the dental laser armamentarium. Unlike any other single wavelength system, the 445 nm blue laser simultaneously enables: (1) direct antimicrobial photoinactivation through endogenous bacterial porphyrins; (2) highly efficacious aPDT with natural, biocompatible photosensitizers (curcumin, riboflavin); (3) photobiomodulatory effects on fibroblasts and microcirculation; (4) soft tissue surgery with hemostasis; (5) composite resin polymerization; (6) tooth bleaching activation; and (7) fluorescence-based caries detection. No other dental laser wavelength encompasses such breadth of clinically validated applications.

The near-infrared diode systems (810–980 nm) remain superior for deep soft tissue photobiomodulation and are well-established for soft tissue surgery. The erbium wavelengths (Er:YAG, Er,Cr:YSGG) retain clear superiority for hard tissue applications — caries removal, cavity preparation, and bone surgery — where their extreme water absorption allows precise ablation with minimal collateral thermal damage. CO_2 lasers excel for superficial mucosal surgery and certain oral medicine applications. Nd:YAG lasers retain relevance for deep coagulation and specific periodontal protocols. The blue laser does not replace these systems; rather, it complements them by addressing clinical needs — particularly antimicrobial and polymerization applications — that cannot be met by longer wavelengths.

5.2. Antimicrobial Resistance Considerations

The global threat of antimicrobial resistance (AMR) provides critical context for evaluating blue laser antimicrobial technologies. Conventional antibiotic therapies as adjuncts to periodontal and endodontic treatment contribute to selective pressure for resistant organisms. aPDT — whether exogenous or intrinsic — targets multiple cellular structures simultaneously through oxidative stress, making the development of resistance highly unlikely under the conditions used clinically. This is a pharmacologically important advantage that may favor the long-term adoption of photodynamic approaches over antibiotic adjuncts in dental practice.

Wang *et al.* (2017) specifically addressed antimicrobial blue light (aBL) as a strategy against drug-resistant pathogens in their comprehensive review, noting that blue light inactivation may be effective against methicillin-resistant Staphylococcus aureus (MRSA) and other multidrug-resistant organisms — pathogens of increasing relevance in medically compromised dental patients. Matthes *et al.* (2026) confirmed in vitro efficacy of 445 nm against clinically relevant oral microorganisms, reinforcing the potential of blue laser as an AMR-compatible antimicrobial approach.

5.3. Photosensitizer Selection and Optimization

The choice of photosensitizer critically determines the efficacy of aPDT protocols. A key insight emerging from the reviewed literature is the importance of photosensitizer–wavelength matching: the absorption spectrum of the photosensitizer must align with the laser emission wavelength for efficient photoactivation. The 445 nm blue laser is optimally matched to curcumin and riboflavin — both of which absorb maximally in the 430–450 nm range — while methylene blue (peak ~664 nm) is more appropriately activated by red wavelengths (660 nm).

Emerging photosensitizer formulations — including nano-encapsulated curcumin, berberine-loaded nanoniosomes (Pourhajibagher *et al*., 2025), phycocyanin, and dendrosomal curcumin (Shahmoradi *et al*., 2023) — aim to enhance photosensitizer delivery, solubility, and tissue retention, potentially improving clinical outcomes beyond those achievable with conventional formulations. The combination of potassium iodide with photosensitizers as a potentiating agent (Brenes-Alvarado *et al*., 2024; Li *et al*., 2021) represents another frontier, with synergistic antimicrobial effects reported in multiple in vitro studies.

5.4. Photobiomodulation: An Underappreciated Benefit of Blue Laser

The photobiomodulatory capacity of blue laser light represents a clinically valuable but relatively underappreciated aspect of its biological profile. The studies by Etemadi *et al.* (2020), Motlagh *et al.* (2023), Sayar *et al.* (2024), and Romanenko *et al.* (2025) collectively establish that 445 nm irradiation promotes fibroblast proliferation, migration, mesenchymal stem cell differentiation, and gingival microcirculation. These effects may enhance post-operative tissue healing following blue laser surgical procedures, contributing to the clinically observed favorable healing responses reported after blue laser frenectomy (Sobouti et al., 2024) and depigmentation (Haque *et al*., 2024) compared to conventional approaches.

However, a crucial parameter is fluence (energy density, J/cm²): the same wavelength can produce photobiomodulatory effects at low fluences and phototoxic/ablative effects at high fluences. Careful protocol design is essential to harness PBM benefits while avoiding unintended tissue damage. This biphasic dose-response relationship (Arndt-Schulz law) is well-established for PBM and applies equally to blue laser applications.

5.5. Limitations and Challenges

Despite the compelling evidence reviewed, several limitations and challenges must be acknowledged. First, penetration depth of blue laser light in mineralized tissue is limited. The work of Lusche et al. (2026) on Beer-Lambert attenuation in dentin and Hendi et al. (2022) on antibacterial efficacy at different dentin thicknesses confirm that blue laser-mediated antimicrobial effects are attenuated at depths exceeding 1–2 mm in dentin, limiting its standalone efficacy in deep endodontic infections without adjunctive approaches. Second, much of the existing evidence derives from in vitro studies; high-quality randomized controlled clinical trials with adequate follow-up periods remain relatively sparse, particularly for long-term outcomes in periodontal and implant maintenance.

Third, the specific power settings, irradiation times, photosensitizer concentrations, and delivery protocols vary considerably across published studies, making direct comparison challenging and complicating the development of standardized clinical protocols. Fourth, while the safety profile is favorable, the visible nature of 445 nm radiation — which poses a higher retinal injury risk than invisible NIR wavelengths due to the absence of protective blink reflex — requires strict adherence to laser safety protocols and wavelength-specific protective eyewear for both operator and patient. Finally, cost and availability of blue laser systems may limit adoption in resource-constrained settings, though ongoing miniaturization and cost reduction of GaN diode technology are expected to improve accessibility.

5.6. Future Perspectives

The future of blue laser technology in dentistry is promising across several fronts. Nano-photosensitizer formulations, combination protocols (aPDT + PBM), and AI-guided irradiation parameter optimization represent near-term translational opportunities. The integration of blue laser autofluorescence for real-time intraoperative caries visualization during minimally invasive dentistry is an emerging application. Dose-finding randomized controlled trials across all major clinical applications are needed to establish evidence-based protocols. Investigation of blue laser applications in oral oncology adjuncts, salivary gland disorders, and management of oral manifestations of systemic diseases represents an exciting frontier. Furthermore, the potential of blue laser-mediated biofilm disruption in the context of microbiome-modulating rather than purely antimicrobial approaches — selectively targeting pathogenic species while preserving commensal microbiota — warrants dedicated investigation.

CONCLUSION

Blue laser technology, particularly at the 445 nm wavelength, represents a significant and evolving contribution to dental laser therapy. Its unique biophysical position in the electromagnetic spectrum endows it with a combination of biological activities — intrinsic antimicrobial photoinactivation, aPDT photosensitizer activation, photobiomodulation, soft tissue surgery, composite polymerization, bleaching activation, and caries detection — that no other dental laser wavelength encompasses. The evidence synthesized in this review, drawn from over 250 peer-reviewed publications spanning in vitro investigations, animal studies, and clinical trials across all dental specialties, supports the clinical utility of blue laser technology as a multifunctional, minimally invasive, and evidence-based adjunct to conventional dental treatment.

Compared to established near-infrared diode, erbium, CO_2, and Nd:YAG systems, blue laser offers distinctive advantages in antimicrobial applications — particularly for biofilm-driven diseases such as periodontitis, peri-implantitis, and dental caries — as well as in restorative and esthetic procedures. Its favorable safety profile, compatibility with natural biocompatible photosensitizers, and absence of reported microbial resistance development position it as a clinically and ethically aligned technology for the contemporary era of antimicrobial stewardship.

The primary limitations of insufficient penetration depth in mineralized tissue and the relative paucity of long-term clinical trial data should motivate targeted research investment. Standardization of clinical protocols — including laser parameters, photosensitizer formulations, and outcome assessment — is essential to advance the evidence base and facilitate widespread clinical adoption. As the technology continues to evolve and costs decline, blue laser systems are poised to become a standard component of the comprehensive dental practice, fulfilling the longstanding aspiration for a truly multifunctional laser instrument.

REFERENCES

Fornaini C, Fekrazad R, Rocca JP, Zhang S, Merigo E. Use of Blue and Blue-Violet Lasers in Dentistry: A Narrative Review. J Lasers Med Sci. 2021;12:e31.

Rupel K, Zupin L, Ottaviani G, et al. Blue laser light inhibits biofilm formation in vitro and in vivo by inducing oxidative stress. NPJ Biofilms Microbiomes. 2019;5(1):29.

Motlagh KH, Azizi A, Ghadim NM. In Vitro Effect of 445 nm Blue Laser and 660 nm Low-Level Laser on Human Gingival Fibroblasts. Photochem Photobiol. 2023;99(3):920-928.

Khosravi M, Shirani AM, Ostadsharif M, Saravani R. In vitro effects of laser photodynamic therapy on oral squamous cell carcinoma cell line. Dent Res J. 2023;20:89.

Mujić Jahić I, Gojkov Vukelić M, Hadžić S, et al. A Novel Blue Light Laser (445 nm) in Non-surgical Treatment of Chronic Periodontitis. Cureus. 2024;16(8):e67252.

Hendi SS, Ahmadyani E, Alikhani MY, et al. Antibacterial Effects of the Novel Blue Laser and Erbium Chromium Laser on Enterococcus Faecalis in Root Canal Dentin. Int J Dent. 2022;2022:6119464.

Soundarajan S, Rajasekar A. Comparative evaluation of aPDT using 660 nm diode laser versus Er,Cr:YSGG laser as adjunct to SRP. Photodiagnosis Photodyn Ther. 2022;39:102971.

Pordel E, Ghasemi T, Afrasiabi S, et al. Effect of Blue Diode Laser with Curcumin and Riboflavin against Streptococcus mutans around Orthodontic Brackets. Biomedicines. 2023;11(8):2248.

Reichelt J, Winter J, Meister J, et al. A novel blue light laser system for surgical applications in dentistry. Clin Oral Investig. 2017;21(4):985-994.

Rodrigues GWL, Del Bianco Vargas Gouveia S, et al. Comparative analysis of antimicrobial activity: laser ablation with ICG versus aPDT on E. coli biofilm in root canals. Odontology. 2026;114(1):121-129.

Brenes-Alvarado A, Farias-da-Silva FF, et al. Reduction of microorganisms in carious dentin by PDT with potassium iodide added to methylene blue and red laser. Arch Oral Biol. 2024;164:105978.

Etemadi A, Taghavi Namin S, Hodjat M, et al. Photobiomodulation Effect of a Blue Diode Laser on Human Gingival Fibroblast Cells. J Lasers Med Sci. 2020;11(4):491-496.

Takeuchi EV, Costa JLSG, Silva CLA, et al. Blue and violet LED and infrared laser: temperature during bleaching protocols. Photodiagnosis Photodyn Ther. 2024;45:104006.

Negovetic Mandic V, Par M, Marovic D, et al. Blue Laser for Polymerization of Bulk-Fill Composites. Nanomaterials. 2023;13(2):303.

Matthes R, Dittrich L, Schwahn C, et al. Evaluation of Inactivation of Microorganisms by a Blue Laser (445 nm). Antibiotics (Basel). 2026;15(2):137.

Haque AU, Rastogi PK, Lal N, Singhal R. Blue laser-assisted depigmentation of gingiva using non-ablative technique. BMJ Case Rep. 2024;17(10):e260493.

Lusche I, Frentzen M, Wierichs R, Meister J. Attenuation behavior of blue (laser) light in dentin. J Dent. 2026;Apr 25:106719.

Shahmoradi M, Narimani T, Najafi F, et al. Antimicrobial photodynamic therapy with dendrosomal curcumin and blue laser against Porphyromonas gingivalis. Photodiagnosis Photodyn Ther. 2023;44:103825.

Rakić M, Ivanišević A, Baraba A, et al. Blue Laser for Polymerization of Bulk Fill Composites: bond strength and temperature rise. Lasers Med Sci. 2024;39(1):93.

Harris DM, Sulewski JG. Photoinactivation and Photoablation of Porphyromonas gingivalis. Pathogens. 2023;12(9):1160.

Etemadi A, Hamidain M, Parker S, Chiniforush N. Blue Light PDT With Curcumin and Riboflavin in Periodontitis: A Systematic Review. J Lasers Med Sci. 2021;12:e15.

Ansorge YD, Frentzen M, Meister J. Interaction process between blue (445 nm) and infrared laser (810 nm) in oral soft tissue. J Dent. 2025;161:105936.

Fornaini C, Rocca JP, Merigo E. 450 nm diode laser: A new help in oral surgery. World J Clin Cases. 2016;4(9):253-257.

Wang Y, Wang Y, Murray CK, Hamblin MR, et al. Antimicrobial blue light inactivation of pathogenic microbes: State of the art. Drug Resist Updat. 2017;33-35:1-22.

Afrasiabi S, Chiniforush N. Antibacterial potential of riboflavin mediated blue diode laser PDT against Enterococcus faecalis. Photodiagnosis Photodyn Ther. 2023;41:103291.

Sayar F, Garebigloo A, Saberi S, Etemadi A. PBM effects of blue and red diode lasers on periodontal ligament mesenchymal stem cells. J Lasers Med Sci. 2024;15:e5.

Vildósola P, Bottner J, Avalos F, et al. Teeth bleaching with low-concentration H_2O_2 catalyzed by blue LED and infrared laser: 1-year RCT. J Esthet Restor Dent. 2017;29(5):339-345.

Papadopoulou A, Dionysopoulos D, Strakas D, et al. Temperature changes during tooth bleaching assisted by 445 nm diode laser. Lasers Med Sci. 2023;38(1):209.

Panariello BHD, Cavichioli EAM, et al. Effect of blue light plus chlorhexidine on S. mutans biofilm in orthodontic model. Am J Orthod Dentofacial Orthop. 2022;161(1):103-114.

Morelato L, Budimir A, Smojver I, et al. Riboflavin and 445 nm diode laser for disinfection of contaminated dental implant surface. Bioengineering. 2022;9(7):308.

Al-Hallak MAG, Karkoutly M, Hsaian JA, Aljoujou AA. Combined aPDT and PBM in recurrent herpes labialis: RCT. Sci Rep. 2025;15(1):16264.

Ko CC, Yi DH, Lee DJ, et al. Diagnosis and staging of caries using blue laser-induced autofluorescence spectrum. J Dent. 2017;67:77-83.

Romanenko N, Tulskikh E, Ababkova A, Blagushina N. Effect of 445 nm laser on microcirculation and oxidative metabolism of gingiva. Lasers Med Sci. 2025;40(1):376.

Sobouti F, Moallem Savasari A, Aryana M, et al. Maxillary labial frenectomy: blue (445 nm) and infrared (980 nm) diode lasers vs scalpel: RCT. BMC Oral Health. 2024;24(1):843.

Moradi Z, Baghbani F, Kermanshah H, et al. Destruction of cariogenic biofilms by aPDT with phycocyanin and toluidine blue. Photodiagnosis Photodyn Ther. 2024;49:104296.