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*Review article*

# The Role of Lasers in Periodontal Tissue Regeneration: A Contemporary Review

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**ABSTRACT**

Lasers offer clear adjunctive benefits in regenerative periodontology, including superior hemostasis, effective bacterial reduction, and photobiomodulation that accelerates wound healing. However, their clinical success depends critically on appropriate case selection, wavelength choice, and protocol standardization rather than universal application. Current evidence supports lasers as complementary tools to traditional bone grafts and guided tissue regeneration, not replacements. The bactericidal effects help control persistent infections that compromise regeneration, while photobiomodulation enhances cellular activity and tissue repair. Nevertheless, significant heterogeneity in laser types, power settings, and treatment protocols across studies precludes definitive clinical guidelines. The most promising outcomes emerge when low-level laser therapy is applied for biostimulation and high-power lasers for surgical hemostasis and decontamination, tailored to specific clinical scenarios. Future research must prioritize standardized parameters, adequate control groups, and long-term follow-up to establish evidence-based protocols. Until then, clinicians should view lasers as valuable supportive devices that, when properly integrated, can improve regenerative outcomes, but their use requires careful patient selection and understanding of laser-tissue interactions to avoid overtreatment or suboptimal results.

## Introduction

At its core, periodontitis involves a detrimental interplay between a dysbiotic bacterial biofilm and an overzealous host immune response. Together, these factors lead to the irreversible breakdown of periodontal ligament fibers and the underlying alveolar bone. Left unchecked, this chronic inflammation eventually results in gingival recession, tooth mobility, and ultimately, tooth loss. This, quite obviously, profoundly impacts a patient's overall health, masticatory function, and aesthetic appearance. Both surgical and non-surgical interventions aim to halt active inflammation and control the infection. Yet, for many dental professionals and their patients, true regeneration represents the ultimate objective. [1,2,3] We define true regeneration as the successful formation of new cementum on a previously diseased root surface, the insertion of fresh Sharpey's fibers, and the simultaneous reconstruction of lost alveolar bone. [2,3]

Traditional approaches to regenerating these tissues typically rely heavily on guided tissue regeneration (GTR), which uses barrier membranes to exclude unwanted epithelial cells. Clinicians also employ bone grafts as a scaffold for new bone formation or enamel matrix derivatives to stimulate cellular growth. Although these methods have shown considerable promise for filling bone defects and enhancing clinical attachment, their outcomes can be inconsistent. Success often hinges on the morphology of the bone defect, the surgeon's proficiency, and patient-specific factors like smoking or diabetes. One of the most significant obstacles during these surgical procedures involves thoroughly cleansing the porous root surface of bacteria and establishing an optimal healing environment within the surgical defect. [2,3,10] This is precisely why lasers have gained such prominence in this field. They provide a unique combination of precise cutting capabilities, profound antibacterial action, and the ability to stimulate cells without direct physical contact or tissue tearing. [1,2,8] In a regenerative context, lasers can effectively decontaminate the root, meticulously remove inflamed soft tissues, modulate the local inflammatory milieu, and directly encourage progenitor cells to initiate the repair process [1, 2].

In the early days of laser dentistry, enthusiasm frequently outpaced scientific evidence. [1]

Many initial studies suffered from small sample sizes, poorly defined protocols, and highly variable power settings. Fortunately, the landscape has shifted. More rigorous randomized trials, meta-analyses, and recent systematic reviews have helped pinpoint precisely where lasers offer genuine value. [2,3,5] For instance, the erbium laser family is now widely accepted as an excellent instrument for calculus removal and root surface preparation. Meanwhile, researchers are intensely investigating diode and photobiomodulation (PBM), because of their capacity to stimulate periodontal fibroblasts, osteoblasts, and vascular cells. [6,7,12] This paper synthesizes contemporary data to offer a pragmatic, realistic perspective on integrating diverse laser technologies into today's regenerative therapies [3, 2].

### *Laser Types and Their Characteristics*

The behavior of a laser within the oral cavity depends entirely on its wavelength and the absorption efficiency of target chromophores in the tissue such as water, melanin, hemoglobin, and hydroxyapatite. This specific interaction dictates

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whether a laser is best suited for bone cutting, achieving hemostasis in soft tissue, or simply stimulating cells without any ablative effect. [8,16]

Erbium Family Lasers: This group, encompassing Er:YAG (2940 nm) and Er,Cr:YSGG (2780 nm) devices, exhibits strong absorption by water and hydroxyapatite. This high affinity leads to thermomechanical ablation. Essentially, water within the calculus or tissue rapidly heats and vaporizes, creating tiny micro explosions that safely dislodge contaminated root layers and calculus without thermally damaging surrounding areas. This makes erbium lasers a very reliable choice for delicate bone reshaping during regenerative surgery. Furthermore, when clinicians reduce the power to non ablative levels, an Er:YAG laser can exquisitely prepare the root surface, leaving it micro roughened and entirely free of a smear layer a condition studies show is ideal for early fibroblast attachment. [5,10]

Diode Lasers: Typically operating in the near infrared range (810–980 nm), diode lasers do not absorb well into water. Instead, they target pigmented tissues containing melanin and hemoglobin. Clinically, this makes them exceptionally effective for soft tissue procedures, such as precisely excising the epithelial lining of a flap or vaporizing highly vascular, inflamed granulation tissue from a defect. Moreover, when these exact wavelengths are applied at significantly lower power settings, they are extensively utilized in photobiomodulation (PBM) to enhance cell metabolism and accelerate healing without inducing destructive heat. [6,7,12]

$CO_2$ Laser (10,600 nm): Operating deep within the far infrared spectrum, the $CO_2$ laser demonstrates a strong affinity for water. It rapidly cuts soft tissue and provides instantaneous hemostasis. Because the light penetrates minimally into the tissue, the risk of inadvertently overheating deeper bone or connective tissues remains very low, provided the surgeon maintains continuous tip movement. However, due to its tissue interaction profile, its primary role in regeneration is limited to managing soft tissue flaps, rather than actively stimulating underlying bone or ligaments. [1,8]

Nd:YAG Lasers (1064 nm): Nd:YAG devices penetrate much deeper into the gingival tissues and are attracted to dark pigmented bacteria and tissues. This characteristic makes them highly effective for targeting key periodontal pathogens deep within a pocket and facilitating stable blood clot formation. Historically, concerns existed regarding potential thermal damage to the tooth root or surrounding bone due to deep heat penetration. Nevertheless, newer, rigorously controlled techniques such as employing extremely short pulses have been developed to completely mitigate these thermal risks. [1,4].

Photobiomodulation (PBM) Unlike surgical lasers, PBMT employs low power continuous or pulsed diodes (typically in the red or near infrared range, such as 660 nm or 810 nm) at very specific, non thermal doses. The objective here is not tissue ablation. [6,7] Instead, the aim is to deliver photons deep into the tissue to trigger beneficial photochemical reactions within cells. This naturally boosts the healing capacity of local blood vessels, bone forming cells, and the periodontal ligament. [6,7,12]

***Mechanisms of Action in Tissue Regeneration***

Lasers positively influence the intricate sequence of periodontal wound healing and tissue regeneration through several distinct, yet complementary, biological mechanisms. These encompass thorough tissue decontamination, precise surface modification, and direct cellular biostimulation. [2,8] First, numerous laser systems exhibit a remarkable ability to reduce bacterial load on altered root surfaces and deep within convoluted periodontal pockets. Both in vitro and clinical investigations consistently demonstrate that erbium and Nd:YAG lasers can effectively disrupt complex biofilms. **[4,5]**

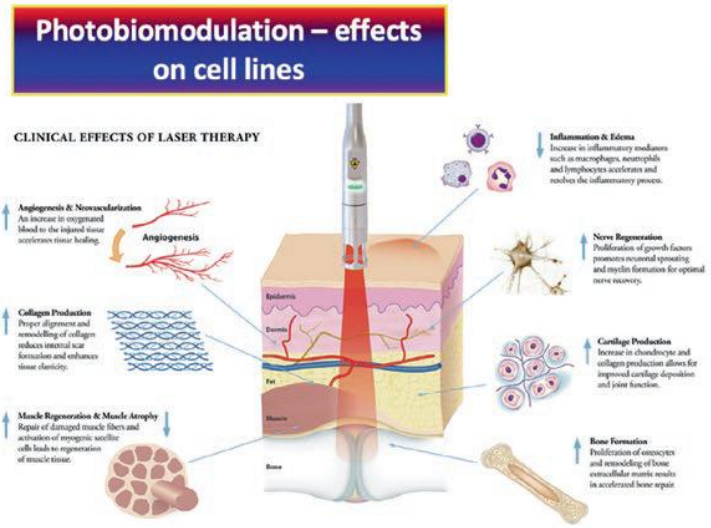
They also modify bacterial endotoxins, such as lipopolysaccharides, and significantly decrease the counts of critical Gram-negative anaerobic pathogens in areas virtually inaccessible to traditional hand instruments. By substantially lowering this microbial burden before graft placement, laser therapy establishes the sterile, highly conducive environment necessary for a stable initial clot to form, thereby priming the regenerative cascade. [4,5,10]

Second, lasers enable the selective microsurgical removal of diseased soft tissues. Specifically, clinicians often use diode and Nd:YAG devices to meticulously de-epithelialize the inner sulcular lining of pockets and vaporize inflamed granulation tissue, all without harming the underlying healthy connective tissue fibers. The biological rationale here is paramount: by eliminating the rapidly proliferating pocket epithelium, the clinician successfully delays epithelial down growth along the root surface. This crucial delay provides the much slower-growing mesenchymal cells (originating from the intact periodontal ligament and alveolar bone) the necessary time to migrate, proliferate, and repopulate the defect. This is an absolute biological prerequisite for achieving true regeneration, rather than merely settling for a long junctional epithelium repair [4, 5].

Third, photobiomodulation acts as a fundamental mechanism to actively accelerate the regenerative process. At the cellular level, applied photons are absorbed by specific mitochondrial chromophores most notably the enzyme cytochrome c oxidase within the electron transport chain as showed in Fig.1. This optical absorption immediately enhances ATP (adenosine triphosphate) generation, shifts the balance of reactive oxygen species, and activates key transcription factors [6, 7].

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| Cell type | Observed effect |
|---|---|
| Fibroblasts | Proliferation, maturation, locomotion. Transformation into myofibroblasts. ↓ secretion of PGE2 and IL-1 Enhanced secretion of βFGF |
| Macrophages | Phagocytosis Secretion of fibroblast growth factors. Fibrin resorption |
| Lymphocytes | Activation / ↑ proliferation |
| Epithelial cells | Motility |
| Endothelium | Increased granulation tissue Relaxation of vascular smooth muscle |
| Neural tissue | Reduced synthesis of inflammatory mediators maturation and regeneration of axonal growth |
| Osteoblasts | Enhanced proliferation |

***Fig.1 PBM affects all cellular types and promotes increases in cellular actions including motility, matrix production, and cellular volumes via mitosis. (Graphic: S. Parker).[8]***

These intracellular signaling events directly correlate with the robust upregulation of essential growth factors, including VEGF, fibroblast growth factor 2, and transforming growth factor β. Collectively, these factors drive neovascularization, early bone formation, and rapid connective tissue repair as shown in Fig.2. Experimental evidence strongly suggests that PBMT not only boosts the proliferation rate but also guides bone-forming differentiation in periodontal ligament stem cells, all while maintaining a balance between osteoblast and osteoclast activity.

Fourth, surgical lasers significantly aid in bleeding control and clot stabilization during regenerative flap procedures. The thermal coagulation of superficial blood components provides the surgeon with a clear, dry operating field, which markedly improves visibility and precision. More importantly, the resulting stable fibrin network functions as a natural scaffold, facilitating the early migration of specific progenitor cells and the deposition of a new extracellular matrix [7, 8].

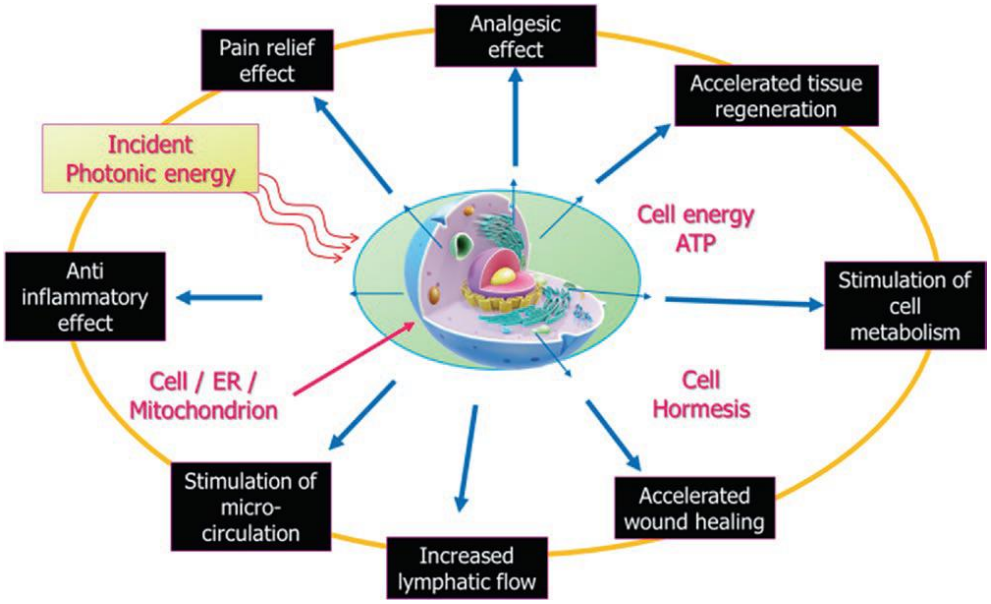



***Fig.2 Summary of PBM effects derived from wavelength specific incident photonic energy. (Graphic: S. Parker) [8]***

Finally, physically modifying the root surface using erbium lasers substantially improves the biological compatibility of the previously diseased root. The precise, non thermal removal of the infected smear layer exposes intrinsic collagen fibrils and

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creates a micro-rough, highly retentive topography. This has been conclusively shown to enhance initial blood clot adhesion and accelerate fibroblast attachment. Ultimately, these optical effects complement and augment the traditional mechanical debridement and chemical conditioning agents employed in standard regenerative protocols, rather than entirely supplanting them.[8]

***Clinical Applications and Protocols***

Dentists and periodontists have developed several specific clinical workflows to leverage these optical and biological advantages. Some represent standalone laser techniques, while others strategically combine particular laser wavelengths with traditional flap surgeries.

Consider the Laser Assisted New Attachment Procedure (LANAP), for example. This well-known, proprietary protocol utilizes a free-running pulsed Nd: YAG laser. It is specifically designed to treat deep periodontal pockets without requiring the surgeon to raise a full-thickness flap. The process follows a strict, step-by-step sequence: first, the laser selectively removes the diseased pocket lining; next, an ultrasonic scaler thoroughly cleans the root; finally, a second laser pass forms a thermal fibrin clot to seal the area from oral bacteria. Randomized controlled studies investigating this method generally report good improvements in probing depths and clinical attachment, alongside an immediate reduction in disease-causing bacteria [4, 9].

In traditional open flap surgeries, the Er: YAG laser has become an invaluable addition, particularly in minimally invasive surgical techniques (MIST). Surgeons meticulously use the erbium laser to remove calculus, fully decontaminate the root, and perform highly precise bone reshaping (osteoplasty) before placing any graft material. When clinicians combine this precise Er:YAG debridement with bone grafts, barrier membranes, or enamel matrix derivatives, patients typically experience superior clinical attachment and greater radiographic bone fill compared to traditional mechanical scaling and root planing alone [10, 11].

Lasers also excel in managing soft tissue during these procedures. Surgeons frequently employ diode or $CO_2$ lasers to cleanly excise the epithelium from flap margins during guided tissue regeneration. This prevents unwanted epithelial cells from folding into the healing defect. They are also excellent for gently contouring the gingiva around surgical sites and implants. Ultimately, using lasers in this manner promotes better tissue adaptation, reduces tension, lowers the risk of subsequent membrane exposure, and safeguards the bone graft.

Finally, we have the adjunctive photobiomodulation (PBM) protocols. These typically involve illuminating the gingival tissues with a low-level diode laser immediately after surgery is completed and sutured.

While the exact parameters (such as wavelength, power, and treatment time) vary considerably across studies, the clinical benefits consistently appear. Patients almost invariably report significantly less postoperative pain and swelling, faster gingival healing, and long-term radiographs often reveal enhanced bone fill [12, 13].

It is worth noting that in everyday clinical practice, a laser is almost never a standalone
magic wand for complex regeneration. They are highly specialized tools that absolutely need to be part of a much larger, comprehensive treatment plan. This plan still has to include meticulous mechanical cleaning, careful management of the patient's risk factors, and the judicious use of appropriate biomaterials.

**Review of Recent Evidence (2020–2025)**

When we examine the research published over the last few years, we finally gain a much clearer, biologically grounded understanding of how effectively lasers perform as surgical adjuncts. A surge of high-quality papers, including systematic reviews, advanced laboratory studies, and randomized clinical trials published between 2020 and 2025, has truly solidified our knowledge [12, 10, 3]. Modern trials have rigorously tested both trademarked protocols and standard diode or erbium adjuncts [4, 9, 11].

Studies specifically investigating laser decontamination within bone defects often indicate that laser approaches perform just as well as and sometimes even slightly better than traditional methods. This holds especially true when clinicians employ the correct biological settings, which frequently translates to shorter surgery times and more satisfied patients reporting improved overall experiences [10, 5].

Concurrently, advanced laboratory data corroborate our clinical observations. In meticulously controlled animal studies examining large periodontal defects, the application of low level Er:YAG or near infrared diode lasers has demonstrably boosted the local release of pro-angiogenic proteins. This directly enhances the rate and quality of new bone formation and even improves the organization of newly formed collagen fibers against the root surface [6, 7].

Despite these encouraging results, the academic community largely agrees on one fundamental principle: lasers must be viewed strictly as valuable additions, not complete replacements, for established, biologically sound regenerative strategies. The quality of available evidence ranges from exceptionally strong (e.g., using Er:YAG for root cleaning or diodes for pain relief) to somewhat less robust when it comes to claims of complete, guaranteed tissue regeneration.

**Advantages, Limitations, and Future Directions**

In the hands of a skilled and thoroughly trained clinician, dental lasers offer some significant advantages for periodontal

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surgery. Surgeons consistently commend the enhanced visibility they gain because the laser's thermal effects seal blood vessels, maintaining a dry surgical field. Beyond that, lasers provide a level of microscopic precision during both soft and hard tissue procedures that is simply unattainable with traditional instruments, allowing surgeons to preserve as much healthy tissue as possible. From the patient's perspective, these minimally invasive techniques typically lead to significantly less postoperative pain and swelling once the anesthesia wears off, enabling a much faster return to normal routines. Moreover, the synergistic effect of the laser's bactericidal capabilities and its cell stimulating properties stabilizes the wound early on and kickstarts the body's natural healing processes.

However, it's important to acknowledge that the technology isn't without its imperfections, several major limitations and practical hurdles still warrant consideration. For one, laser units represent a substantial financial investment for any dental practice. They also demand intensive, specialized training before they can be safely and effectively deployed. If a dentist selects the incorrect wavelength or uses inappropriate power settings especially with continuous wave lasers that penetrate deeply there's a very real danger of inducing thermal necrosis (heat damage) to the delicate root surface, the periodontal ligament, or the surrounding bone [1, 2]. Causing this kind of iatrogenic damage would undoubtedly undermine the desired regenerative outcome rather than facilitate it. On an academic level, it's also crucial to remember that many studies define "success" purely on reduced probing depths or apparent attachment gains. While these are certainly beneficial for the patient, they don't necessarily provide histological proof that true regeneration of the entire periodontium has actually occurred.

Looking ahead, the future of laser assisted periodontology appears incredibly promising. A significant priority for current researchers involves establishing global, standardized protocols for photobiomodulation [12, 8]. We urgently need universally accepted guidelines detailing the precise wavelengths, energy densities, and treatment schedules required for specific types of defects. Another exciting frontier lies in integrating laser technology with next generation biomaterials. Researchers are actively exploring how lasers can "activate" biological scaffolds, platelet concentrates, and growth factors directly within the wound. This synergistic effect on cell recruitment and rapid tissue differentiation could dramatically elevate our success rates. Ultimately, to confidently translate these thrilling laboratory discoveries into reliable everyday treatments, we absolutely require more meticulously designed, multicenter clinical trials that follow patients for extended periods and, whenever ethically feasible, incorporate human histological assessments [14, 8].

## Conclusion

Dental lasers have evolved from simple surgical instruments into valuable adjuncts in periodontal regeneration. Current evidence supports the use of Erbium lasers for effective root surface decontamination and minimally invasive bone surgery, while diode lasers based photobiomodulation can enhance wound healing and postoperative tissue repair. When integrated into biologically based regenerative protocols, laser therapy may improve the local healing environment and contribute to more predictable clinical outcomes.

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