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Artificial intelligence and digital control: navigating the future of laser dentistry

Antonio Luiz Barbosa Pinheiro

Center of Biophotonics, School of Dentistry, Federal University of Bahia, Salvador, Brazil

The combination of artificial intelligence (AI) and digital laser systems is revolutionizing dental practices. It's allowing us to achieve precision we have never seen before: down to the sub-millimeter level and deliver truly personalized care. We can think of AI as a powerful assistant, not just a tool. It quickly processes vast amounts of complex information from sources such as cone-beam CT (CBCT) and intraoral scans, providing us with more reliable predictions for treatment outcomes and continually adjusting safety parameters in real-time.

Where AI really shines is in controlling the laser energy itself. Using advanced deep learning and built-in sensors, the system monitors parameters such as tissue temperature and moisture content in real-time. This enables what we call "intelligent tissue selectivity" as it instantly distinguishes between healthy and diseased tissue. The AI then automatically tweaks the laser settings to cut efficiently where needed, while completely minimizing any thermal damage to the surrounding healthy structure. This makes the procedure significantly less invasive.

For applications such as photobiomodulation (PBM), AI determines the optimal wavelength and light dose based on the specific needs of that patient's cells. This is a crucial step that moves us away from generalized protocols and straight toward truly personalized medicine.

However, we must be careful. Despite its considerable promise, integrating AI into clinical practice carries significant risks. One major concern is *automation bias*, whereby clinicians may place excessive trust in AI-generated recommendations and gradually rely less on their own clinical judgment. Additionally, *algorithmic bias* remains a critical issue: when training data lack sufficient diversity, AI systems can perpetuate or even exacerbate inequities in patient care. Finally, the well-known "black box" problem – where the reasoning behind AI decisions is opaque – can undermine transparency, accountability, and ultimately trust in these technologies. Furthermore, integrating AI raises significant ethical and legal concerns, particularly regarding liability in the event of a negative outcome or the compromise of sensitive patient data. It is essential that the dental community focuses on constant training and independent testing. Our goal is to ensure AI supports our professional judgment, never replaces it.

The convergence of AI and digital lasers in operative dentistry

The combination of AI with modern digital laser systems is fundamentally changing how we practice clinical dentistry. We are moving past the conventional limits of operative care and entering an era defined by truly sub-millimetric precision and individualized patient treatment. This synergy marks the beginning of a new era of therapy, characterized by sub-millimetric precision and phenotypic personalization. The immediate relevance of this technological alliance stems from its capacity to radically redefine the therapeutic window as AI algorithms dynamically modulate laser parameters (*e.g.*, pulse duration, radiant power density) in milliseconds, facilitating instantaneous tissue discrimination. This capability en-

Corresponding author:
Antonio Luiz Barbosa Pinheiro, PhD, Center of Biophotonics, School of Dentistry, Federal University of Bahia,
Av. Araújo Pinho, 62, Canela, Salvador, Brazil.
E-mail: albp@ufba.br

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sures the precise, layer-by-layer ablation of only pathologically compromised tissue (*e.g.*, carious dentin or inflamed gingival substrate), thereby maximizing the preservation of adjacent healthy dental and periodontal structures. Is this the definitive achievement of minimally invasive dentistry?[1-6]

AI as the cognitive core: enhancing precision and predictability

I believe that AI should never replace clinicians; it should serve as a powerful assistant. Think of it as an incredibly fast "co-pilot". It processes massive, complex datasets, including everything from CBCT scans to high-resolution intraoral images, all done instantly. This enables us to make more reliable treatment predictions and execute procedures with dynamic safety checks at speeds that a human mind cannot match.

For advanced therapeutic modalities like PBM, AI enables the individualized dosimetry of photons. It scientifically optimizes wavelength and radiant exposure (fluence) based on the patient's unique cellular requirements (*e.g.*, enhanced wound healing kinetics, targeted temporomandibular joint disorder pain mitigation). This fundamentally shifts care from empirical protocols to truly personalized medicine. By ensuring stringent, millimetric control over energy emission, AI demonstrably reduces the risk of iatrogenic complications, notably collateral thermal damage and subsequent tissue necrosis. This technological assurance translates directly into tangible clinical benefits, including significantly greater patient comfort, reduced postoperative morbidity, and accelerated biological recovery. The bottom line is that AI takes an already sophisticated piece of equipment, the dental laser, and turns it into an intelligent, adaptive therapeutic system. This permanently elevates our clinical quality and predictive standards. The question for the contemporary practitioner is no longer whether this integration is coming, but how rapidly it will define the future standard of care.[5,7,16]

AI's most critical clinical contribution is the dynamic, real-time control of laser energy

While efficacy traditionally relied on a clinician's judgment for precisely calibrated settings, AI systems manage this complexity using sophisticated deep learning algorithms and integrated sensors. The system constantly monitors multiple data streams *via* integrated sensors, capturing factors such as tissue temperature, moisture content, and the characteristics of the ablation plume (the vaporized tissue). A key novelty arising from this constant monitoring is intelligent tissue selectivity. By analyzing these streams, the AI can instantaneously differentiate between healthy and diseased tissue (*e.g.*, sound dentin versus carious dentin). It then automatically adjusts the laser's parameters in the moment to maximize cutting efficiency on the target while minimizing exposure and thermal damage to surrounding healthy structures. This intelligent control system ensures that laser settings remain within safe therapeutic limits, reducing the risk of complications such as overheating and thermal necrosis. This capability significantly enhances the minimally invasive nature of the procedure, ensuring the precise, layer-by-layer ablation of only pathologically compromised tissue, maximizing the preservation of adjacent healthy dental and periodontal structures.

AI in antimicrobial photodynamic therapy: research and development

While the search results strongly confirm the widespread use of antimicrobial photodynamic therapy (aPDT) in clinical and pre-clinical studies, particularly in dentistry and against antibiotic-resistant bacteria, the integration of AI is still in the early, but critical, research and development phase for this specific application. Preliminary studies of AI in aPDT currently fall into two main categories: photosensitizer design and optimization, and prediction of treatment parameters.

aPDT is a recognized strategy supported by extensive clinical and preclinical data for treating localized infections, particularly in dentistry, and against antibiotic-resistant bacterial strains. However, the incorporation of computational intelligence, specifically AI and its subfields, is currently in a critical phase of research and development aimed at optimizing this methodology.

A central challenge in advancing aPDT lies in identifying the optimal photosensitizer, one characterized by high phototoxicity towards target microorganisms, negligible dark toxicity, high aqueous solubility, and effective penetration of biofilms. AI techniques, particularly machine learning (ML) and computational chemistry, are being leveraged to expedite the discovery process. Researchers utilize AI/ML models to establish quantitative structure-

activity relationships (QSAR) between the photosensitizer chemical structure and its aPDT activity, notably its singlet oxygen quantum yield ( ) and subsequent generation of reactive oxygen species, such as singlet oxygen ($^1O_2$). This approach aims to predict the antimicrobial efficacy of novel photosensitizer candidates *in silico* before costly and time-intensive laboratory synthesis and testing.
Computational modeling facilitates the understanding of photosensitizer localization and interaction within diverse microbial envelopes. For instance, models simulate affinity toward the negatively charged cell wall of Gram-negative bacteria or the thick peptidoglycan layer of Gram-positive bacteria. The combination of molecular dynamics (MD) simulations with ML has been employed to suggest a correlation between the spatial orientation of the photosensitizer within the bacterial membrane and its overall antimicrobial efficacy. AI is being integrated with emerging photophysical technologies, such as aggregation-induced emission luminogens (AIEgens), to design novel photosensitizer structures exhibiting superior antibacterial performance, including demonstrable efficacy against multidrug-resistant (MDR) strains.
The efficacy of aPDT is critically dependent on achieving an optimal clinical protocol, requiring the precise balancing of three variables: photosensitizer concentration, light wavelength, and the delivered light dose (fluence). AI algorithms can analyze complex biological and anatomical variables (*e.g.*, tissue depth, local oxygen tension, and microbe density) to provide real-time or pre-treatment recommendations for the ideal irradiation time and light dosage. This is particularly vital in anatomically complex sites, such as deep periodontal pockets or complex root canal systems in dentistry, where achieving a uniform, therapeutic light distribution is technically challenging. As clinical data accrue, ML models can be trained on initial patient and infection parameters to predict treatment success for specific pathologies (*e.g.*, predicting the magnitude of pathogenic bacterial load reduction in patients with periodontitis).
In conclusion, although the clinical implementation of AI-driven aPDT systems is still in its early stages, the foundational research is well-established. AI serves as a computational accelerator to overcome current translational limitations of aPDT by refining photosensitizer properties and facilitating the customization of the therapeutic protocol.[17-24]

Ethical and clinical challenges of AI in laser dentistry
While offering revolutionary precision, the reliance on AI in laser dentistry carries distinct risks primarily centered around automation bias, data integrity, and ethical-legal accountability. The challenge lies in ensuring that AI serves as augmented intelligence, an intelligent co-pilot, rather than leading to passive adoption that undermines the clinician's essential role.
Automation bias occurs when clinicians overly rely on AI's recommendations, potentially neglecting clinical expertise or subtle patient observations. If a clinician unthinkingly follows AI-recommended laser parameters for procedures like peri-implantitis decontamination without noticing an unusual tissue response, they risk thermal damage. This marginalizes the dentist's expertise, reducing their ability to manage "edge cases" that fall outside the AI model's learned distribution.
The AI's performance is intrinsically linked to the data on which it is trained. Algorithmic bias can arise if training data is non-diverse, potentially leading to suboptimal or unfair treatment for patients outside the dominant demographic. Furthermore, the "black box" problem, where sophisticated deep learning models lack transparency (explainable AI [XAI]), hinders clinical trust by obscuring why a particular laser setting was chosen, making error correction difficult.
In diagnostics, AI's high sensitivity can sometimes lead to false positives. Overreliance on these sensitive flags can result in unnecessary and premature laser intervention (*e.g.*, cavity preparation when observation might suffice), introducing avoidable costs and risks that violate the ethical principle of non-maleficence.
Finally, integrating AI raises complex ethical and legal questions. In the event of an adverse outcome (*e.g.*, a laser burn from a faulty AI-driven setting), liability remains unclear: does it rest with the dentist, the software vendor, or the manufacturer? Additionally, AI requires the collection and transfer of vast amounts of sensitive patient data, increasing the vulnerability to cyberattacks and threatening patient confidentiality.
To mitigate these risks, the dental community must prioritize rigorous independent validation, mandatory algorithmic transparency, and continuous training that emphasizes that AI is a tool to augment, not replace, skilled professional judgment. Only through this careful and critical adoption can we truly harness the full potential of AI to revolutionize laser dentistry.[12,16,25-30]

Conclusions

The convergence of AI and digital laser technology is the most crucial development in modern dentistry today. It is pushing us toward highly personalized, data-driven care, all the way down to sub-millimetric precision. We see AI acting as dynamic intelligence, providing intelligent tissue selectivity and optimizing applications such as PBM and aPDT. However, we must remain vigilant. This profound change is not without significant pitfalls: we must address automation bias, the potential for flawed algorithms, the "black box" problem of opaque decision-making, and the challenging ethical and legal questions around liability. The future depends on us insisting on continuous training, mandatory transparency, and rigorous independent validation. AI must always be a tool that *enhances* our professional judgment, not one that supplants it.

Conflict of interest

The author has no conflict of interest to declare.

Ethics approval and consent to participate

Not applicable.

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