

Emerging applications of artificial intelligence in periodontology (Review)

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Abstract. Artificial intelligence (AI) is steadily finding its place in periodontology, providing novel strategies with which to enhance diagnosis, guide treatment and support long-term patient care. The present narrative review aimed to summarise recent advances in AI-driven periodontal diagnostics and therapeutics, discuss the available data and explore potential future pathways in AI-based periodontology. Recent research indicates that deep learning approaches, such as convolutional neural networks and vision transformers, can identify radiographic bone loss, gingival inflammation and complex periodontal defects with notable accuracy. AI has also been applied to salivary and gingival crevicular fluid biomarkers, helping to refine disease staging and predict treatment outcomes. In the clinical setting, robotic assistance, smart toothbrushes, mobile health tools and sensor-based devices are emerging to improve precision and patient adherence. Applications are even extending to halitosis monitoring and forensic identification. Despite these promising advances, the majority of studies continue to rely on small or single-centre datasets, with considerable variation in methods and limited external validation. Concerns around transparency, bias, and data security remain unresolved. Future progress will depend on large, collaborative studies and the development of explainable models that can be integrated into daily practice.

Contents

1. Introduction
2. Search strategy

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3. Applications in periodontal diagnostics
4. Applications in treatment planning
5. Smart devices in periodontal care
6. Applications in halitosis detection and management
7. AI-assisted analysis of biomarkers
8. Applications in surgical robotics
9. Application in forensic periodontology
10. Applications in enhancing oral health related quality of life
11. Research focus
12. Conclusion

1. Introduction

Artificial intelligence (AI) is a branch of computer science that involves simulating human intelligence in machines, particularly computer systems, to perform cognitive functions, such as learning, reasoning and self-correction with increased speed and accuracy (1). While standard software follows manually pre-defined processing steps to reach a result, AI tools use mathematical algorithms to independently identify patterns and leverage connections between inputs and desired outputs (2). John McCarthy coined the term 'artificial intelligence' around 1955 to refer to the ability of machines to perform tasks associated with intelligent behaviour (3), and in 1950, Alan Turing formulated the Turing test to evaluate whether a machine could demonstrate intelligence comparable to that of a human (4).

In the field of dentistry, particularly periodontology, AI and machine learning (ML) models are driving a marked transformation by integrating large volumes of clinical, radiographic and molecular data. AI enhances the accuracy, efficiency and consistency of diagnosis, treatment planning and patient management (1). Periodontal diseases, which range from gingivitis to periodontitis, are widespread and pose a substantial global health burden, affecting a large segment of the population and contributing to oral health issues worldwide (5). Accurate identification and diagnosis are challenging for clinicians owing to subjectivity, time constraints and inconsistencies in radiographic angulation and probing pressure inherent to conventional diagnostic methods in periodontology (6). AI provides a feasible option with which to overcome these limitations by potentially improving patient

outcomes, treatment planning and diagnostic accuracy. The use of AI techniques in periodontal applications has exhibited a notable increase in publications since 2019, indicating that the field is gaining interest and has the potential to be revolutionised by AI (4,7).

Artificial neural networks (ANNs) and convolutional neural networks (CNNs), which form the foundation of medical image analysis in periodontology and can extract features from high-dimensional imaging data, are frequently employed in AI models (8,9). A range of data types are utilised as input, including genetic information, salivary biomarkers, clinical records, panoramic, periapical, bitewing, intra-oral and fluorescent images (7,9,10).

However, despite encouraging progress, the integration of AI into periodontology remains incomplete and faces several significant translational barriers (4,7). A key limitation is the insufficient understanding of AI principles among clinicians, combined with limited awareness of its practical applications and ongoing concerns regarding the reliability of AI-derived outputs (11). At the evidence level, marked heterogeneity in study designs, analytical methods and reported outcomes restricts interstudy comparability and limits the potential for robust evidence synthesis (2). Moreover, unresolved issues related to data quality, lack of standardised protocols, limited applicability across diverse populations and ethical concerns, including data privacy and security, continue to impede broader clinical implementation (6).

The application of AI in clinical settings could herald a new era of precision medicine for periodontal care in which treatment and diagnostic plans are customised to the individual needs of each patient (1,12). To provide a comprehensive perspective for both clinicians and researchers, the present narrative review aimed to summarise recent advances in AI-driven periodontal diagnostics and therapeutics, discuss the available data and explore potential future pathways in AI-based periodontology.

2. Search strategy

A comprehensive literature search was conducted for studies published between 2020 and 2025 using PubMed, Scopus, Web of Science and Google Scholar. The search was limited to articles in the English language. The search items included combinations of AI-related keywords ('artificial intelligence', 'machine learning', 'deep learning' and 'neural networks') and periodontal terms ('periodontitis', 'periodontal disease' and 'dental diagnostics') with Boolean operators (AND/OR). Reference lists of included articles were also hand-searched for additional relevant studies.

3. Applications in periodontal diagnostics

By providing advanced tools to enhance the diagnosis, monitoring and general management of periodontal diseases, AI is transforming healthcare, including the specialised field of periodontology (13). Conventional periodontal diagnosis relies predominantly on manual assessments, including clinical examination, periodontal probing to measure pocket depth and visual interpretation of radiographs. These methods are inherently subjective and prone to significant inter- and

intra-operator variability, influenced by factors, such as probing force, radiographic angulation and clinician experience (12). AI provides a promising strategy with which to overcome these limitations by improving diagnostic accuracy, treatment planning and patient outcomes (6).

Radiographic bone loss detection and staging. AI models, particularly deep learning models such as CNNs, have shown considerable potential in periodontal radiographic analysis (14). These models have been utilised on periapical, bitewing and panoramic radiographs, and on cone-beam computed tomography (CBCT) primarily for detecting and quantifying alveolar bone loss, a key parameter in periodontitis diagnosis and assessment (9,15). Reported accuracies ranging from 73 to 99% demonstrate strong diagnostic capability; however, this variation also suggests that performance is influenced by factors, such as dataset quality, imaging modality, annotation standards and model architecture. Although certain studies have reported results comparable to or better than those of experienced clinicians, these findings need to be interpreted with caution as performance in controlled settings may not translate directly to routine clinical practice. For instance, a CNN model exhibiting 94% sensitivity and 88% specificity reflects strong potential but does not, on its own, confirm generalisability or reproducibility. More advanced architectures, such as vision transformers, have demonstrated improved performance on specific tasks, including furcation classification, suggesting that newer models may enhance radiographic interpretation (4,8,9). Beyond detection, AI has also demonstrated value in assisting with the staging and grading of periodontitis based on bone loss severity (8,14).

Gingivitis and periodontal disease detection (intra-oral images and clinical data). AI exhibits high sensitivity and specificity in identifying locations with or without gingival inflammation (16). AI detects dental plaque using intra-oral photographs or fluorescence images with an accuracy of 73.6-99% (7). In addition, AI has been employed to classify periodontal disease from intra-oral images, achieving diagnostic accuracy of 47-81% (6). ANNs can distinguish between aggressive and chronic periodontitis using immunologic parameters with 90-98% accuracy (9). AI systems have demonstrated notable abilities in detecting complex defects, such as intra-bony lesions and furcation involvements, in CBCT images and panoramic radiographs, thereby enhancing assessment precision and treatment planning (8,14). Furthermore, AI systems can analyse unstructured clinical notes using natural language processing (NLP) to extract relevant information about the periodontal health of a patient, enabling the rapid retrieval of patient history and supporting treatment planning (4,12).

4. Applications in treatment planning

AI assists in devising a treatment plan by enabling the development of personalised strategies that support clinical decision-making (17).

Personalised treatment protocols. AI algorithms analyse patient-specific data to develop customised treatment plans. This data may include periodontal evaluations, genetic markers,

medical history, risk factors and imaging results (18,19). This method aligns with the principles of precision medicine (1). AI-enhanced tools can incorporate patient preferences and clinical guidelines to improve treatment adherence and promote long-term oral health outcomes (6).

Non-surgical periodontal therapy and maintenance. AI systems can optimise non-surgical therapy by providing real-time guidance during procedures, such as scaling and root planning, and by analysing patterns of therapeutic response (6,20). Predictive models can forecast disease progression or treatment outcomes to assist in planning (1). For instance, in a previous study, a random forest model trained on patient, clinical, microbiological and treatment data predicted 1-year post-therapy responses (21). AI-powered smartphone applications and smart toothbrushes (e.g., DENTAL MONITORING[®] software) enable patients to obtain intra-oral images at home for real-time monitoring of oral hygiene and gum condition. This monitoring has been shown to improve periodontal status post-treatment and increase adherence to dental plaque control (1,22). Moreover, wearable diagnostic tools, such as smart mouthguards and sensor-embedded dental implants, provide real-time monitoring of oral conditions (22,23).

Implantology. AI is widely used for implant treatment planning, especially with CBCT scans. AI models can identify the jawbone, sinus anatomy, nerves and existing teeth on CBCT scans, greatly enhancing implant placement accuracy (4,5,8). Robotic-assisted implant placement has demonstrated higher precision than freehand methods (24). AI models also exhibit high accuracy (93.8-98%) in recognising implant types from radiographs (4). In general surgery, AI-powered software can simulate surgeries and guide clinicians during operations, resulting in improved surgical outcomes and fewer complications (19).

5. Smart devices in periodontal care

AI is increasingly integrated into oral health devices and applications. Smart toothbrushes utilise sensors and algorithms to guide brushing. For example, Li *et al* (25) conducted a randomised trial comparing conventional care with an AI-enabled multimodal-sensing toothbrush (AI-MST) combined with personalised application feedback as an adjunct to standard periodontal therapy. After 6 months, the AI-MST group exhibited significantly improved outcomes: Only 44.4% of periodontal pockets remained inflamed compared with 52.3% in the control group. Furthermore, the test group achieved superior oral hygiene scores (25). This finding illustrates that AI-driven oral hygiene coaching can boost patient adherence and improve treatment efficacy. AI toothbrushes can advise patients on brushing pressure and timing, offering real-time feedback. Micro-robotic flossers and AI toothbrushes can automatically target biofilm in hard-to-reach areas. Clinicians may particularly recommend these for patients with poor dexterity or compliance (26). Mobile health applications complement these gadgets; AI-powered applications and wearables monitor brushing frequency, technique and other habits, providing personalised reminders and tips (6).

6. Applications in halitosis detection and management

AI provides a revolutionary and objective approach to halitosis detection and monitoring, notably via the development of AI-powered electronic nose systems (27). AI systems for halitosis detection are based on artificial olfaction, also known as ‘electronic noses’. These systems combine principles of mammalian olfaction with AI to identify specific smell patterns. These systems use an array of non-selective sensors to assess the entire spectrum of exhaled volatile compounds (4,27). Nanomaterial-based sensor arrays coupled with ML algorithms have demonstrated remarkable capabilities. For example, systems comprising 32 metal-oxide sensors integrated with ML algorithms have achieved 98.1% accuracy in distinguishing various biological conditions by profiling volatile organic compounds (VOCs) (27,28). Deep neural networks (such as multi-layer perceptrons, CNNs and long short-term memory networks) are employed to interpret complex VOC patterns, capturing full VOC signatures rather than just volatile sulphur compounds, thereby enabling more accurate diagnosis and monitoring. To facilitate explainable analysis, the platform ‘OdoriFy’ uses a deep neural network to identify individual odorant molecules as malodorous and to predict their interactions with olfactory receptors (27).

7. AI-assisted analysis of biomarkers

AI is being used to analyse salivary and gingival crevicular fluid biomarkers to detect and treat periodontal diseases (29). These biological fluids are abundant and non-invasive sources of molecular indicators that reflect the overall state of periodontal and systemic health. Large datasets are generated from these fluids using ‘omics’ technologies (metabolome, microbiome, proteome, etc.), which are ideally suited for AI analysis to enhance our understanding of the pathophysiology of periodontal disease (1,30).

ML models trained on salivary counts of nine key periodontal bacteria have achieved 93% accuracy in distinguishing healthy from moderate or severe periodontitis, indicating that specific combinations of bacteria in saliva are effective biomarkers for disease severity (29). Support vector machine analysis using subgingival microbial profiles successfully classified periodontal status and distinguished between aggressive and chronic periodontitis with high accuracy (14). An ANN utilised immunologic parameters (e.g., leucocyte counts, interleukins and IgG antibody titres) to differentiate aggressive from chronic periodontitis with 90-98% accuracy (3).

8. Applications in surgical robotics

AI has introduced autonomous robotic systems capable of performing dental procedures with sub-millimetre precision. The Yomi[™] robot, for instance, is an FDA-approved robotic platform for dental implant surgery that employs AI algorithms for detailed surgical planning and provides real-time feedback to the surgeon (24,30,31). AI-driven robotics facilitates minimally invasive surgical techniques, which can minimise surgical trauma and promote rapid healing (30). For comprehensive treatment planning and precise surgical execution, these systems integrate with digital dental workflows, combining data

Table I. Key AI tools.

AI tool/model	Application area(s)	Key notes
CNNs	Radiographic bone loss detection, staging, periodontal defect identification, age estimation	Accuracy up to 99%; used in periapical, bitewing, panoramic radiographs, CBCT; superior in some cases to clinicians (8,15).
ViT	Furcation classification, defect analysis	Shown to outperform older CNNs in furcation defect detection (8).
ANNs	Classifying periodontal disease, differentiating aggressive vs. chronic periodontitis, biomarker analysis	Accuracy 90-98% with immunologic parameters and GCF biomarkers (3,9).
NLP	Analysis of clinical notes	Extracts structured info from unstructured patient records (1,4).
Random forest model	Prediction of periodontal treatment outcomes	AUROC=0.93 for 1-year post-therapy response (21).
SVMs	Classification using microbial profiles	Differentiates aggressive vs. chronic periodontitis (14).
Deep neural networks	Halitosis detection (VOC profiling, electronic nose systems)	Capture complex odour signatures; better than focusing only on VSCs (4,27).
OdoriFy platform	Halitosis / olfaction AI	Uses deep neural networks to classify odorant molecules, predict olfactory receptor interactions (27).
AI-multimodal sensing toothbrush	Smart oral hygiene monitoring	Randomized trial showed improved periodontal pocket outcomes and oral hygiene scores (25).
Smart mouthguards/sensor-embedded ximplants	Real-time monitoring	Wearables for oral health status tracking (22,23).
DENTAL MONITORING [®] software	Smartphone-based intraoral image analysis	Enables remote monitoring and adherence improvement (22).
Yomi [™] Robot	Implant surgery	FDA-approved robotic-assisted implant placement with AI-driven planning (24).
AI-driven surgical simulation software	Surgical planning & guidance	Improves outcomes, reduces complications (30).
Electronic nose systems	Halitosis detection	Sensor arrays + AI algorithms; up to 98.1% accuracy in VOC profiling (28).
Machine learning models on biomarkers (e.g., omics, salivary bacteria count)	Periodontal disease screening	Achieved area under the curve up to 0.96 in differentiating healthy vs. periodontitis (29).
Mixed reality + AI	Surgical planning in implants and periodontal surgery	Immersive pre-surgical simulation environments (32).

CNN, convolutional neural networks; ViT, vision transformers; ANNs, artificial neural networks; NLP, natural language processing; SVM, support vector machine; AI, artificial intelligence; VOC, volatile organic compounds; CBCT, cone beam computed tomography; GCF, gingival crevicular fluid; AUROC, area under the receiver operating characteristics curve; VSCs, volatile sulphur compounds.

from intra-oral scanners, CBCT and AI analysis. Real-time tissue characterisation and surgical planning adjustments are enabled by the synergy of AI and advanced imaging technologies. With this capability, surgeons can adapt their techniques to the individual anatomy and tissue properties of each patient.

Surgeons can visualise and rehearse procedures beforehand using surgical planning environments enabled by the integration of AI and mixed reality technologies. This approach reduces the learning curve for complex periodontal procedures while significantly enhancing surgical accuracy (32). A detailed summary of various AI tools, their

specific applications and reported performance outcomes in periodontal diagnostics and therapeutics is provided in Table I.

9. Applications in forensic periodontology

Foundations of forensic periodontology. Forensic periodontology is crucial in identifying individuals, particularly in cases involving decomposed bodies, large-scale disasters or criminal investigations. The use of AI in forensic periodontal assessment represents a notable advancement in both accuracy and efficiency of identification. AI technologies can analyse

Table II. Addressing key limitations through future research.

Limitations/challenge	Future research focus/directions	(Refs.)
Small, limited datasets	Prioritize large-scale, prospective, multi-centre trials with heterogeneous, diverse populations	(6,14).
Low generalizability (cross-centre validation)	Conduct validation and robustness tests across different datasets and clinical environments. Use standardized protocols and metrics	(14,35,39).
Lack of Interpretability	Develop explainable AI (XAI) models. Research on XAI techniques to enhance clinician and patient understanding of decision processes	(8,14,39).
Retrospective design/ high risk of bias	Emphasize new prospective studies (8). Test models in prospective trials involving healthy volunteers and patients across treatment phases	(39).
Single data modality reliance	Develop models using multiple data modalities (imaging + clinical + omics)	(14,39).
Ethical/regulatory concerns (bias, privacy)	Focus on methods for addressing bias and ensuring equity. Establish governance structures and policies for data sharing and privacy	(12,40).

periodontal patterns, bone loss configurations and dental traits to assist in personal identification procedures (33-35).

AI-driven age and sex estimation. AI algorithms are highly adept at estimating age and sex based on periodontal characteristics. ML models analysing panoramic radiographs can estimate chronological age with accuracy that approaches that of experienced forensic odontologists (36,37). These systems examine patterns of alveolar bone remodelling, modifications in the periodontal ligament space and root resorption that occur with ageing. Deep learning models utilising CNNs can automatically segment dental structures and measure relevant parameters for age estimation, thereby significantly reducing analysis time while maintaining high accuracy (37). The integration of multiple dental and periodontal parameters improves the reliability of age estimation protocols.

Automated pattern recognition in forensic analysis. AI systems excel at recognising complex patterns in periodontal anatomy that are relevant to forensic identification. ML algorithms can analyse combinations of features, including alveolar crest morphology, interproximal bone levels, root surface characteristics and periodontal defect patterns, to generate unique dental profiles (36,38). The development of automated comparison systems enables the rapid screening of ante-mortem and post-mortem dental records, significantly accelerating the identification process in mass-casualty scenarios. These systems can handle large databases of dental records and pinpoint potential matches based on periodontal characteristics (33,38).

10. Applications for enhancing oral health-related quality of life

Role of AI-assisted monitoring in enhancing oral health-related quality of life (OHRQoL). AI-assisted dental monitoring, whether used alone or in combination with health counselling, benefits both treatment outcomes and the long-term OHRQoL for patients with periodontitis. In a previous study, AI-monitoring groups demonstrated a significantly greater

improvement in OHRQoL at the 6-month follow-up compared with the control group (34). AI-assisted dental monitoring reminds patients with periodontitis to maintain proper dental hygiene at home. This technology analyses intra-oral images obtained by the patient at home, evaluates the current oral and gum health of the patient, and provides timely reminders and targeted recommendations to enhance patient engagement and convenience. AI reduces plaque accumulation and improves the effectiveness of periodontal treatment by encouraging self-care habits (14,34).

Critical role of human counselling in OHRQoL enhancement. Studies have demonstrated that AI-assisted monitoring combined with human counselling (AIHC) results in improved treatment outcomes and greater improvements in OHRQoL compared with patients who receive only AI monitoring or standard care. The AIHC group demonstrated a greater improvement in OHRQoL than the AI-only group at the 3-month follow-up. In addition, the AIHC group showed greater improvement in OHRQoL at the 6-month follow-up compared with their baseline (22,34).

11. Research focus

Future research and development in AI for periodontology is warranted to focus on enhancing explainability and clinical relevance. Creating explainable AI systems that provide transparent and interpretable reasoning for their predictions is vital to building trust among clinicians and patients (35). Moreover, further research is required to highlight multi-modal data fusion, combining clinical, imaging and molecular datasets, such as genomic and salivary biomarkers, in order to achieve a more precise, comprehensive understanding of periodontal disease dynamics (1,35). AI models need to advance to predict clinically significant outcomes, including disease severity, progression and personalised treatment responses, aligning with standardised diagnostic and therapeutic frameworks (14,39). The main limitations and the corresponding research directions to address them are outlined in Table II.

Equally critical is the need for longitudinal and prospective validation studies to evaluate AI model performance in predicting real-world disease trajectories and treatment outcomes, moving beyond the limitations of retrospective designs (6,9,14). Seamless clinical integration should also be a key focus. AI tools need to be interoperable, user-friendly and adaptable to existing dental workflows, with the potential for real-time disease monitoring via smart or home-based devices (8,14). Finally, rigorous comparative studies between AI and human clinicians using standardised datasets are essential to define the true capabilities and limits of AI in periodontal diagnosis and management (14).

12. Conclusion

AI is transforming periodontology by improving diagnostics, treatment planning and patient management. Tools such as CNNs, ANNs and NLP enable the precise detection of periodontal diseases, bone loss, gingival inflammation and complex defects from radiographs, intra-oral images, biomarkers and clinical data. Furthermore, AI supports personalised treatment protocols, the optimisation of non-surgical therapies, surgical or implant planning, smart oral health devices, halitosis detection, biomarker analysis and robotic-assisted procedures. In addition, it aids forensic applications such as age and sex determination and automated dental record matching.

However, in order to fully realise this potential, several challenges need to be addressed, including inconsistent data quality, lack of standardised protocols, limited generalisability and ethical concerns, such as privacy and patient trust. Large-scale, demographically diverse validation studies, interpretable AI models, federated learning for secure collaboration and robust cost-effectiveness research are necessary. Integration into clinical workflows requires investment in infrastructure, practitioner training and effective patient communication, while bridging the digital divide remains essential. Future progress depends on collaboration among clinicians, researchers, developers and regulators to ensure safe, ethical and equitable adoption. As AI merges with augmented reality/virtual reality, advanced sensors and mobile platforms, it promises to expand access and precision in periodontal care, ultimately improving global oral health outcomes.

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Authors' contributions

RC and NS were involved in designing the concept of the study followed by conducting the search and drafting the manuscript. DGK, SS and AS were involved in revising and initial

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Ethics approval and consent for publication

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Use of artificial intelligence tools

During the preparation of this work, AI tools were used to improve the readability and language of the manuscript or to generate images, and subsequently, the authors revised and edited the content produced by the AI tools as necessary, taking full responsibility for the ultimate content of the present manuscript.

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