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DIAGNOSTIC ACCURACY OF ARTIFICIAL INTELLIGENCE ALGORITHMS IN PERIODONTAL DISEASE

Periodontology

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ABSTRACT

Background: Periodontal diseases are among the most prevalent chronic inflammatory conditions worldwide and remain a major cause of tooth loss and impaired oral health. Accurate diagnosis is essential for timely intervention; however, conventional clinical and radiographic assessments are often influenced by examiner variability. Recent advances in artificial intelligence (AI) have enabled automated analysis of periodontal clinical and imaging data, offering the potential to improve diagnostic accuracy and consistency. Aim: To critically evaluate the current evidence regarding the diagnostic accuracy, clinical utility, and limitations of AI applications in the detection, classification, and staging of periodontal diseases. **Materials and Methods:** A critical review of peer-reviewed studies investigating AI-based diagnostic systems for periodontal diseases was conducted. Studies evaluating machine learning and deep learning models using radiographic and intraoral imaging datasets were included. Diagnostic performance measures, including sensitivity, specificity, F1-score, Intersection over Union, and area under the receiver operating characteristic curve, were analyzed. **Results:** AI systems demonstrated high diagnostic accuracy for detecting gingivitis, periodontitis, periodontal bone loss, furcation involvement, and disease staging. Most studies reported performance metrics exceeding 80%, with several models achieving results comparable to expert clinicians. However, challenges including limited external validation, dataset heterogeneity, and variability in imaging protocols were consistently identified. **Conclusions:** AI shows considerable potential to enhance periodontal diagnostics. Nevertheless, robust validation, standardized datasets, and prospective clinical studies are required before widespread clinical implementation.

KEYWORDS

Artificial Intelligence, Diagnostic Accuracy, Deep Learning, Tele dentistry, Periodontal Disease

INTRODUCTION

Periodontitis is a chronic multifactorial inflammatory disease affecting the supporting structures of the teeth, resulting in progressive destruction of the periodontal ligament and alveolar bone. If left untreated, it may lead to tooth loss and has been associated with several systemic conditions, including diabetes mellitus, cardiovascular diseases, and adverse pregnancy outcomes [1]. Given its high global prevalence, affecting more than one billion individuals worldwide, and its significant impact on both oral and systemic health, early and accurate diagnosis remains a fundamental objective in periodontal care.

Conventional periodontal diagnosis relies on clinical parameters such as probing depth, clinical attachment level, and bleeding on probing, complemented by radiographic assessment of alveolar bone loss. Although these methods remain the cornerstone of periodontal evaluation, they are time-consuming, technique-sensitive, and susceptible to inter- and intra-examiner variability, which may affect diagnostic consistency and accuracy [2]. Furthermore, radiographic interpretation often depends on clinician expertise and may be complicated by anatomical variations and image quality limitations.

Recent advances in artificial intelligence (AI), particularly machine learning and deep learning technologies, have created new opportunities for improving periodontal diagnostics. By analyzing large volumes of clinical and radiographic data, AI algorithms can identify complex patterns, automate image interpretation, and generate objective and reproducible diagnostic outputs [3,4]. These capabilities have generated considerable interest in the use of AI for the detection, classification, and staging of periodontal diseases. In addition, AI-driven diagnostic systems have the potential to reduce diagnostic variability, enhance early disease detection, support clinical decision-making, and improve access to periodontal care through digital and teledentistry platforms, particularly in resource-limited settings [3,4].

Despite the promising performance of AI-based diagnostic systems, concerns regarding dataset quality, external validation, algorithm transparency, ethical considerations, and clinical applicability remain. Therefore, a critical appraisal of the available evidence is necessary to determine the strengths, limitations, and future potential of AI in periodontal disease diagnostics. This review aims to evaluate the diagnostic accuracy, clinical utility, and challenges associated with AI-based approaches and to explore their role in the future of periodontal healthcare.

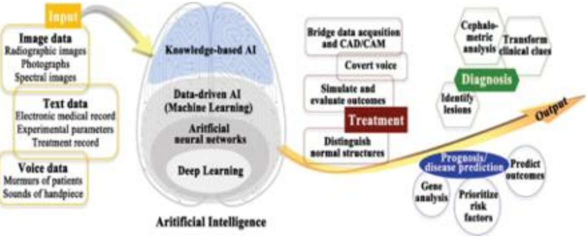

Fig 1: Hierarchical Relationship Between Artificial Intelligence, Machine Learning Deep Learning, and Commonly Used Periodontal Diagnostic Algorithms.

METHODOLOGY

This review was conducted to evaluate the current evidence regarding the application and diagnostic performance of artificial intelligence (AI) algorithms in periodontal disease diagnostics. A comprehensive literature search was performed using electronic databases including PubMed, Scopus, MEDLINE, Web of Science, and Google Scholar. Additional articles were identified through manual screening of reference lists from relevant publications.

The search strategy incorporated combinations of Medical Subject Headings (MeSH) terms and keywords including "Artificial Intelligence," "Machine Learning," "Deep Learning," "Convolutional Neural Network," "Periodontitis," "Periodontal Disease," "Periodontal Diagnosis," "Alveolar Bone Loss," "Dental Radiography," and "Periodontology." Studies published in English up to April 2025 were considered for inclusion.

Eligible studies included original research articles evaluating AI-based systems for the detection, classification, staging, or prediction of periodontal diseases. Studies utilizing machine learning, deep learning, computer vision, or hybrid AI models in conjunction with radiographic, clinical, or photographic datasets were included. Review articles, editorials, conference abstracts, duplicate publications, and studies lacking quantitative evaluation of diagnostic performance were excluded.

Following title and abstract screening, full-text assessment was performed to determine eligibility. A total of thirty studies fulfilled the inclusion criteria and were critically analyzed. Information regarding study design, imaging modality, AI architecture, dataset characteristics, performance metrics, and clinical applications was extracted and synthesized. Particular emphasis was placed on diagnostic accuracy measures including sensitivity, specificity, F1-

score, area under the receiver operating characteristic curve (AUC), and Intersection over Union (IoU).

The methodological quality of the selected studies was evaluated through critical appraisal of study design, dataset composition, validation procedures, and reporting transparency. The findings were synthesized narratively to identify current trends, strengths, limitations, and future opportunities in AI-assisted periodontal diagnostics.

Clinical Applications of Artificial Intelligence in Periodontology

Detection of Gingivitis Gingivitis represents the earliest stage of periodontal disease and is characterized by reversible inflammation of the gingival tissues. Early identification of gingivitis is essential because timely intervention may prevent progression to periodontitis. Traditional diagnosis relies on clinical examination and assessment of inflammatory signs such as erythema, edema, and bleeding on probing [5].

Recent AI-based systems have demonstrated the ability to detect gingival inflammation through analysis of intraoral photographs, fluorescence imaging, and digital clinical records [5]. Deep learning algorithms can identify subtle color variations, textural changes, and plaque accumulation patterns associated with gingival inflammation. Several studies have reported high diagnostic accuracy for automated gingivitis detection, suggesting that AI may serve as an effective screening tool in both clinical and community settings [5]. The integration of AI with smartphone-based imaging systems further enhances accessibility and may facilitate remote periodontal screening through teledentistry platforms.

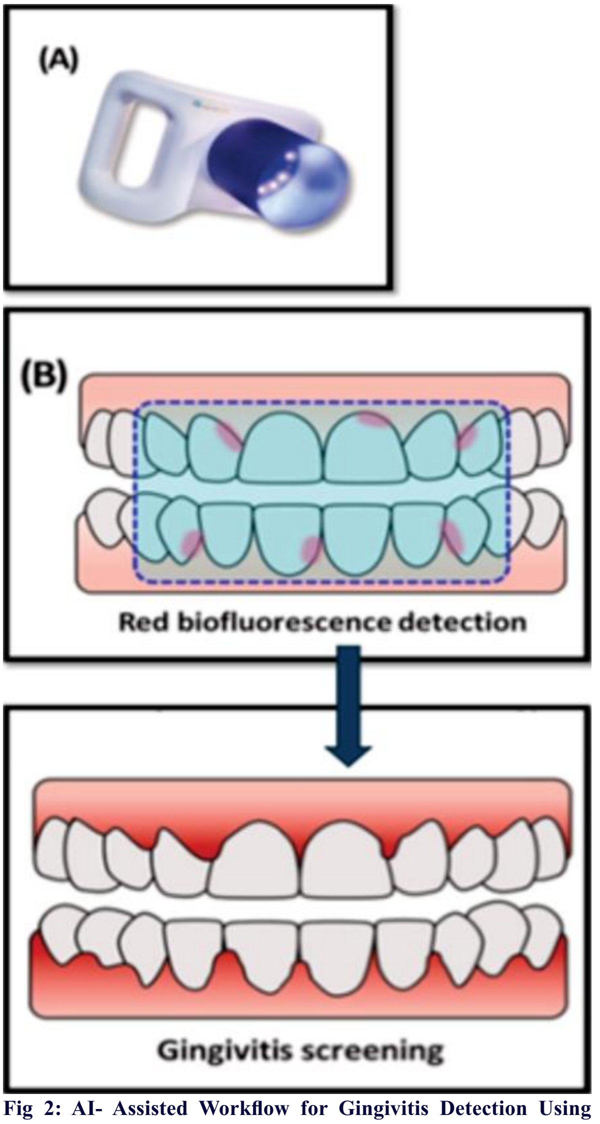

Fig 2: AI- Assisted Workflow for Gingivitis Detection Using Quantitative Light-induced Fluorescence Imaging.

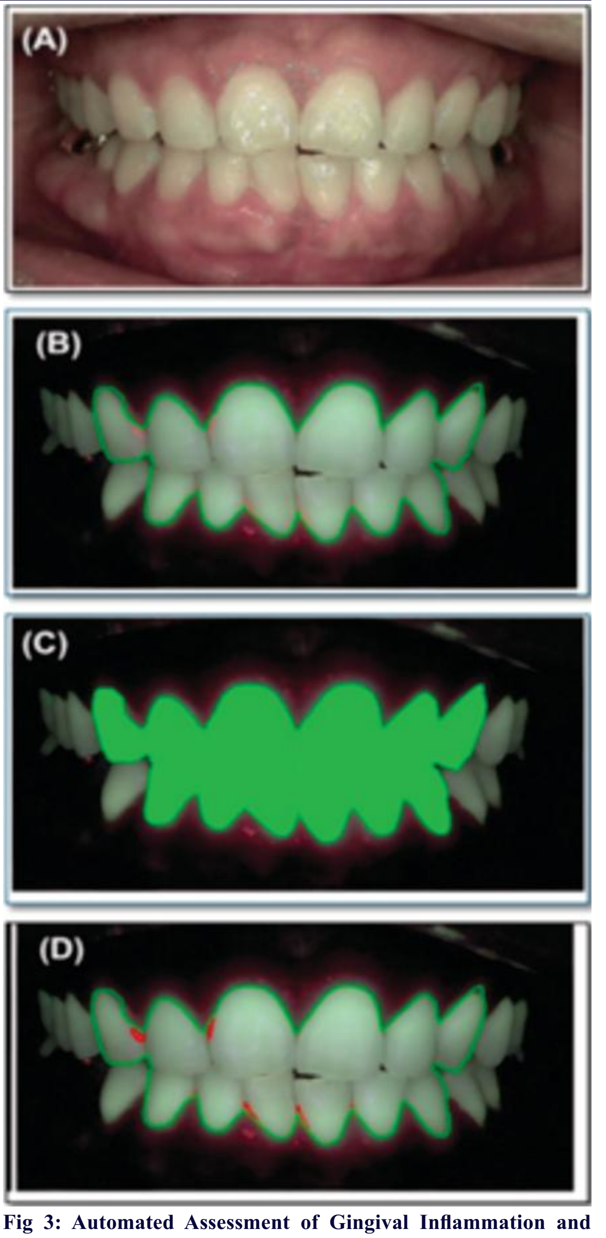

Fig 3: Automated Assessment of Gingival Inflammation and Plaque Accumulation Using Artificial Intelligence.

Detection and Classification of Periodontitis: The diagnosis of periodontitis requires evaluation of clinical attachment loss, periodontal pocket formation, and radiographic bone destruction. AI algorithms have demonstrated considerable potential for automating these assessments through analysis of radiographic and clinical datasets [6]. Deep learning models have successfully distinguished healthy periodontal tissues from varying stages of periodontitis with high levels of accuracy. Automated classification systems can categorize disease severity according to established periodontal staging frameworks, thereby supporting clinicians in treatment planning and disease monitoring [6]. Numerous studies have reported performance metrics comparable to those achieved by experienced periodontists, highlighting the potential role of AI as a decision-support tool rather than a replacement for clinical expertise.

Assessment of Alveolar Bone Loss: Assessment of alveolar bone loss represents the most extensively investigated application of AI in periodontology. Accurate quantification of bone loss is critical for diagnosis, staging, prognosis, and treatment planning. Conventional radiographic evaluation is often subject to observer variability and may require considerable clinical experience [7]. AI-assisted systems can automatically identify key anatomical landmarks such as the cementoenamel junction, alveolar crest, and root apex, enabling objective measurement of bone levels. CNNs, U-Net models, Mask R-CNN architectures, and YOLO frameworks have all demonstrated excellent performance in automated bone loss assessment [7]. Several studies have reported strong agreement between AI-generated measurements and expert clinician assessments. Automated quantification not only improves consistency but also reduces the time required for radiographic interpretation [7].

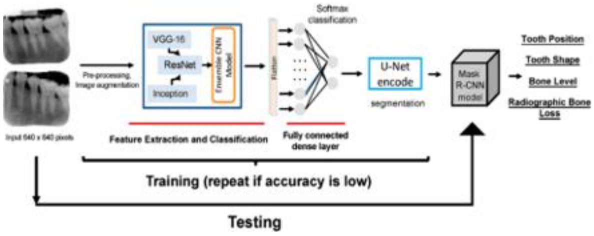

Fig 4: Deep Learning-based Segmentation and Quantification of Periodontal Bone Loss Using Mask R-CNN and Related Architectures.

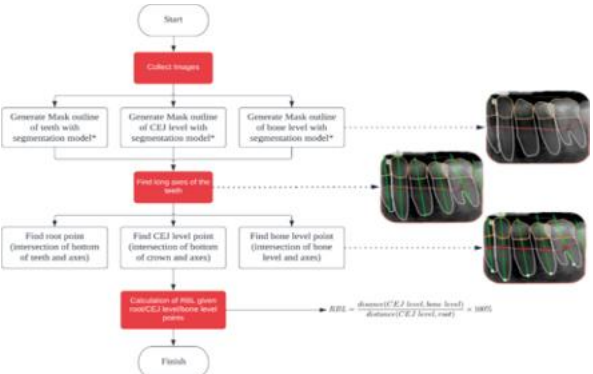

Fig 5: Automated Identification of Cementoenamel Junction, Alveolar Crest, and Root Apex Landmarks For Periodontal Bone Loss Measurement.

Detection of Furcation Involvement: Furcation involvement represents one of the most challenging periodontal conditions to diagnose accurately because of the complex anatomical morphology of multirooted teeth and the inherent limitations of two-dimensional radiographic imaging. Accurate identification of furcation defects is essential for prognosis determination, treatment planning, and long-term maintenance of affected teeth [8]. Conventional diagnosis relies on a combination of clinical probing and radiographic assessment; however, diagnostic accuracy may be compromised by anatomical superimposition, radiographic distortion, and examiner variability [6,8]. Recent advances in artificial intelligence have facilitated the development of automated systems capable of identifying furcation defects from radiographic images with a high degree of precision. Deep learning algorithms, particularly CNNs and object-detection models such as YOLO, have demonstrated promising results in detecting furcation involvement and differentiating between varying degrees of defect severity [3,9]. These systems can automatically localize furcation regions, identify radiolucent defects, and classify involvement according to established periodontal criteria. The integration of AI-assisted furcation detection into clinical workflows may improve diagnostic consistency and reduce the likelihood of missed lesions [5,9]. Furthermore, automated assessment may facilitate longitudinal monitoring of furcation defects and assist clinicians in evaluating treatment outcomes over time [9].

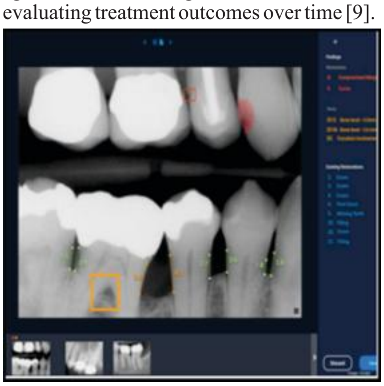

Fig 6: AI-assisted Identification and Classification of Furcation Involvement in Multirooted Teeth.

Disease Staging and Grading: The contemporary classification system for periodontitis emphasizes staging and grading to characterize disease severity, complexity, extent, and rate of progression. Accurate staging and grading are critical because they directly influence treatment planning and prognostic assessment. However, the process requires integration of multiple clinical and radiographic variables, which may introduce variability among clinicians [10]. Artificial intelligence offers a promising solution by integrating diverse datasets and generating standardized diagnostic classifications. Machine learning and deep learning models can simultaneously analyze radiographic bone loss, tooth loss, probing depth measurements, attachment loss, and patient-related risk factors to generate comprehensive periodontal classifications [10]. Several studies have demonstrated successful automated classification of periodontal disease stages using radiographic datasets alone, while more advanced models incorporate both clinical and radiographic information [10]. The ability of AI systems to process large quantities of multidimensional data may ultimately support precision periodontology by enabling individualized disease characterization and risk stratification. As these technologies continue to evolve, automated staging and grading systems may become valuable adjuncts in clinical decision-making [10].

Teledentistry and Remote Periodontal Screening: The increasing adoption of telehealth technologies has generated substantial interest in AI-assisted teledentistry applications. Limited access to periodontal specialists remains a significant challenge in many rural and underserved regions, resulting in delayed diagnosis and treatment of periodontal diseases [11,12]. Artificial intelligence has the potential to address these disparities by enabling automated remote screening and preliminary diagnostic assessment. AI-based screening platforms can analyze intraoral photographs, radiographic images, and patient-reported information submitted through digital communication systems [11,12]. Such platforms may provide preliminary risk assessments, identify patients requiring specialist referral, and facilitate early intervention. Smartphone-based imaging systems integrated with deep learning algorithms have demonstrated encouraging results for the detection of gingival inflammation, plaque accumulation, and periodontal tissue destruction. The combination of AI and teledentistry may improve healthcare accessibility while reducing clinician workload and healthcare costs. Nevertheless, successful implementation requires robust validation studies, secure data management systems, and adherence to ethical and regulatory standards [11,12].

Diagnostic Accuracy of Artificial Intelligence Algorithms

Diagnostic accuracy represents the most critical parameter for evaluating the clinical utility of artificial intelligence systems in periodontal diagnostics. Numerous studies have investigated the performance of machine learning and deep learning algorithms across a wide range of periodontal applications, including gingivitis detection, bone loss assessment, furcation involvement identification, and disease classification.

Overall, contemporary evidence indicates that AI algorithms can achieve high levels of diagnostic performance, frequently approaching or exceeding those obtained by experienced clinicians. The most commonly reported performance metrics include sensitivity, specificity, accuracy, precision, recall, F1-score, Area Under the Receiver Operating Characteristic Curve (AUC), and Intersection over Union (IoU).

Accuracy, Precision, Recall, and F1-Score: Accuracy represents the proportion of correctly classified cases among all evaluated cases. While accuracy remains an important performance indicator, it may be misleading in imbalanced datasets where one class predominates [10,13]. Consequently, precision, recall, and F1-score are increasingly reported in AI studies [11,13]. Precision reflects the proportion of positive predictions that are truly positive, whereas recall corresponds to sensitivity. The F1-score combines precision and recall into a single metric, providing a balanced assessment of model performance. High F1-scores reported across multiple studies indicate that AI systems are capable of maintaining both strong detection capability and low false-positive rates [13]. These metrics are particularly valuable when evaluating automated periodontal screening systems intended for large-scale population applications [7,13].

Future Directions

Despite promising results, several challenges must be addressed before AI can be fully integrated into routine periodontal practice. Future research should focus on developing large, diverse, multicentre datasets to improve model generalizability and reliability. Integration of multimodal data, including clinical parameters, radiographic findings, biomarkers, and patient-related risk factors, may enhance diagnostic accuracy and support precision periodontology. The development of explainable AI systems is essential to improve transparency, clinician trust, and regulatory acceptance. Additionally, prospective clinical validation studies are needed to evaluate real-world performance and clinical utility. Advances in federated learning, predictive analytics, and chairside AI-assisted diagnostic systems are expected to further expand the role of AI in periodontal diagnosis, risk assessment, and personalized patient care.

CONCLUSION

Artificial intelligence has emerged as a promising adjunctive tool in periodontal diagnostics, demonstrating high accuracy in the detection, classification, and assessment of periodontal diseases. AI-based systems can improve diagnostic consistency, reduce observer variability, facilitate early disease detection, and support clinical decision-making. However, limitations related to dataset diversity, external validation, interpretability, and ethical considerations must be addressed before widespread clinical implementation. With continued technological advancement and rigorous clinical validation, AI is expected to become an integral component of modern periodontal practice, contributing to more efficient, objective, and personalized periodontal care

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