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THE IMPORTANCE OF ARTIFICIAL INTELLIGENCE IN THE EARLY DIAGNOSIS OF DENTAL DISEASES

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Abstract: Artificial intelligence (AI) is rapidly becoming an important component of modern dental practice, particularly in the early diagnosis of dental diseases. Oral diseases are among the most common health problems worldwide. Untreated dental caries affects billions of people, while periodontal disease, oral cancer, periapical lesions, and developmental abnormalities continue to cause pain, tooth loss, disability, and reduced quality of life. Early diagnosis is essential because many dental conditions are initially asymptomatic or present with subtle clinical and radiographic changes that may be difficult to identify. AI, especially machine learning and deep learning, can analyze clinical photographs, intraoral scans, radiographs, cone-beam computed tomography images, and biological data with high speed and consistency. This article reviews the role of AI in the early detection of dental caries, periodontal disease, oral cancer, endodontic pathology, and other oral conditions. A narrative review method was applied using recent scientific literature and authoritative health sources. The evidence indicates that AI systems can assist clinicians by identifying early lesions, improving image interpretation, supporting risk assessment, reducing diagnostic variability, and expanding access to screening. However, limitations remain, including inadequate external validation, biased datasets, lack of interpretability, privacy concerns, regulatory uncertainty, and the danger of relying on AI without professional judgment. AI should therefore be used as a clinical decision-support tool rather than as a replacement for dentists. Its responsible integration may promote earlier intervention, minimally invasive treatment, improved diagnostic accuracy, and more equitable oral healthcare.

Keywords: artificial intelligence, dentistry, early diagnosis, dental caries, periodontal disease, oral cancer, deep learning, dental radiography.

Introduction

Oral health is an essential component of general health and well-being. Dental diseases affect individuals of all ages and may lead to pain, difficulty eating, speech problems, tooth loss, psychological distress, and reduced social functioning. According to the World Health Organization, untreated dental caries in permanent teeth is one of the most common health conditions globally. In addition, severe periodontal disease affects approximately one billion people,

while oral cancers represent a significant cause of morbidity and mortality[1]. The high prevalence of oral diseases creates a substantial burden for patients, families, healthcare systems, and national economies.

The success of dental treatment is strongly influenced by the timing of diagnosis. Caries detected at an early stage may be managed through preventive measures, fluoride therapy, dietary modification, remineralization, and improved oral hygiene. When the disease is diagnosed late, extensive tooth preparation, endodontic treatment, or extraction may be required. Similarly, early periodontal inflammation can often be controlled through professional cleaning and behavioral interventions, whereas advanced periodontal destruction may result in irreversible bone loss and tooth mobility. Early recognition of oral potentially malignant disorders and oral cancer can improve the possibility of successful treatment and long-term survival.

Despite its importance, early diagnosis is not always easy. Initial carious lesions may be small, hidden in interdental areas, or difficult to distinguish from normal anatomical structures. Periodontal diagnosis requires interpretation of clinical signs, probing measurements, radiographic bone levels, and patient risk factors. Oral cancer may present as a subtle mucosal color or texture change that resembles a benign lesion. Conventional diagnosis depends on the clinician's experience, visual attention, equipment, and available time. Differences among clinicians may also produce variability in the detection and interpretation of disease.

Artificial intelligence offers new possibilities for addressing these challenges. AI refers to computer systems capable of performing tasks that normally require human intelligence, including pattern recognition, classification, prediction, and decision-making. Machine learning systems learn associations from data, while deep learning systems, particularly convolutional neural networks, can identify complex patterns in images. In dentistry, AI models have been developed to analyze bitewing, periapical, panoramic, and cone-beam computed tomography images, as well as intraoral photographs, facial images, digital impressions, and salivary biomarkers[2].

The importance of AI in dental diagnosis is not limited to improving accuracy. AI may support earlier detection, reduce the workload of clinicians, standardize image interpretation, prioritize high-risk patients, and extend screening services to communities with limited access to dental professionals. However, promising performance in research settings does not automatically guarantee safe or effective clinical use. Models must be evaluated on diverse populations and in real-world clinical environments. The purpose of this article is to examine the contribution of AI to the early diagnosis of dental diseases, discuss its potential benefits and limitations, and outline the conditions required for responsible implementation.

Methods

[1]World Health Organization. **Oral Health**. Geneva: World Health Organization; 2025. Available at: https://www.who.int/news-room/fact-sheets/detail/oral-health

[2]Patil S, et al. Artificial Intelligence in the Diagnosis of Oral Diseases. *International Journal of Environmental Research and Public Health*. 2022. Available at: https://pubmed.ncbi.nlm.nih.gov/35626185/

Surdu A, et al. Using AI in Optimizing Oral and Dental Diagnoses—A Narrative Review. *Diagnostics*. 2024;14(24):2804. Available at: https://pubmed.ncbi.nlm.nih.gov/39767164/

This article was prepared as a narrative review using recent peer-reviewed publications, systematic reviews, and authoritative public health sources. Literature was identified through searches concerning artificial intelligence in dentistry, deep learning in dental imaging, dental caries detection, periodontal disease diagnosis, oral cancer screening, endodontic diagnosis, and oral health epidemiology. Publications were selected according to their relevance to early diagnosis and their discussion of diagnostic performance, clinical application, limitations, or ethical considerations.

The reviewed evidence included studies involving machine learning, deep learning, convolutional neural networks, computer-aided detection, and AI-assisted analysis of radiographic and clinical images. Evidence from systematic reviews and meta-analyses was prioritized when available. The analysis focused on five themes: the clinical importance of early dental diagnosis, AI applications in specific dental diseases, potential benefits for clinical practice, limitations and risks, and future requirements for implementation. Because the article is a narrative review, it does not represent a formal systematic review or quantitative meta-analysis. *The worldwide burden of oral disease and the promising diagnostic performance of AI systems are summarized in Table 1.*

Table 1. Global burden of oral diseases and reported performance of artificial intelligence in dental diagnosis

Oral health indicator or AI application	Statistical information
Untreated dental caries in permanent teeth	Approximately 2.5 billion people affected worldwide
Severe periodontal disease	Approximately 1 billion people affected worldwide
Complete tooth loss	Approximately 350 million people affected worldwide
AI-assisted caries detection on dental radiographs	Reported accuracy of approximately 91.5% in reviewed studies
AI-assisted periodontal bone-loss detection	Reported accuracy of approximately 93% in reviewed studies
AI-assisted tooth identification and numbering	Reported accuracy of approximately 93.67%
AI-assisted oral cancer detection	Reported sensitivity of approximately 91% and specificity of approximately 89%

Results

Artificial intelligence and early detection of dental caries

Dental caries is a progressive disease caused by interactions among cariogenic microorganisms, dietary carbohydrates, tooth structures, and time. Early enamel demineralization may be reversible, but progression into dentin increases the likelihood of cavitation and restorative treatment. Accurate identification of non-cavitated and early cavitated lesions is therefore central to minimally invasive dentistry.

AI has been particularly investigated for caries detection on bitewing and periapical radiographs. Deep learning models can be trained to identify radiolucent areas associated with proximal or occlusal caries. Some systems can also localize the suspected lesion and mark it on the image, allowing the dentist to review the finding. A systematic review of AI-based radiographic detection of dental diseases reported high diagnostic performance for several applications, including caries and periodontal bone loss[3]. Other reviews have found that AI models demonstrate clinically acceptable accuracy in the detection of approximal caries on bitewing radiographs, although performance varies according to lesion depth, image quality, and the reference standard used[4].

One of the most important advantages of AI is its potential to identify small or easily overlooked lesions. Dentists may interpret numerous images during a busy clinical session, and fatigue or time pressure can affect visual concentration. An AI system can examine every region of a radiograph systematically and provide a second opinion. This may be especially useful for lesions located between teeth, near restorations, or in anatomically complex areas.

AI does not simply replace visual inspection. It can combine radiographic findings with patient-specific information, such as age, previous caries experience, fluoride exposure, diet, oral hygiene, and salivary characteristics. In the future, predictive models may estimate the probability that a questionable lesion will progress. Such risk-based diagnosis could help clinicians decide whether to monitor a lesion, provide preventive treatment, or perform operative intervention. This approach is consistent with modern dentistry, which emphasizes preservation of healthy tooth structure.

Nevertheless, caries detection remains challenging. Radiographs provide two-dimensional representations of three-dimensional structures, and early enamel lesions may not produce sufficient contrast. Restorative materials, overlapping structures, image distortion, and variations in exposure can create false-positive or false-negative findings. AI should therefore support, rather than replace, clinical examination and professional judgment.

Artificial intelligence in periodontal disease diagnosis

Periodontal diseases range from reversible gingivitis to destructive periodontitis. Periodontitis is characterized by inflammation and progressive loss of supporting periodontal tissues. If untreated,

[3] Albano D, et al. Artificial Intelligence for Radiographic Imaging Detection of Dental Caries: A Systematic Review. *BMC Oral Health*. 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/38402191/

[4] Carvalho BKG, et al. Diagnostic Accuracy of Artificial Intelligence for Approximal Caries on Bitewing Radiographs: A Systematic Review. *Journal of Dentistry*. 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/39396775/

it may produce periodontal pockets, alveolar bone loss, tooth mobility, and tooth loss. Diabetes, smoking, poor oral hygiene, genetics, age, and socioeconomic factors influence disease risk.

Periodontal diagnosis depends on several types of information. Clinical measurements include probing depth, clinical attachment loss, bleeding on probing, tooth mobility, and plaque levels. Radiographs demonstrate bone loss but may not show active inflammation. AI can assist by analyzing radiographic bone levels, classifying the severity of periodontal destruction, and identifying patterns that may be difficult to assess consistently.

A review of AI applications in panoramic radiography reported promising accuracy for the detection of periodontal bone loss, with some models achieving performance above 90% in selected research datasets[5]. AI systems may automatically identify the cemento-enamel junction, alveolar crest, and root surfaces, then estimate the degree of bone loss. This could improve screening and help clinicians detect disease in patients who have not yet developed severe symptoms.

AI may also support population-level periodontal screening. Panoramic radiographs are frequently available in dental clinics, and automated analysis could flag patients who require a detailed periodontal examination. This is valuable because periodontal disease can remain relatively painless for long periods. Patients may therefore seek treatment only after substantial tissue destruction has occurred.

Another potential application is longitudinal monitoring. By comparing radiographs obtained at different times, AI may detect subtle changes in bone height or lesion progression. Such analysis could help evaluate treatment response and identify patients with continuing disease activity. Integration with electronic dental records may allow the system to combine radiographic changes with systemic risk factors, smoking history, glycemic status, and periodontal measurements.

The limitations are significant. Radiographic bone loss is not identical to current disease activity, and an AI system cannot determine all aspects of periodontal health from an image alone. Clinical examination remains essential. In addition, variations in radiographic angulation, patient positioning, missing teeth, restorations, and advanced bone loss may affect model performance.

Artificial intelligence and oral cancer detection

Oral cancer is one of the most serious diseases encountered in dental practice. It may develop on the lips, tongue, buccal mucosa, gingiva, floor of the mouth, palate, or oropharyngeal tissues. Delayed diagnosis is common because early lesions may be painless and may be mistaken for trauma, infection, or benign mucosal changes.

AI-based oral cancer screening systems commonly analyze photographs obtained with smartphones, intraoral cameras, or specialized imaging devices. Deep learning algorithms can classify images according to the presence of normal tissue, potentially malignant disorders, or malignant lesions. A recent systematic review reported promising diagnostic performance for AI in detecting oral cancer, with pooled estimates in some analyses reaching approximately 91%

[5] Turosz N, et al. Applications of Artificial Intelligence in the Analysis of Dental Panoramic Radiographs: A Systematic Review. 2023. Available at: https://pubmed.ncbi.nlm.nih.gov/37665008/

sensitivity and 89% specificity[6]. Other studies have reported high sensitivity for identifying oral potentially malignant disorders and malignant tumors, although specificity has varied[7].

The principal benefit of AI in this context is improved access to preliminary screening. Many communities lack sufficient numbers of oral medicine specialists or oral and maxillofacial pathologists. A trained healthcare worker or dentist could capture a standardized image and submit it to an AI system for risk assessment. Patients with suspicious results could then be referred for specialist examination and biopsy.

AI can also encourage dentists to pay attention to lesions that might otherwise be overlooked. It may identify asymmetry, abnormal pigmentation, ulceration, surface irregularity, or changes in vascular patterns. When used appropriately, this can increase vigilance and reduce delays in referral.

However, an image-based system cannot establish a definitive diagnosis of cancer. Histopathological examination remains necessary. A false-positive result may cause anxiety and unnecessary referrals, whereas a false-negative result may delay treatment. Lighting, image focus, camera quality, tissue moisture, and lesion location can affect classification. The dataset must also include patients from different ethnic groups and with a broad range of normal anatomical variation to prevent biased outcomes.

Artificial intelligence in endodontic and periapical diagnosis

Endodontic diseases, including apical periodontitis, pulp inflammation, and root fractures, may be difficult to diagnose because symptoms do not always correspond to radiographic findings. Early periapical inflammation may not be visible on conventional radiographs. AI has been used to evaluate periapical radiolucencies, identify root morphology, estimate working length, detect missed canals, and assist in the assessment of treatment quality[8].

Cone-beam computed tomography provides detailed three-dimensional information and may be analyzed by AI to identify periapical lesions or root fractures. Artificial intelligence may improve consistency in detecting subtle findings and reduce the time required to examine large image volumes. In endodontics, this is particularly useful for complex anatomy and treatment planning.

AI models have also been explored for predicting the presence of apical periodontitis when clinical and radiographic variables are combined. In the future, systems may integrate patient symptoms, pulp-test results, percussion sensitivity, radiographic appearance, and previous treatment history. Such integration could help distinguish reversible conditions from those requiring endodontic intervention.

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[6] Diagnostic Performance of Artificial Intelligence in Detecting Oral Cancer: A Systematic Review and Meta-analysis. *Frontiers in Oral Health*. 2024. Available at: https://www.frontiersin.org/journals/oral-health/articles/10.3389/froh.2024.1494867/full

[7] Kouketsu A, et al. Detection of Oral Cancer and Oral Potentially Malignant Disorders Using Artificial Intelligence and Oral Cavity Images. 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/38860703/

[8] Ahmed ZH, et al. Artificial Intelligence and Its Application in Endodontics. 2023. Available at: https://pubmed.ncbi.nlm.nih.gov/38238281/

The use of AI in endodontics must be cautious because treatment decisions depend on clinical findings that may not be visible in an image. A radiographic abnormality may represent scar tissue, anatomical variation, or a non-endodontic lesion. Therefore, AI output should be interpreted within a complete diagnostic process.

AI for salivary and biological data

In addition to image analysis, AI may contribute to the diagnosis of dental diseases through saliva and other biological samples. Saliva contains proteins, nucleic acids, metabolites, microorganisms, and inflammatory mediators. These substances may provide information about oral cancer, periodontal inflammation, systemic disease, and treatment response.

Machine learning can analyze complex combinations of salivary biomarkers that may be difficult to interpret using conventional statistical methods. Research on AI-assisted salivary biomarker discovery suggests potential applications in oral cancer and other oral diseases[9]. Although this field is still developing, it could eventually lead to non-invasive screening tests that complement clinical examination.

Salivary AI tools may be particularly valuable for repeated monitoring. A patient at high risk of periodontal disease or oral cancer could undergo regular testing, allowing changes to be detected before visible symptoms appear. However, biomarker concentrations may be influenced by diet, medications, smoking, systemic illness, hydration, and collection methods. Large prospective studies are needed before these tests can be incorporated into routine care.

Discussion

The findings of this review demonstrate that AI has considerable potential to improve the early diagnosis of dental diseases. Its strongest current application is image analysis. AI can detect, classify, localize, and quantify abnormalities on radiographs and clinical photographs. Reviews have reported promising performance in caries detection, tooth identification, periodontal bone-loss assessment, and oral cancer screening[10]. These capabilities can increase diagnostic consistency and support clinicians in recognizing lesions at an earlier stage.

The clinical importance of early detection is substantial. Early caries treatment may preserve tooth structure and avoid extensive restorations. Early periodontal diagnosis may prevent irreversible bone destruction. Early identification of suspicious mucosal lesions may accelerate referral and biopsy. In each case, the patient may benefit from less invasive treatment, lower costs, shorter treatment time, and improved long-term outcomes.

AI may also reduce variations between clinicians. Human interpretation is affected by experience, fatigue, image quality, and cognitive bias. A computer-assisted system applies the same algorithm to every image. It can function as an additional observer, highlighting areas that deserve

[9] Adeoye J, et al. Artificial Intelligence in Salivary Biomarker Discovery and Applications in Oral Health. 2023. Available at: https://pubmed.ncbi.nlm.nih.gov/37335832/

[10] Albano D, et al. Artificial Intelligence for Radiographic Imaging Detection of Dental Caries: A Systematic Review. *BMC Oral Health*. 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/38402191/

closer examination. Studies of dental radiographs suggest that AI can achieve high levels of accuracy in tooth numbering and the detection of several disease categories[11].

Another important benefit is improved access to care. In rural and underserved communities, there may be limited access to dentists, radiologists, oral medicine specialists, or pathology services. AI-assisted tele-dentistry could help prioritize referrals and support remote screening. It cannot eliminate the need for professional care, but it may help distribute specialist attention more efficiently.

Despite these advantages, several limitations prevent AI from being considered an autonomous diagnostic authority. First, many AI systems are trained on datasets collected from a limited number of institutions. The images may not represent different ethnicities, age groups, disease severities, imaging devices, or clinical environments. A model that performs well internally may perform less effectively in another country or clinic. External validation and prospective clinical trials are therefore essential[12].

Second, AI systems may reproduce the biases present in their training data. If early lesions are underrepresented, the model may fail to detect them. If images from certain demographic groups are scarce, the system may be less accurate for those populations. Fairness must be evaluated explicitly rather than assumed.

Third, many deep learning models are difficult to interpret. They may produce a probability score without explaining why a specific lesion was classified as suspicious. Explainable AI methods, including heat maps and visual attention tools, can help clinicians understand the basis of a prediction. However, visual explanation does not guarantee that the underlying reasoning is clinically valid.

Fourth, false-positive and false-negative findings have different consequences. A false positive may lead to anxiety, additional radiographs, biopsies, or unnecessary treatment. A false negative may create false reassurance and delay care. AI systems should therefore be calibrated according to the clinical purpose. Screening tools may prioritize sensitivity, while treatment-planning tools may require a different balance between sensitivity and specificity.

Fifth, ethical and legal issues must be considered. Dental images and health records contain sensitive personal information. Data must be collected, stored, and processed according to privacy regulations. Patients should be informed when AI is used and should understand that the final diagnosis remains the responsibility of a qualified professional. Clear standards are needed concerning liability when AI recommendations conflict with clinical judgment.

The most appropriate model is collaborative intelligence. In this model, AI performs repetitive pattern-recognition tasks while dentists provide contextual interpretation, communication, ethical judgment, and treatment planning. AI may identify a suspicious radiolucency, but the dentist must

[11] Webster S, et al. Artificial Intelligence and Dental Panoramic Radiographs: A Systematic Review. 2024. Available at: https://pubmed.ncbi.nlm.nih.gov/38273112/
Dashti M, et al. Comparative Analysis of Deep Learning Algorithms for Dental Disease Detection. 2024. Available at: https://pmc.ncbi.nlm.nih.gov/articles/PMC11622875/
[12] Lee JE, et al. Radiographic Diagnosis of Periodontitis Using Artificial Intelligence: A Systematic Review and Meta-analysis. 2025. Available at: https://pmc.ncbi.nlm.nih.gov/articles/PMC12720480/

determine whether it is clinically relevant. AI may flag a mucosal lesion, but the dentist must examine the patient, assess risk factors, arrange referral, and obtain biopsy when necessary.

Professional education will be essential. Dental students and practicing clinicians should learn how AI systems are trained, how performance metrics should be interpreted, and how errors may occur. Sensitivity, specificity, positive predictive value, negative predictive value, and area under the receiver operating characteristic curve should be understood in relation to disease prevalence. Clinicians must also recognize that a high accuracy value in a research paper does not necessarily mean that the tool is appropriate for every patient.

Future research should focus on standardized datasets, prospective validation, integration with clinical workflows, and assessment of patient outcomes rather than only technical accuracy. Studies should examine whether AI actually reduces diagnostic delay, prevents unnecessary treatment, improves referral rates, and increases the detection of early disease. Research should also evaluate cost-effectiveness and the impact of AI on health inequalities.

Conclusion

Artificial intelligence is becoming an important support technology for the early diagnosis of dental diseases. Its ability to analyze radiographs, clinical photographs, digital scans, and biological data may improve the detection of dental caries, periodontal disease, oral cancer, endodontic pathology, and other conditions. By identifying subtle abnormalities and standardizing image interpretation, AI can assist dentists in providing earlier, more preventive, and more personalized care.

The greatest value of AI lies not in replacing the dentist but in strengthening professional decision-making. AI can act as a second reader, screening assistant, monitoring tool, and risk-prediction system. Nevertheless, its results must be interpreted alongside clinical examination, patient history, professional expertise, and appropriate confirmatory tests. Data quality, external validation, transparency, privacy protection, and ethical governance are necessary for safe implementation.

When responsibly integrated into dental practice, AI may reduce diagnostic errors, improve access to specialist assessment, support minimally invasive treatment, and contribute to better oral health outcomes. Its future success will depend on a balanced partnership between advanced technology and human clinical judgment.

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