Global Academic Journal of Dentistry and Oral Health

Available online at https://www.gajrc.com
DOI: https://doi.org/10.36348/gajdoh.2025.v07i03.002

OPEN ACCESS

ISSN-2706-8994 (P)
ISSN-2707-8868 (O)

Review Article

A Systematic Review on the Future of Dental Diagnosis: Applications and Challenges of Artificial Intelligence

Zahraa Raheem Abed Alzamiliy[1*]
[1]University of Al-Qadisiyah, Dentistry College, Department of Conservative and Preventive Dentistry

***Corresponding Author**
Zahraa Raheem Abed Alzamiliy
University of Al-Qadisiyah, Dentistry College, Department of Conservative and Preventive Dentistry

Article History
Received: 21.07.2025
Accepted: 18.09.2025
Published: 20.09.2025

Abstract: Artificial intelligence (AI), particularly deep learning, is rapidly transforming dental diagnostics from automated interpretation of radiographs to remote screening using intraoral photos. Recent systematic reviews and meta-analyses report high accuracy for AI models in tasks such as caries detection and radiographic interpretation, and new clinical deployments are appearing. However, important challenges remain: dataset bias and poor socio-demographic reporting, explainability, data privacy and regulatory gaps, integration into clinical workflows, and real-world validation. This review synthesizes current applications, core enabling technologies, clinical benefits, major challenges, and realistic future directions to guide researchers, clinicians, developers, and regulators toward safe, effective, and equitable AI-enabled dental care.

Keywords: AI, Dental, CNN, CBCT, XAI.

1. INTRODUCTION

Dental diagnosis relies heavily on imaging (periapical, bitewing, panoramic radiographs, CBCT), clinical examination, and patient history. AI techniques primarily convolutional neural networks (CNNs) and other deep-learning architectures offer the ability to automate detection, quantify disease, assist treatment planning, and triage patients remotely. Multiple recent narrative and systematic reviews demonstrate substantial progress and report promising diagnostic performance across many dental tasks [1]. This paper reviews the state of AI in dental diagnosis (2020–2025), examines the major practical and ethical challenges to deployment, and outlines priority research and policy actions needed for responsible adoption [2].

In recent years, the field of dentistry has witnessed remarkable advancements driven by digital technologies, among which artificial intelligence (AI) stands out as one of the most transformative. Dentistry, traditionally reliant on clinical expertise, visual examination, radiographs, and patient-reported symptoms, is now entering a new era where intelligent systems have the potential to enhance diagnostic accuracy, predict disease progression, and personalize treatment planning. The integration of AI into dental diagnosis promises not only to augment the decision-making capacity of practitioners but also to reshape the way oral healthcare is delivered worldwide [3].

Artificial intelligence, broadly defined as the simulation of human cognitive functions by computer systems, has already demonstrated significant utility in various medical fields, including radiology, pathology, dermatology, and cardiology. Within dentistry, AI applications such as deep learning, convolutional neural networks (CNNs), and machine learning algorithms are being increasingly employed to analyze radiographic images, identify carious lesions, detect periodontal disease, evaluate periapical pathologies, and even screen for oral cancers at early stages. The ability of AI systems to process vast datasets with speed and precision enables them to recognize subtle patterns often missed by the human eye, thereby contributing to earlier and more accurate diagnoses [4].

The future of AI in dental diagnostics holds considerable promise. Integration with digital imaging technologies, intraoral scanners, and electronic health records could enable real-time diagnostic support and predictive analytics. AI-powered platforms may also facilitate teledentistry, extending access to underserved populations and bridging gaps in oral healthcare delivery. Furthermore, patient-specific risk assessment models, generated through AI, could lead to precision dentistry, where preventive and therapeutic strategies are tailored to individual needs [5].

Despite these prospects, the implementation of AI in dental practice is not without challenges. Ethical concerns regarding patient data privacy, algorithmic bias, lack of standardization, and the need for rigorous clinical validation remain significant obstacles. Moreover, the dependence on large annotated datasets for algorithm training, the risk of over-reliance on automated systems, and the necessity of integrating AI seamlessly into existing clinical workflows present practical hurdles. Dental professionals must also navigate issues of trust, liability, and regulatory compliance before AI can be fully embraced in mainstream practice [6].

Therefore, understanding the applications and challenges of AI in dental diagnosis is crucial for shaping the trajectory of future oral healthcare. This discussion not only highlights the technological innovations driving this paradigm shift but also underscores the importance of addressing ethical, clinical, and operational barriers to ensure that AI serves as a tool for enhancing rather than replacing human expertise in dentistry [7].

2. METHODS

We synthesized recent peer-reviewed reviews, systematic reviews, original studies, and regulatory analyses from 2020–2025 identified through searches of PubMed/PMC, ScienceDirect, Nature journals, MDPI, and other scholarly outlets. Priority was given to systematic reviews, meta-analyses, and recent high-impact clinical studies to summarize evidence and identify trends.

3. Current and Emerging Applications in Dental Diagnosis

3.1 Radiographic Interpretation (Caries, Periapical Pathology, Bone Loss)

AI models have been applied extensively to dental radiographs for caries detection, periapical lesion identification, periodontal bone loss quantification, and detection of impacted teeth. Systematic reviews and meta-analyses report that many deep-learning models achieve diagnostic performance comparable to or exceeding non-specialist clinicians in controlled test sets, especially for caries detection on bitewing and periapical radiographs [2, 3].

Radiographic imaging has long been an indispensable diagnostic tool in dentistry, providing clinicians with a non-invasive means of visualizing hard and soft tissues that are not apparent during clinical examination. With the integration of artificial intelligence (AI), radiographic interpretation is undergoing a significant transformation, as machine learning algorithms are increasingly capable of analyzing complex imaging data with remarkable precision and efficiency. Current and emerging AI-driven applications in radiographic interpretation primarily focus on three key diagnostic domains: caries detection, periapical pathology identification, and assessment of alveolar bone loss [9].

Caries Detection

Dental caries remains one of the most prevalent oral diseases worldwide, and its early detection is critical for preventing progression and avoiding invasive treatments. Traditional interpretation of bitewing and periapical radiographs is subject to variability depending on the clinician's experience, leading to potential under- or over-diagnosis. AI models, particularly convolutional neural networks (CNNs), have demonstrated high sensitivity and specificity in detecting incipient carious lesions by identifying subtle radiolucencies that may escape human observation. Emerging systems are capable of not only detecting caries but also classifying their severity, offering valuable guidance in deciding between preventive and restorative interventions [10].

Periapical Pathology Identification

Accurate detection of periapical pathology, such as granulomas, cysts, and abscesses, is essential for endodontic diagnosis and treatment planning. AI-based diagnostic systems trained on large datasets of annotated radiographs and cone-beam computed tomography (CBCT) scans have shown promise in distinguishing between normal periapical tissues and pathological changes. These models can quantify lesion size, track progression over time, and provide differential diagnostic support. By offering standardized, reproducible interpretations, AI reduces inter-observer variability and enhances diagnostic confidence in cases where radiographic findings are ambiguous [11].

Bone Loss and Periodontal Assessment

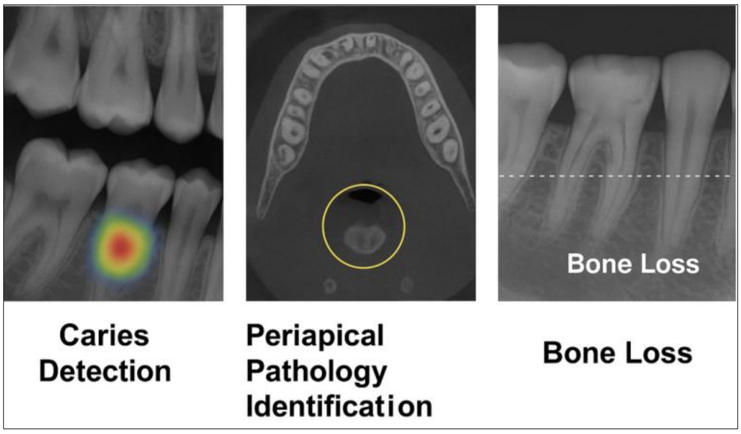
Periodontal disease, characterized by progressive loss of supporting alveolar bone, often requires radiographic evaluation for diagnosis and monitoring. AI applications are being developed to automate the detection and measurement of bone loss on periapical, panoramic, and CBCT images.

These systems can map bone levels across dentition, identify angular defects, and provide quantitative assessments that aid in monitoring disease progression and treatment outcomes. Emerging tools are also exploring integration with digital periodontal charts, thereby enabling comprehensive, AI-assisted periodontal diagnostics [12].

Emerging Directions

The future of AI in radiographic interpretation is likely to involve multimodal analysis, where radiographic findings are combined with patient-specific clinical, genetic, and historical data to generate holistic diagnostic insights. Cloud-based platforms are also being developed to allow real-time AI-assisted radiographic interpretation, making this technology accessible in both clinical and teledentistry settings. Additionally, continuous advancements in deep learning architectures are expected to improve diagnostic accuracy across diverse patient populations, thereby increasing the generalizability of AI tools [13].

In summary, the incorporation of AI into radiographic interpretation represents one of the most promising applications of artificial intelligence in dentistry. By enhancing accuracy, consistency, and efficiency in the detection of caries, periapical pathology, and bone loss, AI has the potential to significantly improve patient outcomes and elevate the standard of diagnostic care [14].



3.2 Oral Mucosal Lesion and Oral Cancer Screening

AI applied to intraoral photographs and adjunctive imaging has shown promise for screening mucosal lesions and flagging suspicious areas for urgent referral. Recent studies demonstrate feasibility for remote triage using patient-supplied photos, expanding access in low-resource and tele-dentistry settings [4].

3.3 Orthodontics, Prosthodontics, and Endodontics

Automated landmark detection, cephalometric analysis, segmentation for treatment simulation, prediction of orthodontic outcomes, and detection of vertical root fractures or root-canal anatomy with CBCT are active areas of development. These tools can speed workflow and assist treatment planning [15].

3.4 Chairside Decision Support & Predictive Analytics

AI models are being developed to predict restoration failure, risk of peri-implantitis, and treatment prognosis by combining imaging, clinical parameters, and electronic health records. Early clinical prototypes offer real-time decision support, though most remain at the pilot stage [5].

3.5 Population Screening and Tele Dentistry

Automated triage using smart phone images and cloud-based AI enables remote screening campaigns and preliminary diagnosis in community dentistry, which may improve access and early detection. Recent clinical deployments and pilot projects illustrate operational feasibility [6, 7].

4. Enabling Technologies and Trends

- Convolutional Neural Networks (CNNs) for image classification/segmentation (most radiographic tasks).
- Transformer architectures and large multimodal models for combining text, images, and structured EHR data; LLMs are increasingly investigated for report generation and clinical summarization [8].
- Federated learning to train models across institutions without sharing raw patient images — an emerging approach to tackle privacy and dataset heterogeneity.
- Explainable AI (XAI) methods (saliency maps, attention maps, counterfactuals) to

make model outputs interpretable to clinicians.

- Edge and mobile deployment for point-of-care and teledentistry solutions.

5. Clinical Benefits and Opportunities

Improved diagnostic sensitivity and consistency, particularly for routine, high-volume tasks (e.g., caries detection) [2].

Workflow Efficiency: automated flagging, measurement, and report drafts reduce clinician time on mundane tasks.

Access: remote screening/triage can extend care to underserved populations [4-6].

Data-Driven Risk Prediction: proactive interventions through individualized risk stratification.

6. Major Challenges and Limitations

6.1 Dataset Bias, Representativeness, and Generalizability

Many published models are trained and evaluated on single-center or convenience datasets, often without reporting patient demographics. Reviews of FDA-approved AI/ML devices show poor reporting of race/ethnicity and socioeconomic representation, raising the risk of biased performance across populations. External validation on diverse, multi-center datasets is frequently lacking [9, 10].

6.2 Explainability and Clinician Trust

Black-box models hinder clinician acceptance. Explainability tools can help, but must be validated: saliency maps may mislead if not used carefully. Clinicians need transparent performance metrics (sensitivity/specificity by subgroups) and clear failure modes [10].

6.3 Data Privacy, Security, and Governance

AI requires large volumes of patient data. Ensuring compliance with data protection laws (GDPR, HIPAA-equivalents) and implementing secure storage, anonymization, and access controls are essential. Legal frameworks are evolving but vary by jurisdiction, complicating multi-national deployments [11, 12].

6.4 Regulatory and Liability Uncertainty

AI tools used for diagnosis may be regulated as medical devices. Regulatory pathways are developing but inconsistent globally. Questions remain about responsibility and liability if an AI misdiagnoses and leads to harm. Clinicians and vendors need clear guidance from regulators [12, 9].

6.5 Integration into Clinical Workflow and Reimbursement

Practical integration into dental practice management software, PACS, and EHRs requires interoperability standards. Reimbursement models for AI-assisted diagnostics are not yet well defined, which affects adoption incentives.

6.6 Robustness to Real-World Variation

Models trained on high-quality images may fail on suboptimal or patient-taken photos, devices with different imaging parameters, or in the presence of restorations/orthodontic appliances. Prospective, real-world evaluations are limited [13].

6.7 Ethical and Social Implications

Automating diagnosis may affect clinician training and patient-clinician relationships. There is potential for over-reliance on AI and for unequal access if solutions are expensive or proprietary.

7. Recommendations and Future Directions

7.1 Improve Dataset Quality and Reporting

* Create/openly share large, annotated, multi-center datasets with standardized labels and metadata including age, sex, race/ethnicity, and imaging device.
* Mandate subgroup performance reporting in publications and regulatory submissions [9].

7.2 Prioritize External Validation and Prospective Clinical Trials

Move beyond retrospective test-set reporting to prospective studies and randomized implementation trials measuring patient-level outcomes, workflow impact, and cost-effectiveness [18].

7.3 Emphasize Explainability and Human-AI Teaming

Develop validated XAI methods and human-in-the-loop designs where AI augments, not replaces, clinician judgment. User interface studies should measure how clinicians interpret AI outputs.

7.4 Adopt Privacy-Preserving Training Paradigms

Use federated learning, differential privacy, and secure multiparty computation to guard patient privacy while enabling multi-institution learning [19].

7.5 Regulatory Alignment and Standards

Harmonize regulatory requirements for AI as medical devices, including post-market surveillance, continuous learning policies, and requirements for bias and safety testing.

7.6 Education and Workforce Readiness

Update dental curricula and continuing education to include AI literacy, interpretation of model outputs, and an understanding of limitations and biases.

7.7 Equity and Access Focus

Design deployment strategies that prioritize underserved communities, low-cost mobile solutions, and offline/edge models to reduce access disparities.

8. CONCLUSION

AI has matured from proof-of-concept toward clinically relevant tools in dental diagnosis, with strong performance reported for radiographic tasks such as caries detection and expanding work in intraoral image screening and teledentistry. However, realizing the promise of AI in dental practice requires confronting dataset bias, ensuring real-world validation, protecting patient privacy, clarifying regulation and liability, and designing clinician-centric, explainable systems. Multidisciplinary collaboration among dentists, data scientists, ethicists, and regulators will be essential to build safe, equitable, and effective AI-enabled dental diagnostics.AI shows high diagnostic accuracy in controlled studies for caries and radiographic interpretation, but external validation is limited.. Real-world deployments (tele-screening and institutional scanners) are emerging, demonstrating feasibility beyond research labs. Major barriers: dataset bias and poor demographic reporting, explain ability, privacy/regulatory gaps, and integration into work flows. Future work should emphasize federated learning, prospective clinical trials, interoperable standards, and clinician education to ensure safe adoption. Artificial intelligence (AI) is increasingly transforming dental diagnostics through enhanced imaging analysis, automated detection of dental conditions, personalized treatment planning, and streamlined clinical workflows. AI algorithms have demonstrated high accuracy in detecting caries, periodontal disease, and other oral conditions using X-rays, CBCT, and other imaging modalities. Emerging technologies like robotic dental procedures, tele dentistry, AI-driven chat bots, and multi-modal large language models promise to further evolve dental practice toward greater efficiency, personalization, and accessibility. However, significant challenges remain: data scarcity and quality—especially for rare conditions—and inconsistent imaging standards across clinics hinder generalizability. Ethical concerns such as transparency, bias, privacy, and integration with existing systems persist. Additionally, cost, clinician training, and the need for interdisciplinary collaboration pose barriers to widespread adoption.

REFERENCES

1. Ali, M. A. (2024). The role of artificial intelligence in modern dentistry: Applications, challenges, and future directions. Future Dental Research, 2(2), 39–49.
2. Musleh, D., Almossaeed, H., Balhareth, F., Alqahtani, G., Alobaidan, N., Altalag, J., & Aldossary, M. I. (2024). Advancing dental diagnostics: A review of artificial intelligence applications and challenges in dentistry.
3. Empowering modern dentistry: The impact of artificial intelligence on patient care and clinical decision making. (2024). Diagnostics, 14(12), 1260.
4. Royal College of Surgeons of England. (2023). Artificial intelligence in dentistry: Current state and future directions.
5. Artificial intelligence in dental imaging: A new era of precision and predictive diagnosis*. (n.d.). IP Int J Maxillofacial Imaging.
6. Artificial Intelligence in Dentistry: A Narrative Review of Diagnostic and Therapeutic Applications PMC.
7. Accuracy of artificial intelligence in caries detection: A systematic review and meta-analysis. (2025). Head & Face Medicine, 21, 24.
8. Dental Research Journal (2024). Prospects of artificial intelligence in dentistry. Dental Research Journal, 21(1), 35.
9. Exploring the applications of artificial intelligence in dental image detection: A systematic review. (2024). Diagnostics, 14(21), 2442.
10. Applications of Artificial Intelligence in Dental Medicine: A Critical Review PubMed
11. Advancements in Dentistry with Artificial Intelligence: Current Clinical Applications and Future Perspectives PubMed.
12. Huang, H., Zheng, O., Wang, D., Yin, H., Xu, C., Yang, R., & Shi, B. (2023).
13. Periodontitis diagnosis: A review of current and future trends in artificial intelligence(n.d.).
14. Sarwar, S., & Jabin, S. (2023). AI techniques for cone beam computed tomography in dentistry: Trends and practices.
15. Application and performance of artificial intelligence technology in detection, diagnosis and prediction of dental caries (DC)—A systematic review. Diagnostics, 12(5), 1083.
16. DeepHealth: Review and challenges of artificial intelligence in health informatics. (2019).
17. Economic Times (2025, July 16). Maulana Azad Institute of Dental Sciences sets up AI powered scanner for provisional diagnosis.
18. Royal College of Surgeons of England. (2023). Artificial intelligence in dentistry: Current state and future directions