OPEN ACCESS

Saudi Journal of Oral and Dental Research

Abbreviated Key Title: Saudi J Oral Dent Res
ISSN 2518-1300 (Print) | ISSN 2518-1297 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Original Research Article **Dentistry**

Revolutionizing Dentistry: The Role of Artificial Intelligence in Diagnosis, Treatment Planning, and Patient Care

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DOI: https://doi.org/10.36348/sjodr.2025.v10i06.002 | **Received:** 17.04.2025 | **Accepted:** 31.05.2025 | **Published:** 05.06.2025

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Abstract

Artificial intelligence (AI) has significantly impacted dentistry by enhancing diagnostic accuracy, treatment planning, and patient care across various specialties, including endodontics, radiology, and periodontology. This review synthesizes findings from five key studies examining AI applications in dentistry, focusing on convolutional neural networks (CNNs) and deep learning models.AI-assisted diagnostics have shown superior accuracy compared to traditional methods, with CNNs achieving up to 94% accuracy in detecting periapical lesions and surpassing human radiologists in specific diagnostic tasks. Additionally, AI-assisted caries detection improves tooth retention and reduces treatment costs, demonstrating its potential economic benefits. However, challenges such as data biases, ethical considerations, and regulatory barriers remain future research should focus on developing transparent AI models, standardizing datasets, and addressing cost-effectiveness concerns to enhance clinical integration. ***Methods:*** A comprehensive review of five peer-reviewed articles was conducted, highlighting AI applications in dentistry. The articles were selected based on relevance to diagnostic advancements, clinical decision-making, and patient outcomes. Key methodologies included CNN-based image analysis, deep learning applications for caries detection, and neural networks for treatment optimization. ***Results:*** AI applications in dentistry demonstrated superior diagnostic performance. CNNs achieved 94% accuracy in detecting periapical lesions and surpassed human radiologists in specific diagnostic tasks. AI-assisted caries detection improved tooth retention by 62.8 years on average, with cost savings of €378 per patient compared to traditional methods. In endodontics, AI accurately identified root fractures and predicted treatment outcomes with up to 95.6% accuracy. Despite these advancements, limitations such as data biases and interpretability of AI models were noted. ***Conclusion:*** AI holds transformative potential for modern dentistry by improving diagnostic precision and clinical efficiency. However, integrating AI into routine practice requires addressing data standardization, ethical frameworks, and regulatory barriers. Future research should focus on developing transparent AI models and exploring their cost-effectiveness and long-term impact on patient care.

Keywords: Artificial Intelligence in Dentistry, Convolutional Neural Networks (CNNs), Dental Diagnostics, Machine Learning Applications, Patient-Centered Care.

INTRODUCTION

The integration of artificial intelligence (AI) into modern dentistry has revolutionized clinical workflows, diagnostic capabilities, and treatment planning. AI, a multidisciplinary field of computer science, enables machines to mimic human intelligence and perform tasks such as decision-making, pattern recognition, and problem-solving. While AI concepts date back to the 1950s, recent advancements in computational power, deep learning algorithms, and the availability of big data have propelled its applications across numerous dental disciplines, including endodontics, orthodontics, prosthodontics, radiology, and oral surgery.

AI technologies, particularly machine learning (ML) and deep learning (DL), are the backbone of AI systems in dentistry. These technologies leverage algorithms that analyze large datasets, identify patterns, and generate predictive models for clinical decision-making. Supervised learning, unsupervised learning, and reinforcement learning are primary methods employed in

AI frameworks. Convolutional Neural Networks (CNNs), a subset of deep learning, have proven highly effective for image-based tasks, particularly in dental radiology and pathology. AI-assisted diagnostic tools, for instance, exhibit superior accuracy in identifying caries, detecting periapical lesions, and classifying dental anomalies compared to conventional manual methods.

In the realm of radiology, AI has significantly enhanced diagnostic precision by analyzing two- and three-dimensional imaging modalities, such as bitewing radiographs, panoramic X-rays, and Cone-Beam Computed Tomography (CBCT) scans. AI models such as CNNs can detect subtle radiographic features, including early-stage caries, vertical root fractures, and periapical pathologies, with remarkable accuracy. This technological advancement not only improves diagnostic efficiency but also reduces human error and clinician fatigue, underscoring AI's role as a powerful adjunctive tool.

AI has also demonstrated immense utility in treatment planning and prognostic evaluations. In endodontics, for example, AI algorithms effectively measure working lengths, predict treatment outcomes, and identify root canal morphologies, facilitating precision in therapeutic interventions. Similarly, AI applications in orthodontics support automated cephalometric analysis, aligner treatment simulation, and occlusal assessments, enabling clinicians to optimize treatment strategies with data-driven insights.

The potential benefits of AI extend to personalized dentistry, where machine learning models analyze multimodal patient data, including clinical history, radiographs, and genetic markers, to predict disease risks and tailor preventive care. Such approaches align with the principles of evidence-based dentistry (EBD) while offering scalability, efficiency, and improved patient outcomes. For instance, predictive models have been applied to assess the progression of periodontitis and the likelihood of postoperative pain, allowing clinicians to intervene proactively.

Despite these advancements, AI integration into clinical practice faces several challenges. Ethical concerns, data standardization, and the interpretability of AI models remain key obstacles. Additionally, regulatory compliance and cost-effectiveness considerations impact AI adoption in everyday dental practice (Agrawal & Nikhade, 2022). This review provides a comprehensive overview of AI applications in dentistry, summarizing advancements, limitations, and future directions.

The transformative potential of AI in dentistry lies in its ability to complement, rather than replace, the expertise of dental professionals. By automating repetitive tasks, enhancing diagnostic accuracy, and facilitating data-driven decision-making, AI empowers clinicians to focus on complex case management and patient-centered care. This review aims to provide a comprehensive overview of AI applications in dentistry, summarizing advancements, challenges, and future directions while highlighting the importance of integrating AI with existing clinical workflows.

METHODS

This review employs a narrative review design to evaluate the application and impact of artificial intelligence (AI) in dentistry. The primary aim is to synthesize the existing body of evidence, identify knowledge gaps, and explore the implications of AI in clinical practice, focusing on diagnostic accuracy, cost-effectiveness, ethical considerations, and future directions (Ding *et al*., 2023).

Search Strategy and Selection Criteria
Databases Used: PubMed, Scopus, and Google Scholar
Search Terms: "Artificial Intelligence," "Dentistry," "Deep Learning," "Diagnostic Accuracy," "Clinical Decision-Making"

Inclusion Criteria: Peer-reviewed studies published between 2020 and 2024 focusing on AI applications in dental diagnostics, treatment planning, or patient care

Exclusion Criteria: Non-dental AI studies, papers lacking empirical data, and non-English publications

A purposive sampling strategy was applied to select the most relevant and methodologically rigorous articles. The review process included article identification, data extraction, and synthesis of findings into key thematic

The participants in this review are represented by the primary studies included, which assessed AI applications in various dental disciplines such as endodontics, oral radiology, prosthodontics, and periodontics. Sources were retrieved from **PubMed**, **Scopus**, and **Google Scholar** databases using predefined search terms, including "artificial intelligence," "dentistry," "deep learning," "diagnostic accuracy," and "clinical decision-making." A combination of Boolean operators and Medical Subject Headings (MeSH) terms ensured a broad and targeted search. Inclusion criteria required studies to focus on AI applications in dental diagnostics, treatment planning, or patient care, while exclusion criteria omitted studies not related to dentistry or lacking empirical data

A purposive sampling strategy was applied to select articles with the highest relevance and methodological rigor. After an initial screening of titles and abstracts, eligible articles underwent a full-text review to ensure alignment with the review objectives. The sampling process included studies employing AI technologies such as convolutional neural networks (CNNs), supervised and unsupervised machine learning, and reinforcement learning. Key measurements extracted from the studies included diagnostic accuracy (e.g., sensitivity and specificity), cost-effectiveness metrics, computational performance (e.g., speed and efficiency), and qualitative assessments of ethical and practical implications. Additional metrics included AI's effectiveness in improving patient outcomes, operational workflows, and its integration into evidence-based dentistry frameworks

The review process was conducted in three phases: article identification, data extraction, and synthesis. During the identification phase, articles were evaluated for relevance using predefined criteria. Data extraction focused on extracting thematic elements such as AI methodologies, dental applications, and their outcomes. A qualitative content analysis approach was used to categorize findings into themes, including AI's diagnostic performance, economic implications, and ethical challenges. Quantitative findings, such as sensitivity and specificity data, were aggregated to provide an overview of AI's diagnostic reliability across different dental disciplines.

Analysis emphasized comparative evaluations of AI models against traditional methods, highlighting areas where AI outperformed human practitioners or showed significant limitations. Ethical concerns, including transparency in AI decision-making, data security, and workforce implications, were also critically appraised. The results were synthesized to address the study's objectives and identify gaps for future research

RESULTS

Study	Type of Data	Type of Algorithm	Accuracy	Sensitivity	Specificity	limilations
Semerci & Yardımcı (2024) [12]	CBCT images for endodontic diagnoses	CNN, Mask R-CNN	90% (Pulp detection)	97.1% (Lesion detection)	88%(lesion detection)	Limited dataset diversity
Schwendicke *et al*. (2022) [13]	Bitewing radiographs	CNN, Resnet-18	94%	Not reported	Not reported	Cost-effectiveness uncertainty
Shan *et al*. (2021) [14]	CBCT and panoramic radiographs	CNN, SVM, ANN,	81-94%(disease specific)	93%(oral cancer)	94% (periapical cyst)	Variability in training datasets
Agrawal & Nikhade (2022) [15]	Dental radiographs	CNN, ANN	Not reported	75%(periapical lesion detection)	Not reported	Lack of validation in clinical settings
Ding *et al*. (2023) [16]	Various dental radiographs and images	CNN, Deep Learning	Not reported	Not reported	Not reported	Limited interpretability of AI models

Artificial Intelligence (AI) has rapidly emerged as a transformative force in dentistry, revolutionizing how dental professionals diagnose, treat, and predict patient outcomes. The five studies reviewed in this paper reflect the breadth of AI applications in modern dental care, especially in diagnostics, caries detection, treatment planning, and image analysis. This section will synthesize the findings from these studies, focusing on the types of AI algorithms used, the accuracy, sensitivity, and specificity of the models, and their respective contributions to enhancing clinical outcomes.

AI Applications in Endodontics and Radiology

Endodontics and oral radiology have been primary beneficiaries of AI's integration into dentistry, with several studies demonstrating significant improvements in diagnostic accuracy. The narrative review by **Semerci & Yardımcı (2024)** [12] discusses the role of AI, particularly convolutional neural networks (CNNs), in diagnosing periapical lesions and identifying vertical root fractures (VRFs) using cone beam computed tomography (CBCT) images. In their study, CNN models such as Spatial Configuration-Net (SCN) and Mask R-CNN were highly effective in localizing teeth and detecting periapical lesions, achieving an impressive sensitivity of 97.1% and specificity of 88.0%. These models demonstrated a clear advantage over conventional diagnostic techniques, with AI significantly outperforming human radiologists in terms of diagnostic precision for periapical lesions.

The study further highlights that AI models have been instrumental in improving diagnostic accuracy for complex endodontic conditions such as root fractures. Altındag *et al*. (cited in Semerci & Yardımcı) employed the Mask R-CNN model to detect pulp stones with 90% sensitivity, underscoring the model's ability to detect minute anatomical features that are often missed by human clinicians. Moreover, Johari *et al*. applied probabilistic neural networks (PNNs) to diagnose VRFs, showing higher accuracy in CBCT images compared to conventional periapical radiographs. These findings collectively suggest that AI, particularly deep learning models like CNNs and PNNs, are not only augmenting but potentially surpassing human diagnostic capabilities in certain complex cases.

AI in Caries Detection and Economic Implications

Caries detection has been another critical area where AI has shown substantial potential. **Schwendicke** *et al*. **(2022)** [13] explored the cost-effectiveness and diagnostic accuracy of AI in detecting caries lesions from bitewing radiographs using a convolutional neural network (CNN) model. In their study, the model was trained on 29,011 tooth images without caries and 19,760 tooth images with caries. The CNN demonstrated increasing accuracy as the dataset size grew, with the most significant performance improvement occurring when the training dataset was expanded from 10% to 25% of the total data. The study reported an accuracy of 94% for caries detection, confirming the efficacy of AI in improving diagnostic outcomes.

Notably, Schwendicke's study also addressed the economic aspects of AI implementation in dentistry, employing a health economic model to assess the cost-effectiveness of AI-assisted caries detection. The results showed that AI not only improved tooth retention over a patient's lifetime but also reduced overall treatment costs compared to traditional diagnostic methods. The cost-effectiveness analysis revealed that AI was more effective in retaining teeth (62.8 years) compared to dentists without AI (60.4 years), with AI being less costly (378 euros vs. 419 euros). This finding underscores the dual benefit of AI in dentistry: enhancing diagnostic accuracy while also offering economic advantages, a critical consideration for large-scale AI adoption in healthcare.

AI for Oral Cancer Detection and Disease Prediction

The application of AI extends beyond routine diagnostics to more complex conditions like oral cancer. **Shan** *et al*. **(2021)** [14] conducted an extensive review of AI's role in diagnosing oral and maxillofacial conditions, particularly using image-based data such as CBCT and panoramic radiographs. Their study focused on how machine learning (ML) models like support vector machines (SVMs), artificial neural networks (ANNs), and CNNs have been used to identify various oral pathologies, including periapical cysts, keratocystic odontogenic tumors, and oral cancers. Shan's review reported that these AI models achieved diagnostic accuracies ranging from 81% to 94%, depending on the specific condition being diagnosed.

In particular, the SVM model demonstrated 94% accuracy in differentiating periapical cysts from keratocystic odontogenic tumors, while CNN-based models showed 93% sensitivity in detecting oral cancer from cytology images. These results highlight the growing importance of AI in assisting with early detection of oral cancers, which is critical for improving patient outcomes. By enabling faster and more accurate diagnoses, AI holds the potential to significantly reduce mortality rates associated with oral cancer, particularly in regions with limited access to specialist care.

Challenges and Opportunities in AI Integration

Despite these promising advancements, several challenges persist in integrating AI into routine clinical practice. **Agrawal & Nikhade (2022)** [15] provide an overview of AI's applications in dentistry, particularly in endodontics, where AI models have shown potential in diagnosing periapical lesions, measuring root canal lengths, and predicting treatment success. However, their study points to key obstacles such as the need for larger and more diverse datasets to train AI models, the lack of standardization in AI algorithms, and the potential for biases in data collection. For example, while CNN models achieved 75% sensitivity in detecting periapical lesions, the authors noted that the model's performance varied depending on the quality and diversity of the input data.

Moreover, Agrawal & Nikhade emphasize the importance of validating AI models in real-world clinical settings. Many AI systems have been tested in controlled environments with carefully curated datasets, but their effectiveness in routine clinical practice, where data may be noisier or less structured, remains uncertain. This highlights the need for ongoing validation and calibration of AI models to ensure they perform reliably across different clinical contexts.

Multi-modal AI Systems and Future Directions

One of the most exciting future directions for AI in dentistry is the development of multi-modal AI systems that integrate data from multiple sources to enhance diagnostic accuracy and clinical decision-making. **Ding** *et al*. **(2023)** [16] review the latest advancements in AI applications across various dental disciplines, including operative dentistry, orthodontics, and prosthodontics. Their study explores how AI can synthesize data from radiographs, optical images, patient demographics, and clinical history to provide more comprehensive diagnoses and treatment recommendations.

For instance, Ding *et al*. discuss the potential of AI models to predict not only dental diseases but also systemic conditions by analyzing dental images alongside other medical data. This multi-modal approach could revolutionize precision medicine in dentistry by enabling clinicians to make more informed decisions based on a holistic view of the patient's health. However, the authors also point out that significant challenges remain, particularly in terms of data uniformity and the computational power required to process large, multi-modal datasets. As AI technology continues to evolve, addressing these challenges will be crucial for the successful integration of AI into everyday dental practice.

DISCUSSION

The integration of artificial intelligence (AI) into dentistry is transformative, offering the potential to significantly improve diagnostic accuracy, patient care, and clinical decision-making. Across various dental disciplines, including endodontics, radiology, orthodontics, and general diagnostics, AI has demonstrated its capability to enhance clinical outcomes by providing precise and consistent diagnostic support, aiding in treatment planning, and delivering robust prognostic assessments. Despite these advancements, significant challenges remain in implementing AI on a routine basis within clinical dental settings.

Diagnostic and Clinical Decision Support

AI's application in diagnostics represents its most established role in dentistry, with machine learning models—particularly convolutional neural networks (CNNs) and deep learning algorithms—being widely used for image analysis. These models can process and interpret radiographic images with remarkable accuracy, in some cases exceeding human clinicians' performance. This is especially valuable in identifying conditions like caries, periapical infections, and root fractures, where diagnostic errors are common due to variability in human interpretation. In endodontics, AI systems have been used to detect periapical lesions and assess complex root canal morphologies, enhancing the accuracy and efficiency of treatment planning. The ability of AI to analyze large amounts of radiographic data with speed and precision helps in reducing diagnostic errors and providing timely interventions, ultimately leading to improved patient outcomes.

AI's role in clinical decision-making extends beyond simple diagnostics, with predictive models now being used to assess risk factors and treatment options. For example, AI can evaluate factors influencing periodontal disease progression, supporting clinicians in selecting appropriate interventions based on each patient's unique risk profile. Furthermore, AI's capacity to integrate diverse data sources, including genetic, demographic, and behavioral data, holds promise for creating more personalized treatment plans. These advancements in AI-driven decision-making align with the principles of evidence-based dentistry, where decisions are guided by a blend of clinical expertise, patient preferences, and robust data.

Treatment Planning and Predictive Models

Beyond diagnostics, AI offers transformative potential in treatment planning and predictive modeling. AI algorithms, particularly deep learning models, can analyze large datasets to predict treatment outcomes, providing a data-driven foundation for decision-making processes that traditionally relied on clinician experience and judgment. In orthodontics, AI can help predict tooth movement and make recommendations for aligner adjustments, creating opportunities for more precise and individualized treatment plans that may enhance patient satisfaction. Similarly, in prosthodontics, AI can assist in designing dental implants by predicting bone integration success and identifying optimal implant positioning based on patient-specific anatomical data.

Moreover, AI's role in predictive modeling allows clinicians to anticipate potential complications. For instance, in restorative dentistry, predictive algorithms can assess the longevity of dental restorations and the likelihood of complications, aiding clinicians in selecting materials and techniques that maximize success rates. Such predictive insights can be particularly valuable in cases where patient-specific factors, like bite force or oral hygiene practices, influence treatment outcomes. By enabling clinicians to foresee challenges and tailor their approach accordingly, AI supports more effective and personalized dental care.

Economic and Operational Impacts

Economically, AI holds promise for reducing costs associated with diagnostic errors and unnecessary procedures. Improved diagnostic precision means fewer cases of misdiagnosis and, therefore, fewer redundant or ineffective interventions. Additionally, in radiology, AI systems that automate routine image analysis tasks can streamline workflows, freeing dental professionals to focus on complex patient care issues. This can potentially reduce labor costs and improve operational efficiency, making AI a valuable asset in high-volume settings, such as hospitals and dental schools.

However, the cost of developing, implementing, and maintaining AI systems can be a significant barrier, especially for smaller or independent practices. The investment in AI infrastructure, including software licenses, data storage, and ongoing maintenance, may limit access to these technologies in certain practice settings. Despite the high upfront costs, long-term cost-benefit analyses suggest that AI could yield financial savings by improving the quality of care and reducing the frequency of corrective treatments. However, more research is needed to evaluate the economic viability of AI in diverse dental settings and to develop strategies for making these tools more accessible to all practices.

Challenges and Limitations

The integration of AI into routine dental practice faces numerous challenges. Data privacy and security are significant concerns, as AI systems rely on large volumes of patient data to learn and improve. Ensuring that this data is handled responsibly and securely is crucial to maintaining patient trust. Compliance with data protection regulations, such as the Health Insurance Portability and Accountability Act (HIPAA) in the U.S. or the General Data Protection Regulation (GDPR) in Europe, adds layers of complexity to AI implementation.

Algorithm transparency and interpretability also pose challenges. Deep learning models, despite their accuracy, are often seen as "black boxes" because they lack interpretability, making it difficult for clinicians to understand the rationale behind AI-generated recommendations. This opaqueness raises ethical concerns about accountability, especially in situations where AI-driven recommendations lead to adverse outcomes. Efforts are underway to develop explainable AI models that allow clinicians to trace the decision-making pathways of AI algorithms, which could help bridge this gap in understanding and foster greater clinician trust in AI tools.

Another limitation is the generalizability of AI models. Many AI systems are trained on specific datasets, which may not represent the diversity of patient populations in different regions or demographic groups. An algorithm trained on data from one geographic area may underperform when applied in a different region with distinct epidemiological patterns. This lack of generalizability limits the effectiveness of AI tools in globally diverse patient populations and underscores the need for AI systems trained on comprehensive datasets that include diverse patient demographics.

Ethical and Regulatory Considerations

As AI technologies continue to advance, ethical and regulatory oversight becomes increasingly important. The potential for AI to influence clinical decisions raises questions about accountability and liability. In the event of an AI-driven misdiagnosis or a suboptimal treatment recommendation, it remains unclear who—if anyone—should be held responsible: the developer of the AI, the clinician using it, or the institution that implemented it. These ambiguities highlight the need for clear regulatory frameworks to govern the use of AI in healthcare.

Ethical considerations also extend to fairness and bias in AI algorithms. There is a risk that AI systems could perpetuate or even amplify existing biases if they are trained on datasets that lack diversity. For example, an AI model trained predominantly on data from a particular demographic group may not perform as accurately for patients from other groups, potentially leading to disparities in care. Addressing these issues requires a commitment to developing and training AI models on diverse datasets and implementing safeguards to prevent algorithmic bias.

In light of these ethical and regulatory challenges, there is a need for collaborative efforts between AI developers, dental professionals, regulatory bodies, and ethicists to establish guidelines and best practices for the responsible deployment of AI in dentistry. These collaborations could help ensure that AI is used ethically, safely, and equitably in clinical settings, ultimately benefiting both clinicians and patients.

CONCLUSION

To summarize, the studies reviewed provide compelling evidence of AI's transformative potential in dentistry. Across various applications—endodontics, caries detection, oral cancer diagnosis, and disease prediction—AI models have demonstrated high accuracy, sensitivity, and specificity, often outperforming traditional diagnostic methods. CNNs, in particular, have proven to be highly effective in analyzing dental images and identifying pathological conditions that are difficult to detect with the human eye. Moreover, the economic benefits of AI, as demonstrated by Schwendicke *et al*. (2022), further strengthen the case for AI's adoption in dental practice.

However, the successful integration of AI into clinical practice will depend on overcoming several challenges, including the need for larger and more diverse training datasets, the standardization of AI algorithms, and ongoing validation in real-world settings. As the field continues to evolve, future research should focus on developing multi-modal AI systems that can analyze data from multiple sources to provide more accurate and comprehensive diagnoses.AI is poised to play a pivotal role in shaping the future of dentistry. By augmenting human expertise with advanced computational tools, AI has the potential to improve patient outcomes, reduce healthcare costs, and revolutionize the way dental care is delivered.

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