

Artificial Intelligence and the Future of Dentistry: A Comprehensive Review

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ABSTRACT

Background: Artificial Intelligence (AI) has emerged as a transformative force in healthcare, particularly within dentistry. The integration of AI in dental diagnostics, treatment planning, imaging analysis, and patient management is rapidly advancing. These technologies promise to improve diagnostic accuracy, operational efficiency, and treatment outcomes.

Objective: This review aims to comprehensively evaluate the current applications of AI in dentistry, focusing on its impact on diagnostics, treatment protocols, clinical workflows, and patient care. The review also highlights future trends and challenges associated with AI adoption in dental practice.

Methods: A systematic review of peer-reviewed literature from 2018 to 2024 was performed using databases such as PubMed, Scopus, and Google Scholar. Keywords such as "artificial intelligence dentistry," "machine learning dental imaging," and "deep learning in dentistry" were used. Eligible studies included clinical trials, reviews, and meta-analyses focusing on AI-based applications in dental disciplines including orthodontics, prosthodontics, radiology, and oral oncology.

Results: AI technologies have demonstrated significant capabilities in detecting dental caries, periodontal diseases, orthodontic abnormalities, and oral cancers. Deep learning-based systems, such as Convolutional Neural Networks (CNNs), outperform traditional diagnostic methods in many

areas. Furthermore, AI has optimized dental workflows by automating image analysis, improving prosthetic design, and enhancing patient communication through chatbots and virtual platforms.

Conclusion: AI is revolutionizing dental care by improving diagnostic precision, streamlining treatment planning, and boosting patient engagement. Future developments should prioritize integration with robotics, bioengineering, and tele-dentistry to enhance accessibility and personalization of care, while addressing ethical and data security issues.

Keywords: Artificial Intelligence, Dentistry, Deep Learning, Dental Imaging, Digital Dentistry, Machine Learning, Orthodontics.

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Article History:

Received: 05-08-2025, Revised: 27-08-2025, Accepted: 24-09-2025

Access this article online	
Website: www.ijmrp.com	Quick Response code 
DOI: 10.21276/ijmrp.2025.11.5.001	

INTRODUCTION

Artificial Intelligence (AI) is poised to transform various sectors of healthcare, and dentistry is no exception. The development of AI technologies has accelerated over the past decade due to advances in computational power, the availability of large datasets, and the refinement of machine learning algorithms. In dentistry, AI applications now span multiple domains, ranging from diagnostic imaging and disease detection to treatment planning, prosthetic design, and patient management.

AI refers to the simulation of human intelligence processes by computer systems. These processes include learning (acquiring information and rules for using it), reasoning (using rules to reach approximate or definite conclusions), and self-correction.¹ Machine Learning (ML), a subset of AI, enables systems to learn from data patterns without explicit programming. Deep Learning (DL), a further extension of ML, uses artificial neural networks to mimic the human brain's decision-making abilities.²

In dental practice, AI technologies offer multiple advantages. First, they enhance diagnostic accuracy by minimizing human error and variability. AI-driven image analysis can detect subtle abnormalities in radiographs that may be missed by clinicians.³ Second, AI improves efficiency by automating time-consuming processes such as cephalometric analysis in orthodontics or crown design in prosthodontics.⁴ Third, AI personalizes patient care by utilizing predictive analytics to recommend tailored treatments based on individual patient profiles.⁵

Several studies have validated the performance of AI-based systems in dental diagnostics. For example, AI models have achieved accuracy rates exceeding 90% in detecting dental caries and periodontal diseases from radiographs.⁶ Moreover, AI has significantly contributed to oral oncology, where deep learning algorithms are capable of identifying malignant lesions with high sensitivity and specificity.⁷

Despite its potential, AI adoption in dentistry also faces certain limitations. These include concerns related to data privacy, algorithm transparency, and the need for rigorous clinical validation. Furthermore, the cost of implementing AI systems can be prohibitive for some dental practices, especially in low-resource settings.⁸

This review aims to provide a comprehensive analysis of the current status, applications, and future perspectives of AI in dentistry. By critically evaluating the available literature, we aim to inform clinicians, researchers, and policymakers about the opportunities and challenges associated with AI-driven dental care.

METHODS

Literature Search Strategy

A systematic search of relevant literature was conducted between January 2018 and May 2024 using the following databases:

- PubMed
- Scopus
- Google Scholar

The search strategy included keywords such as:

- "Artificial Intelligence in Dentistry"
- "Machine Learning Dental Imaging"
- "Deep Learning in Oral Health"
- "AI in Orthodontics"
- "Dental Prosthetics AI"

Boolean operators such as "AND" and "OR" were used to refine the search results.

Inclusion Criteria

- Studies published in English.
- Peer-reviewed articles, including original research, reviews, and meta-analyses.
- Articles focusing on the application of AI in dental diagnostics, treatment planning, imaging, orthodontics, prosthodontics, and oral oncology.

Exclusion Criteria

- Non-English publications.
- Conference abstracts without full text.
- Studies not directly related to dentistry or AI applications.

Data Extraction and Synthesis

Relevant data were extracted from the selected studies, including:

- Type of AI technology used (e.g., ML, DL, CNNs).
- Dental specialty involved.
- Diagnostic accuracy and clinical outcomes.
- Benefits, limitations, and future recommendations.

The extracted data were categorized and synthesized into thematic sections for qualitative analysis.

RESULTS

1. AI in Diagnostic Imaging

Diagnostic imaging is among the most significant areas where AI has demonstrated high impact. Deep learning models, particularly Convolutional Neural Networks (CNNs), have been employed for radiographic analysis to detect:

- Dental caries
- Periapical lesions

- Periodontal diseases
- Jawbone pathologies

Lee et al.⁹ demonstrated that a CNN-based AI system achieved 92.5% sensitivity and 89.3% specificity in detecting dental caries from bitewing radiographs. Another study by Mertens et al.¹⁰ revealed that AI algorithms could detect periodontal bone loss with comparable accuracy to expert clinicians.

2. AI in Orthodontics

AI has transformed orthodontic diagnostics and treatment planning. Automated cephalometric landmark detection using deep learning significantly reduces human error and improves treatment accuracy. Hwang et al.¹¹ reported that a DL algorithm achieved a mean landmark error of less than 2 mm, meeting clinical standards. AI also enables virtual orthodontic treatment simulations, allowing orthodontists to predict tooth movements and optimize treatment outcomes.

3. AI in Prosthodontics and Restorative Dentistry

AI-powered software systems facilitate crown design, occlusal surface analysis, and digital impressions. Revilla-León et al.¹² conducted a scoping review and concluded that AI improves the precision of prosthetic designs while reducing laboratory processing time. Furthermore, AI-driven CAD/CAM systems allow for rapid creation of dental prostheses with minimal human intervention.

4. AI in Oral Oncology

AI applications in oral oncology have shown significant promise in early cancer detection. Kann et al.¹³ developed a deep learning algorithm that accurately identified oral squamous cell carcinoma in histopathological slides, achieving an AUC of 0.94. AI systems can also assist in risk stratification and treatment planning for oral cancer patients.

5. AI in Patient Management

AI-based systems have been integrated into dental practice management software to optimize appointment scheduling, patient communication, and billing. Chatbots powered by Natural Language Processing (NLP) provide 24/7 patient support, answer FAQs, and guide patients through treatment processes.¹⁴ Predictive analytics models assess patient records to forecast treatment success rates, enabling dentists to personalize treatment protocols.

DISCUSSION

The findings of this review indicate that AI is revolutionizing various aspects of dental practice, particularly in diagnostics, treatment planning, and patient management.

Diagnostic Accuracy and Efficiency

AI has significantly enhanced diagnostic capabilities by reducing human error and improving reproducibility. Automated systems analyze thousands of radiographic images rapidly and consistently, which is especially valuable in high-volume dental clinics. Deep learning algorithms outperform traditional methods in detecting dental diseases, including caries, periodontal conditions, and oral malignancies. However, most AI applications require large, high-quality datasets for effective training and validation.

Limited datasets can result in algorithmic biases, potentially compromising diagnostic accuracy in certain populations.¹²

Personalized Treatment Planning

AI enables the development of personalized treatment plans through predictive analytics. By analyzing patient-specific data such as age, medical history, and oral health status, AI can recommend customized treatment approaches. In orthodontics, virtual treatment simulations based on AI predictions have improved treatment planning accuracy and patient satisfaction.

Digital Workflows and Automation

AI-powered CAD/CAM systems have streamlined digital workflows in restorative dentistry and prosthodontics. These systems reduce the need for manual impressions and allow for same-day restorations, increasing clinic productivity. Furthermore, AI tools in orthodontics automate cephalometric analyses, saving time and minimizing errors.

Challenges and Ethical Considerations

Despite its potential, several challenges hinder the widespread adoption of AI in dentistry:

1. **Data Privacy:** Ensuring the confidentiality of patient data used to train AI models.
2. **Regulatory Compliance:** Lack of standardized guidelines for AI implementation in dental care.
3. **Cost:** High initial investment and maintenance expenses for AI systems.
4. **Technological Literacy:** Dental practitioners may require additional training to effectively use AI tools.

Furthermore, AI algorithms often operate as "black boxes," making it difficult for clinicians to understand how decisions are made, raising concerns about accountability and transparency.¹⁴

Future Directions

The future of AI in dentistry is promising, with several emerging trends:

- Integration with robotics for dental surgeries.
- AI-driven tele-dentistry platforms to expand care access.
- Multi-modal AI systems combining imaging, genetic, and clinical data for holistic diagnostics.
- Explainable AI models to enhance clinical trust.

Collaborations among AI developers, dental practitioners, and regulatory bodies are crucial for advancing safe and effective AI solutions.

CONCLUSION

AI is rapidly transforming the field of dentistry, offering substantial benefits in diagnostics, treatment planning, and patient care. Deep learning models demonstrate superior performance in detecting oral diseases, while AI-powered digital workflows increase clinical efficiency and precision. Despite challenges related to cost, data privacy, and ethical considerations, the future integration of AI with robotics and tele-dentistry holds the potential to revolutionize oral healthcare delivery globally. A collaborative, multidisciplinary approach is necessary to ensure that AI systems are safe, effective, and equitable.

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Source of Support: Nil.

Conflict of Interest: None Declared.

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Cite this article as: Bader A Hassosah, Abdullah Khalid Alghamdi, Tariq Mohammed Alshehri, Abdullah Rabee Alghtany. Artificial Intelligence and the Future of Dentistry: A Comprehensive Review. *Int J Med Res Prof.* 2025 Sept; 11(5): 1-3. DOI:10.21276/ijmrp.2025.11.5.001