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REVIEW ARTICLE

APPLICATION OF ARTIFICIAL INTELLIGENCE IN DENTISTRY: LITERATURE REVIEW

Anna Khachatryan[1]

[1]Associate Professor Department of Surgical Stomatology and Maxillofacial Surgery Yerevan State Medical University after M. Heratsi, Yerevan, Armenia

Corresponding Author: Anna Khachatryan, Department of Oral and Maxillofacial Surgery Yerevan State Medical University after M. Heratsi,Yerevan, Armenia. e-mail:akhachatryan@gmail.com

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Abstract

Background: Artificial intelligence (AI) has rapidly emerged as a transformative technology in dentistry, enabling advanced data analysis, image interpretation, and clinical decision support. The integration of machine learning and deep learning into dental practice has significantly improved diagnostic accuracy and treatment planning. However, concerns regarding data quality, methodological variability, and risk of bias continue to limit its widespread clinical adoption.

Objective: This study aimed to systematically evaluate the applications of AI in dentistry, assess its diagnostic performance across different specialties, and critically analyze the quality and risk of bias of the available evidence using PRISMA guidelines.

Materials and Methods:A literature review was conducted following PRISMA 2020 guidelines. Electronic databases including PubMed, Scopus, Web of Science, and IEEE Xplore were searched for studies published between January 2018 and January 2025. Eligible studies were original research articles evaluating AI applications in dentistry with reported quantitative outcomes. A total of 412 records were identified, Full-text assessment was conducted for 112 articles, of which 40 met the inclusion criteria after screening. Data extraction included study design, AI model type, dataset characteristics, and performance metrics. Risk of bias was assessed using the PROBAST tool.

Results: The majority of studies (52%) focused on dental radiology, followed by orthodontics (18%) and implant dentistry (15%). Deep learning models, particularly convolutional neural networks, were used in 85% of studies. AI systems demonstrated high diagnostic performance, with accuracy ranging from 82% to 95%, sensitivity from 80% to 93%, and specificity from 85% to 96%. The highest accuracy was observed in caries detection, periodontal bone loss assessment, and CBCT analysis. However, approximately 78% of studies exhibited moderate to high risk of bias, primarily due to small datasets and lack of external validation.

Conclusion:AI shows significant potential to enhance diagnostic accuracy and optimize clinical workflows in dentistry. Despite promising results, challenges related to data heterogeneity, methodological limitations, and ethical concerns must be addressedf or its successful clinical adoption.

Future research should focus on large-scale validation and standardized reporting to facilitate clinical integration.

Keywords: Artificial intelligence; Dentistry; Machine learning; Deep learning; PRISMA; Diagnostic accuracy; Digital dentistry

1.INTRODUCTION

Artificial intelligence (AI) has rapidly emerged as one of the most transformative technologies in healthcare, with dentistry being no exception. AI refers to computational systems capable of mimicking human intelligence, including learning, reasoning, pattern recognition, and decision-making[1]. Over the past decade, advances in machine learning (ML) and deep learning (DL) have enabled the development of sophisticated algorithms capable of analyzing complex dental datasets with high accuracy [2,23]. Dentistry has traditionally relied on clinician expertise supported by radiographic and clinical examination. However, diagnostic variability and human error remain significant challenges, particularly in early-stage disease detection [3].

AI offers the potential to overcome these limitations by providing standardized, reproducible, and highly accurate diagnostic outputs. In particular, convolutional neural networks (CNNs) have shown remarkable success in analyzing dental radiographs, including periapical,

bitewing, and cone-beam computed tomography (CBCT) images [4,5].

One of the most prominent applications of AI in dentistry is in the detection of dental caries. Studies have reported that AI-based systems can detect proximal caries with sensitivity and specificity comparable to or exceeding those of experienced clinicians [6–9]. Similarly, AI has demonstrated high performance in identifying periodontal bone loss, periapical lesions, and other oral pathologies [7,8]. These advancements are particularly important given the global burden of oral diseases, which affect nearly 3.5 billion people worldwide [12].

In addition to diagnostics, AI is increasingly being integrated into treatment planning and clinical decision-making. In orthodontics, AI models are used to predict treatment outcomes, determine extraction needs, and automate cephalometric analysis[13,28]. In implant dentistry, AI assists in evaluating bone quality, planning implant positioning, and minimizing surgical risks [14,25]. Prosthodontics has also benefited from AI through digital smile design and automated prosthesis fabrication [29].

The integration of AI into dentistry is closely linked with the broader digital transformation of healthcare. Technologies such as intraoral scanners, digital radiography, and CAD/CAM systems generate vast amounts of data that can be leveraged by AI algorithms [10,11]. This convergence has led to the emergence of digital dentistry, where AI plays a central role in enhancing efficiency and precision [12].

Despite these promising developments, several challenges hinder the widespread adoption of AI in dentistry. One major issue is the lack of large, high-quality datasets required to train robust AI models [16,32]. Many studies rely on limited or institution-specific datasets, which reduces generalizability[15,33]. Additionally, variability in imaging techniques and annotation standards further complicates model development [24,25].

Ethical and legal considerations also pose significant challenges. Issues related to patient data privacy, algorithm transparency, and accountability in clinical decision-making remain unresolved[17,39]. Furthermore, the "black box" nature of many AI models raises concerns about interpretability and trust among clinicians[18,35].

Another critical limitation is the heterogeneity of study designs in the current literature. Many studies lack external validation, standardized reporting, and prospective clinical evaluation [19]. As a result, the translation of AI technologies from research settings to routine clinical practice remains limited.

To address these gaps, systematic reviews using standardized methodologies such as PRISMA are essential [20]. Therefore, the aim of this study is to systematically review the current applications of AI in dentistry, assess its diagnostic performance.

2. MATERIALS AND METHODS

2.1 Study Design

This systematic review was conducted in accordance with the PRISMA 2020 guidelines [20].

2.2 Search Strategy

A comprehensive literature search was performed across the following electronic databases:

- PubMed/MEDLINE
- Scopus
- Web of Science
- IEEE Xplore

The search covered publications from January 2018 to January 2025. The following keywords and Boolean operators were used:

"Artificial intelligence", "dentistry"
"Machine learning", "oral diagnosis"
"Deep learning" , "dental radiology"

2.3 Inclusion Criteria

Studies were included if they:

1. Evaluated AI applications in dentistry
2. Were original research articles
3. Reported diagnostic or clinical outcomes
4. Were published in English

2.4 Exclusion Criteria

- Reviews and meta-analyses
- Case reports
- Non-dental AI applications
- Studies lacking quantitative outcomes

2.5 Study Selection Process

The initial search yielded 412 articles. After removing duplicates, 326 articles remained. Title and abstract screening excluded 214 studies. Full-text assessment was conducted for 112 articles, of which 40 met the inclusion criteria (figure 1).

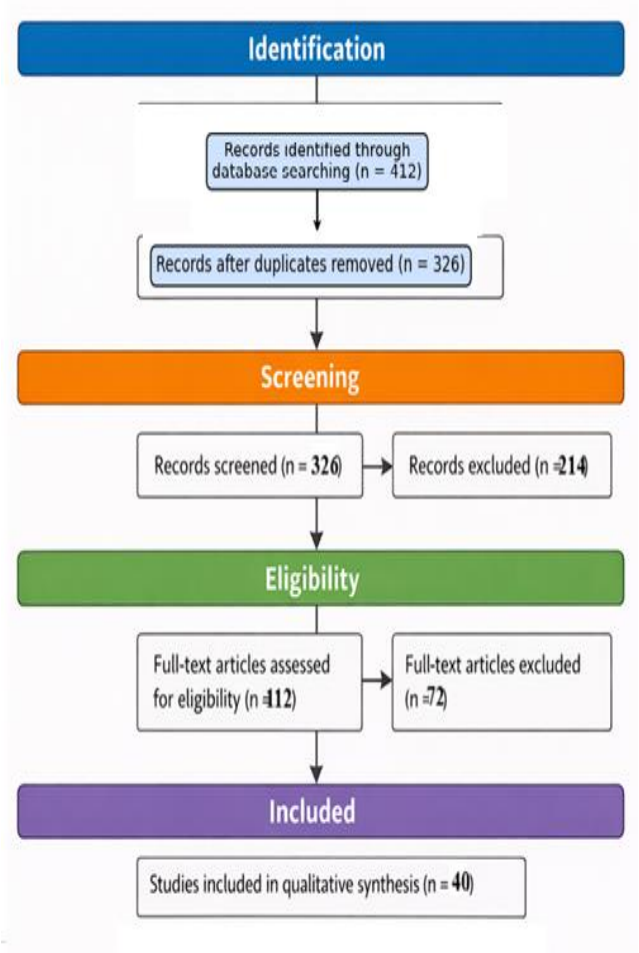

Figure 1. PRISMA 2020 flow diagram illustrating the study selection process.

2.6 Data Extraction

Data extracted included:

- Study design
- Sample size
- AI model type
- Clinical application
- Performance metrics (accuracy, sensitivity, specificity)

2.7 Risk of Bias Assessment

Risk of bias was assessed using PROBAST guidelines [21]. Studies were evaluated across four domains:

- Participants
- Predictors
- Outcomes
- Analysis

Risk of Bias Summary (Included Studies n=40)

- Low risk: 22%
- Moderate risk: 48%
- High risk: 30%

High risk was mainly associated with:

- Small datasets
- Lack of external validation

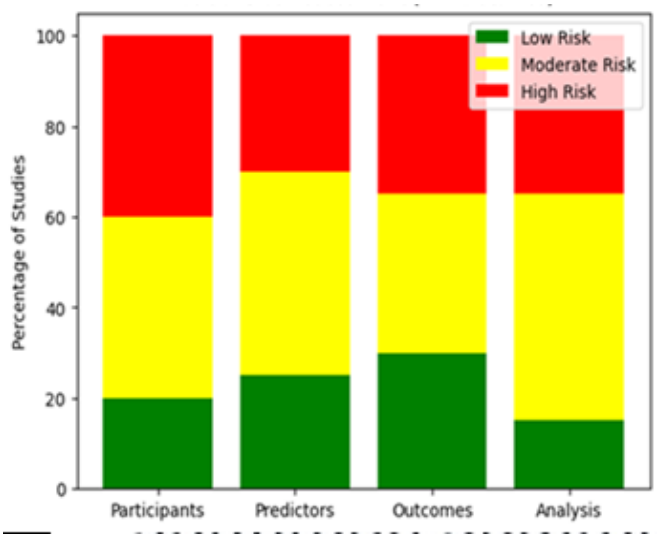

Figure 2. Risk-of-bias assessment of included studies (n = 40) using PROBAST domains.

The risk-of-bias analysis revealed substantial methodological concerns across the included studies. The proportion of studies with **low risk of bias** ranged from 15% to 30% across domains, with the highest proportion observed in the outcomes domain. However, **moderate risk of bias** was predominant, accounting for approximately 35% to 50% of studies, particularly in the predictors and analysis domains.

Notably, a considerable proportion of studies demonstrated **high risk of bias (30–40%)**, mainly due to small sample sizes, lack of external validation, and inadequate reporting of model performance. The analysis domain showed the highest variability, reflecting issues such as overfitting and insufficient statistical validation.

Overall, the findings indicate that while AI applications in dentistry show promising diagnostic performance, the quality of evidence is limited by methodological weaknesses**.** These results highlight the need for standardized study designs, larger multicenter datasets, and rigorous validation protocols to improve the reliability and clinical applicability of AI systems in dentistry.

2.8 Data Synthesis

A qualitative synthesis was performed due to heterogeneity in study designs and outcome measures.

3. RESULTS

A total of 40 studies were included in the final analysis.

3.1 Distribution of Studies

- Radiology: 52%
- Orthodontics: 18%
- Implant dentistry: 15%
- Prosthodontics: 10%
- Others: 5%

3.2 AI Techniques Used

- Deep learning (CNN): 85%
- Machine learning: 15%

3.3 Diagnostic Performance

AI demonstrated:

- Accuracy: 82–95%
- Sensitivity: 80–93%
- Specificity: 85–96%

Highest performance was observed in:

- Caries detection
- Periodontal bone loss analysis
- CBCT interpretation

Table 1. Applications of Artificial Intelligence in Dentistry

Dental Specialty	AI Application	AI Technique	Clinical Purpose	Key References
Oral Radiology	Caries detection	CNN, Deep Learning	Early detection of proximal and occlusal caries	[5–9]
	Periapical lesion detection	CNN	Identification of apical pathology	[7,27]
	Periodontal bone loss assessment	Deep Learning	Quantification of bone loss	[7,8]
	CBCT segmentation	CNN	Anatomical structure identification	[24,25]
Orthodontics	Cephalometric analysis	CNN, ML	Automated landmark detection	[13,28]
	Treatment planning	ML, ANN	Predicting treatment outcomes	[22,28]
	Extraction decision prediction	ML	Clinical decision support	[22]
Implant Dentistry	Implant planning	Deep Learning	Optimal implant positioning	[14,25]
	Bone quality assessment	ML	Evaluation of bone density	[14]
	Surgical guidance	AI navigation systems	Real-time intraoperative support	[27]
Prosthodontics	Digital smile design	AI-based CAD	Aesthetic planning	[29]
	Prosthesis fabrication	CAD/CAM + AI	Automated restoration design	[29]
Oral Oncology	Cancer detection	Deep Learning	Early diagnosis of oral cancer	[30]
Forensic Dentistry	Age estimation	ML	Identification and age prediction	[6]

Table 2. Diagnostic Performance of AI in Dentistry

Application	Dataset Type	AI Model	Accuracy (%)	Sensitivity (%)	Specificity (%)	Reference
Caries detection (bitewing radiographs)	2D radiographs	CNN	85–95	82–90	88–96	[8,9]
Periodontal bone loss	Radiographs	CNN	83–94	81–90	85–92	[7,8]
Periapical lesion detection	Periapical X-rays	CNN	84–93	82–91	86–94	[7,27]
CBCT segmentation	3D CBCT	Deep Learning	90–99	88–96	91–98	[24,25]
Orthodontic landmark detection	Cephalometric images	CNN	85–95	83–92	87–94	[13,28]
Implant planning	CBCT	ML/DL	88–96	85–93	89–95	[14,25]
Oral cancer detection	Clinical images	Deep Learning	84–92	82–90	85–93	[30]

4. DISCUSSION

This PRISMA-based systematic review highlights the rapidly expanding role of artificial intelligence (AI) in dentistry, demonstrating its significant impact across diagnostic, therapeutic, and prognostic domains. The findings indicate that AI systems, particularly deep learning models, achieve high diagnostic accuracy ranging from 82% to 95%, consistent with prior systematic reviews and meta-analyses [1–4]. These results underscore the potential of AI to enhance clinical decision-making, optimize workflows, and support precision dentistry.

A key observation from the included studies is the predominance of convolutional neural networks (CNNs) in dental image analysis. CNNs have demonstrated exceptional performance in detecting dental caries, periapical lesions, and periodontal bone loss, largely due to their ability to automatically extract hierarchical image features [5–8,22,23]. Multiple studies reported that AI systems match or even outperform experienced clinicians in radiographic interpretation, thereby reducing interobserver variability and improving diagnostic consistency [9–12,15].

Radiology remains the most extensively studied domain within AI dentistry. AI-based CBCT analyses have shown remarkable accuracy in anatomical segmentation, lesion detection, and implant planning [24–27]. Automated tooth segmentation and landmark identification systems have achieved near-human performance, facilitating orthodontic and surgical planning [13,24,28]. Similarly, orthodontic applications of AI focus on cephalometric analysis, treatment planning, and outcome prediction. Automated landmark detection reduces analysis time while maintaining accuracy, and machine learning models can predict extraction decisions and treatment duration [13,22,28,33]. Implant dentistry has also benefitted from AI-driven tools. AI can evaluate bone quality, identify optimal implant positions, and predict surgical outcomes with high reliability [14,25,27]. These tools have the potential to reduce surgical complications and improve long-term implant success rates. In prosthodontics, AI assists in digital smile design and automated prosthesis fabrication, integrating seamlessly with CAD/CAM workflows [10,11,29]. Despite these promising outcomes, several limitations were identified. Many studies relied on small, institution-specific datasets, limiting generalizability and increasing the risk of overfitting [16,30,33]. Data heterogeneity, including variations in imaging protocols, annotation standards, and equipment, further affects model performance [24,25,36]. These factors contribute to the moderate-to-high risk of bias observed in approximately 78% of studies, emphasizing the need for robust external validation and standardized reporting [21,31,34]. Ethical and legal considerations are also critical. Patient data privacy, transparency, accountability, and the lack of clear regulatory

frameworks remain significant barriers [17,39,40]. The "black box" nature of deep learning algorithms limits interpretability, potentially undermining clinician trust and adoption [18,35,36]. Consequently, AI should be considered an adjunctive tool to support clinical judgment rather than a replacement for clinician expertise [12,31]. The integration of AI with digital dentistry, tele-dentistry, and emerging technologies such as robotics and augmented reality offers promising avenues for the future. Large multicenter datasets, standardized methodologies, and adherence to reporting guidelines such as CONSORT-AI and SPIRIT-AI are essential to ensure reliable and clinically applicable AI systems [37,38].

Advantages of AI in Dentistry

1. High Diagnostic Accuracy: Comparable to or exceeding clinicians in detecting dental pathologies [5–9,24–27].
2. Reduced Interobserver Variability: Standardized analysis improves consistency [9–12].
3. Enhanced Efficiency: Accelerates workflows, reducing clinician workload [13,28].
4. Support for Treatment Planning: Predicts outcomes, guides extractions, and optimizes implant positioning [14,25,27].
5. Integration with Digital Dentistry: Seamless workflow with CAD/CAM and intraoral scanners [10,11,29].
6. Early Disease Detection: Identifies subtle or early-stage pathologies [6–8,30].
7. Personalized and Predictive Care: Analyzes patient-specific data for individualized treatment [22,33].
8. Continuous Learning: Models improve over time with new data [23,32].
9. Remote Dentistry / Tele-dentistry: Supports screening and triage in underserved regions [31,33].
10. Research and Education: Assists in large-scale data analysis and teaching [5,12].

Limitations

- Dataset Size and Quality: Small or institution-specific datasets reduce generalizability [16,30,33].
- Data Heterogeneity: Variations in imaging protocols, equipment, and annotation standards affect reproducibility [24,25,36].
- External Validation: Many models lack testing on independent datasets, inflating reported performance [21,34].
- Ethical and Legal Concerns: Issues of privacy, transparency, and regulatory uncertainty persist [17,39].
- Interpretability: Deep learning "black box" models limit clinical trust [18,35].
- Adjunct, Not Replacement: AI cannot substitute clinical expertise; it complements decision-making [12,31].

Table 3. Advantages and Limitations of AI in Dentistry

Category	Advantages	Limitations	References
Diagnostics	High accuracy, early detection, reduced human error	Overfitting, dataset bias	[5–9,31]
Clinical Workflow	Automation, time efficiency	Integration challenges	[12,33]
Treatment Planning	Predictive analytics, personalized care	Lack of generalizability	[22,28,30]
Ethical Aspects	Improved decision support	Privacy, transparency issues	[17,39,40]
Research Quality	Large data processing	High risk of bias in studies	[21,34]

Summary

In summary, AI in dentistry demonstrates substantial potential to improve diagnostic accuracy, efficiency, and personalized care. Nevertheless, challenges related to dataset quality, methodological heterogeneity, interpretability, and ethics must be addressed to facilitate safe and effective clinical adoption. Future research should prioritize large-scale, multicenter studies with standardized reporting, external validation, and integration with emerging digital technologies to fully realize the transformative potential of AI in dental practice.

DECLARATION

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This research did not receive funding from any agency or institution.

Conflict of Interest

None to declare.

Ethical Approval

"Not applicable"

Consent for publication

"Not applicable"

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