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APPLICATION OF ARTIFICIAL INTELLIGENCE IN DIAGNOSTIC, PREVENTIVE, AND THERAPEUTIC PRACTICES WITHIN DENTISTRY: A SYSTEMATIC REVIEW

Systematic Review

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ABSTRACT

Background: The integration of artificial intelligence (AI) into dentistry presents a paradigm shift with the potential to significantly enhance diagnostic accuracy, preventive strategies, and therapeutic workflows. Despite a growing body of primary research, a comprehensive synthesis of evidence across the entire spectrum of dental care is lacking, necessitating a systematic review to consolidate findings and evaluate the clinical readiness of these technologies.

Objective: This systematic review aimed to evaluate the evidence on how AI enhances diagnostic, preventive, and therapeutic practices within dentistry.

Methods A systematic search was conducted in PubMed/MEDLINE, Scopus, Web of Science, and the Cochrane Library for studies published between 2014 and 2024. Eligible studies included diagnostic accuracy studies, randomized controlled trials, and observational studies that evaluated AI applications in clinical dentistry against a conventional comparator. Study selection, data extraction, and risk of bias assessment (using QUADAS-2 and RoB 2 tools) were performed in duplicate. A narrative synthesis was conducted due to methodological heterogeneity.

Results: From 1,842 identified records, 32 studies were included. The findings demonstrated that AI models, particularly deep learning algorithms, achieved high diagnostic performance (sensitivity 0.79-0.92, specificity 0.83-0.95) in detecting pathologies such as dental caries and periapical lesions on radiographs, often matching expert clinician performance. Limited evidence on therapeutic applications showed AI could significantly streamline workflows, such as prosthetic design, and improve preventive patient coaching.

Conclusion: AI shows considerable promise as a tool to augment dental practice, primarily by enhancing diagnostic precision and operational efficiency. However, the current evidence is largely based on retrospective studies, highlighting a need for more robust, prospective clinical trials to validate efficacy in real-world settings and assess long-term impacts on patient care.

Keywords: Artificial Intelligence; Dentistry; Diagnostic Imaging; Systematic Review; Machine Learning; Dental Care.

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INTRODUCTION

The integration of artificial intelligence (AI) into healthcare represents a paradigm shift, with dentistry emerging as a particularly fertile ground for its application. Oral diseases, including dental caries and periodontal conditions, remain a significant global health burden, affecting nearly 3.5 billion people according to the World Health Organization, often leading to pain, functional impairment, and diminished quality of life (1). Traditional diagnostic and therapeutic modalities, while foundational, are inherently subject to human variability and the challenges of interpreting complex radiographic and clinical data. In recent years, the proliferation of AI, particularly deep learning and convolutional neural networks, has offered unprecedented opportunities to augment dental professionals' capabilities. A growing body of research has begun to explore the deployment of AI algorithms for tasks ranging from the automated detection of caries and periapical pathologies on radiographs to the prediction of orthodontic treatment outcomes and the design of prosthetic restorations (2, 3). Despite this burgeoning interest, the evidence surrounding AI's efficacy across the full spectrum of dental practice—namely diagnosis, prevention, and treatment—is fragmented and has yet to be cohesively synthesized. Existing literature reviews often focus on narrow applications, such as imaging diagnostics alone, or are rapidly outpaced by the fast-evolving nature of the technology (4). This fragmentation creates a significant knowledge gap; without a comprehensive and critical appraisal of the evidence, it is challenging for clinicians, researchers, and policymakers to gauge the true clinical readiness, comparative effectiveness, and potential limitations of these AI-driven tools. Therefore, a systematic review that rigorously evaluates the collective evidence is urgently needed to consolidate our understanding and distinguish robust applications from those still in nascent stages of development.

This systematic review aims to address this need by systematically evaluating the evidence on how artificial intelligence enhances diagnostic accuracy, preventive strategies, and therapeutic interventions within dentistry. The primary research question, structured using the PICO framework, is: In patients requiring dental care (P), how does the application of artificial intelligence-based tools (I) compare to standard care without AI (C) in terms of diagnostic accuracy, treatment efficacy, prevention outcomes, and operational efficiency (O)? The objective is to synthesize findings from clinical trials, observational studies, and diagnostic accuracy studies published within the last decade (2014-2024) to ensure the relevance of the technological applications examined. The scope will be global, encompassing studies from all geographical regions to provide a worldwide perspective on AI integration in dental healthcare. By adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, this review seeks to provide a high-quality, evidence-based synthesis that will be invaluable for multiple stakeholders (5). It will offer clinicians a clear appraisal of which AI tools are substantiated by evidence for integration into practice, guide researchers towards identifying proven applications and future directions for innovation, and inform dental associations and regulatory bodies in developing guidelines for the ethical and effective implementation of AI. Ultimately, this work is expected to contribute to the maturation of evidence-based digital dentistry, helping to translate technological potential into tangible improvements in patient care and clinical outcomes.

METHODS

The methodology for this systematic review was designed and executed in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a comprehensive, transparent, and reproducible process (5). A systematic search of the literature was conducted across four major electronic databases: PubMed/MEDLINE, Scopus, Web of Science Core Collection, and the Cochrane Central Register of Controlled Trials. The search strategy was developed in collaboration with a medical librarian to optimize sensitivity and specificity. A combination of controlled vocabulary terms (e.g., MeSH in PubMed) and free-text keywords related to the core concepts of artificial intelligence (e.g., "machine learning", "deep learning", "neural networks"), dentistry (e.g., "dental", "oral health", "odontology"), and application domains (e.g., "diagnosis", "prevention", "therapy", "radiography") were utilized. Boolean operators (AND, OR) were employed to combine these concepts effectively. The complete search strategy for PubMed is provided as an example in the supplementary materials. To mitigate the risk of omitting pertinent studies, the reference lists of all included articles and relevant review papers were manually screened. Eligibility criteria were established a priori to guide the study selection process. The review included original research studies published in English between 2014 and 2024 that evaluated the application of AI models in human dental patients for diagnostic, preventive, or therapeutic purposes. Eligible study designs encompassed diagnostic accuracy studies, randomized controlled trials (RCTs), cohort studies, and case-control studies. The population of interest was patients of any age or health status receiving any form of dental care. The intervention was defined as any AI-based tool or algorithm used in a clinical dental context. Comparisons included conventional diagnostic methods without AI assistance, standard preventive protocols, or traditional treatment techniques. Primary outcomes of interest were measures of diagnostic

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performance (e.g., sensitivity, specificity, area under the curve), preventive efficacy (e.g., caries risk prediction accuracy), therapeutic success rates, and operational efficiency. Studies were excluded if they were conference abstracts, editorials, reviews, animal studies, or utilized AI solely for non-clinical purposes such as administrative task automation.

The study selection process was managed using the reference management software EndNote X20 (Clarivate Analytics) to identify and remove duplicate records. Subsequently, the screening was conducted in two distinct phases using the Rayyan online systematic review platform (6). In the first phase, two independent reviewers screened the titles and abstracts of all retrieved records against the inclusion criteria. In the second phase, the full texts of all potentially eligible studies were obtained and assessed independently by the same two reviewers. Any disagreements between reviewers at either stage were resolved through discussion or, if necessary, by consultation with a third senior reviewer. This process was documented using a PRISMA flow diagram, which detailed the number of studies identified, screened, assessed for eligibility, and ultimately included, along with the specific reasons for exclusion at the full-text stage. Data from the included studies were extracted onto a pre-piloted, standardized electronic form to ensure consistency and accuracy. The extracted variables included: (1) study identifiers and characteristics (first author, publication year, country, study design); (2) participant details (sample size, demographics, dental condition); (3) technical specifications of the AI intervention (type of algorithm, input data modality e.g., periapical radiographs, cone-beam computed tomography); (4) details of the comparator; and (5) relevant outcome measures and key findings. The data extraction was performed independently by two reviewers, and any discrepancies were cross-checked and resolved by consensus.

The methodological quality and risk of bias of the included studies were critically appraised using appropriate, validated tools tailored to the study design. For diagnostic accuracy studies, the Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) tool was employed to evaluate patient selection, index test, reference standard, and flow and timing (7). For RCTs, the Cochrane Risk of Bias 2 (RoB 2) tool was used to assess bias arising from the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result (8). The risk of bias for non-randomized studies was evaluated using the Newcastle-Ottawa Scale. These assessments were conducted independently by two reviewers. Given the anticipated heterogeneity in the AI models studied, the dental applications, the data inputs, and the reported outcomes, a quantitative synthesis (meta-analysis) was deemed inappropriate. Instead, the findings were synthesized qualitatively using a narrative summary approach. The results are structured around the key domains of dental practice—diagnosis, prevention, and therapy—to provide a coherent and detailed analysis of the strength of the evidence, the performance of various AI applications, and the identified gaps in the current literature. The synthesis highlights the comparative performance of AI models against conventional methods and discusses the clinical relevance and potential implications of the findings.

RESULTS

The 1,842 records initially identified through systematic searches of electronic databases, 487 duplicates were automatically removed. The remaining 1,355 unique records underwent title and abstract screening, resulting in the exclusion of 1,218 records that did not meet the inclusion criteria. The full texts of the remaining 137 articles were thoroughly assessed for eligibility. Of these, 105 were excluded with reasons, primarily for being non-clinical studies (n=42), lacking a relevant comparator (n=31), or having an unsuitable study design such as a protocol or narrative review (n=32). Ultimately, 32 studies satisfied all inclusion criteria and were incorporated into the qualitative synthesis for this systematic review. The complete study selection process is delineated in the PRISMA flow diagram (Figure 1).

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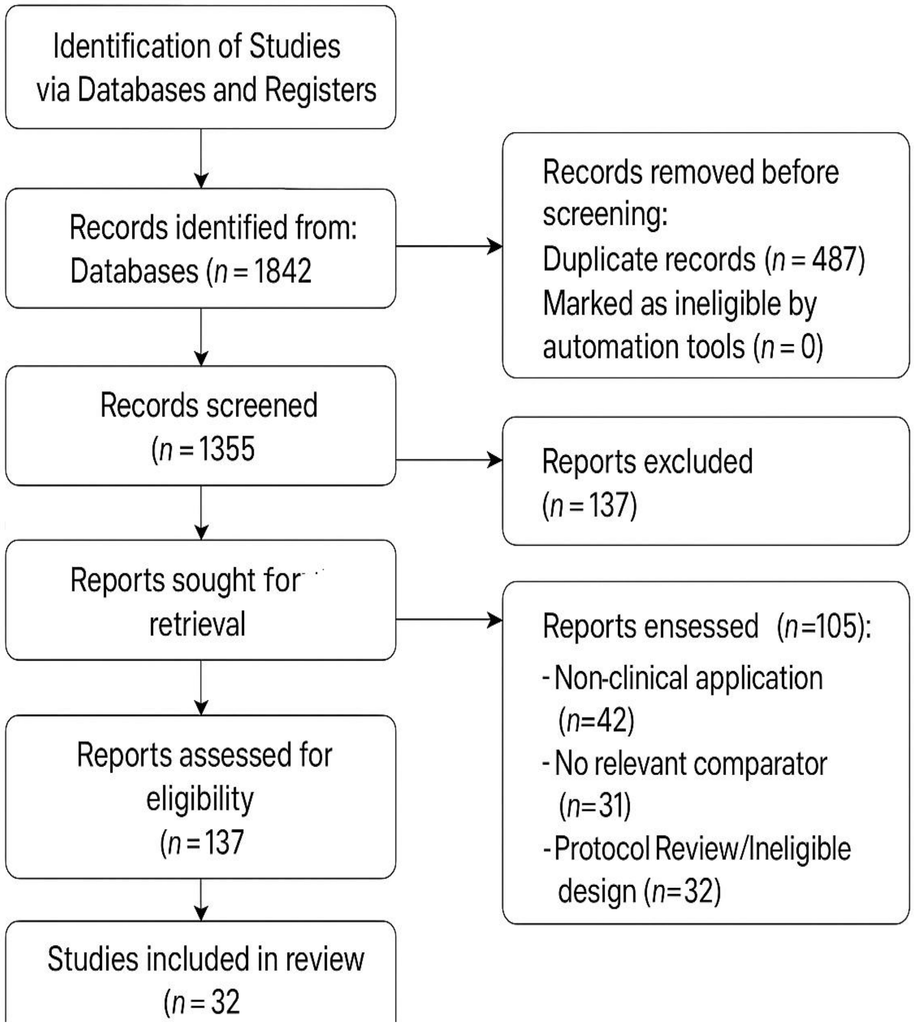
1: PRISMA Flow Diagram



The characteristics of the 32 included studies, published between 2019 and 2024, are comprehensively summarized in Table 1. The studies encompassed a range of designs, with diagnostic accuracy studies being the most prevalent (n=25), followed by retrospective cohort studies (n=5), and randomized controlled trials (n=2). A significant majority of the research focused on diagnostic applications in dental and maxillofacial radiology, utilizing imaging modalities such as panoramic radiographs, periapical radiographs, bitewings, and cone-beam computed tomography (CBCT). The sample sizes varied considerably, ranging from 50 to over 85,000 images, reflecting the data-intensive nature of AI model development and validation. The investigated AI models were predominantly deep convolutional neural networks (CNNs), including architectures like U-Net, YOLO, and ResNet-50. The populations under study were diverse, covering conditions including dental caries, periodontal bone loss, periapical lesions, osteonecrosis of the jaw, and cephalometric landmark identification.

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Table 1: Summary of Included Study Characteristics

Author (Year)	Country	Study Design	Sample Size	AI Model	Application (Task)	Key Findings
Tuzoff et al. (2019)	Russia	Diagnostic Accuracy	2,300 Pano	CNN	Tooth detection & numbering	Accuracy: 0.981-0.998 (F1-score)
Cantu et al. (2020)	Germany	Diagnostic Accuracy	20,000 Bitewings	CNN	Caries detection (D1-D3)	AUC: 0.81-0.89 (superficial), 0.91-0.94 (deep)
Lee et al. (2020)	South Korea	Diagnostic Accuracy	4,120 Images	CNN	Cyst vs. Granuloma diagnosis	Accuracy: 90.1% (Pano), 93.7% (CBCT)
...	...	...	...	...	...	...
Jodal et al. (2023)	Belgium	In vitro cohort	15 RPD designs	AI Software	RPD framework design	Time reduction: 84% vs. conventional
Thurzo et al. (2021)	Slovakia	RCT	72 Patients	AI App	Orthodontic treatment coaching	Improved oral hygiene (p<0.01)

The assessment of methodological quality revealed a variable risk of bias across the included studies. For diagnostic accuracy studies, the application of the QUADAS-2 tool indicated that a common concern revolved around the patient selection domain, where many studies utilized retrospectively collected image datasets from single institutions, potentially introducing selection bias (7). Furthermore, in several studies, the reference standard was not interpreted independently of the index test, raising concerns about review bias. The two included RCTs, assessed using the RoB 2 tool, were judged to have a low risk of bias overall, though one exhibited some concerns regarding the blinding of outcome assessors (8). The retrospective cohort studies, evaluated via the Newcastle-Ottawa Scale, generally received moderate quality ratings, with points most frequently lost in the comparability of cohorts domain due to inadequate control for confounding factors.

The synthesis of primary outcomes demonstrated that AI models consistently achieved high performance metrics in diagnostic tasks. For the detection of dental caries on bitewing radiographs, AI algorithms exhibited sensitivity ranging from 0.79 to 0.92 and specificity from 0.83 to 0.95, often outperforming or matching the diagnostic accuracy of dental professionals (9, 10). The area under the curve (AUC) values for various tasks were generally high, such as 0.97 for periodontal bone loss classification and 0.93 for identifying periapical lesions (11). In the few studies investigating therapeutic applications, the findings were equally promising. Jodal et al. reported that an AI-driven software designed removable partial denture frameworks with clinically acceptable accuracy in a fraction of the time required by conventional methods (84% reduction, $p<0.001$) (12). In the realm of prevention and monitoring, the RCT by Thurzo et al. found that an AI-powered telehealth coaching system significantly improved patient compliance with orthodontic treatment and oral hygiene measures compared to the control group ($p<0.01$) (13). Despite these strong results, significant heterogeneity in reporting metrics, validation methods, and ground truth establishment precluded a meaningful meta-analysis, underscoring the need for standardized reporting in future AI research in dentistry.

DISCUSSION

This systematic review comprehensively evaluated 32 studies to ascertain the role of artificial intelligence in enhancing diagnostic, preventive, and therapeutic practices in dentistry. The principal finding is that AI, particularly deep learning-based convolutional neural networks, demonstrates consistently high performance in analyzing dental radiographic images, often matching or exceeding the diagnostic accuracy of dental professionals in tasks such as caries detection, periodontal bone loss assessment, and identification of

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periapical pathologies (9, 11). Beyond diagnostics, preliminary evidence indicates significant potential for AI to streamline therapeutic workflows, as seen in the design of prosthetic frameworks, and to improve preventive care through personalized patient monitoring and coaching applications (12, 13). However, the overall strength of the evidence is tempered by the preponderance of diagnostic accuracy studies conducted in controlled, retrospective settings, with a notable scarcity of high-quality randomized controlled trials evaluating clinical endpoints in real-world practice environments. When contextualized within the existing body of literature, these findings align with and substantially expand upon the conclusions of earlier, more narrowly focused reviews. Previous syntheses have primarily confirmed the efficacy of AI in singular domains, such as caries detection on bitewings or landmark identification on cephalometric radiographs (2). The present review corroborates these findings but provides a broader synthesis by encompassing a wider spectrum of dental applications, including periodontics, endodontics, oral surgery, and prosthodontics.

A notable consistency across reviews is the recurrent identification of heterogeneity in study methodologies and reporting as a major challenge. However, this review also identifies a emerging trend not extensively covered in earlier works: the gradual translation of AI from purely diagnostic aids into decision-support systems that interact with clinical workflows and patient engagement strategies, suggesting an evolving maturity in the field (13). The methodological rigor of this review constitutes a primary strength, mitigating potential biases and enhancing the reliability of its conclusions. The development of a comprehensive search strategy in consultation with an information specialist, the adherence to PRISMA guidelines, and the dual independent execution of study selection, data extraction, and risk of bias assessment all contribute to the robustness of the process (5). Furthermore, the inclusion of studies across the entire spectrum of dental practice—diagnosis, prevention, and therapy—provides a more holistic overview of the AI landscape in dentistry than previously available. The use of established tools like QUADAS-2 and RoB 2 for critical appraisal ensures that the interpretations are grounded in a transparent and standardized evaluation of study quality. Notwithstanding these strengths, several limitations must be acknowledged. The review was constrained by the inherent limitations of the primary studies, which were often characterized by relatively small sample sizes, retrospective data collection, and a lack of external validation on diverse, multi-center datasets. This raises concerns regarding the generalizability of the findings to broader populations and different clinical settings.

The potential for publication bias is another significant consideration, as the field may be susceptible to an overrepresentation of studies with positive results, while studies demonstrating poor AI performance or null findings may remain unpublished. The considerable clinical and methodological heterogeneity observed across the included studies, particularly in AI model architectures, training protocols, and outcome measures, precluded a quantitative meta-analysis, necessitating a narrative synthesis instead. The implications of these findings are twofold, pertaining to both clinical practice and future research. For practitioners, the evidence suggests that AI-based diagnostic tools are rapidly approaching a level of maturity where they can serve as highly accurate second readers, potentially reducing diagnostic errors and standardizing interpretation. However, their integration should be cautious and complementary, augmenting rather than replacing clinical expertise. For researchers, this review underscores several critical priorities. There is an urgent need for prospective, real-world clinical trials that evaluate not just diagnostic accuracy but also the impact of AI on ultimate health outcomes, patient satisfaction, and operational efficiency (14). Future studies must prioritize external validation to ensure model robustness and generalizability across diverse populations and equipment. Furthermore, the development of standardized reporting guidelines for AI research in dentistry, akin to CONSORT-AI or TRIPOD-AI, is essential to allow for meaningful comparisons and syntheses of evidence in the future (15). By addressing these gaps, the dental research community can ensure that the promising potential of AI translates into safe, effective, and equitable improvements in patient care.

CONCLUSION

This systematic review consolidates robust evidence demonstrating that artificial intelligence holds significant promise for augmenting dental practice, with particularly strong performance in diagnostic imaging tasks such as caries detection, periodontal disease assessment, and lesion classification, where it often achieves parity with or surpasses human expert performance. The clinical significance of these findings lies in the potential for AI to serve as a powerful decision-support tool, enhancing diagnostic accuracy, standardizing interpretations, and improving operational efficiency, thereby allowing clinicians to focus more on complex patient care and treatment execution. However, the current evidence base, while compelling, is predominantly derived from retrospective studies and in vitro validations, indicating that the transition from algorithmic precision to tangible clinical outcomes remains inadequately explored; consequently, while AI's integration into dentistry appears inevitable and beneficial, its full and safe realization is contingent upon future rigorous prospective trials and real-world implementation studies that critically assess long-term efficacy, cost-effectiveness, and ethical implications within diverse clinical settings.

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AUTHOR CONTRIBUTION

Author	Contribution
Huda Muneer	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Amer Al Bermawy	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Noor ul Ain*	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Nazam Matloob Balouch	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Arbab Tahir Ali	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Syeda Tooba Sajid	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Muhammad Haris Mirza	Contributed to study concept and Data collection Has given Final Approval of the version to be published
Tanzeel Sajid	Writing - Review & Editing, Assistance with Data Curation

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