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INTEGRATION OF ARTIFICIAL INTELLIGENCE IN DIAGNOSTIC DENTISTRY: CURRENT TRENDS AND FUTURE POSSIBILITIES – A NARRATIVE REVIEW

Narrative Review

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ABSTRACT

Background: Artificial intelligence (AI) has emerged as a transformative force in modern healthcare, with growing applications in dentistry. As oral diseases such as dental caries and periodontal conditions continue to affect billions worldwide, the integration of AI offers a novel approach to improving diagnostic accuracy, reducing clinician variability, and streamlining decision-making processes. The increasing digitalization of dental practices underscores the need to explore how AI can be leveraged for timely and precise diagnostics.

Objective: This narrative review aims to explore the current applications and future possibilities of AI in diagnostic dentistry, with a specific focus on caries detection, radiographic analysis, and the development of personalized dental care planning.

Main Discussion Points: The review synthesizes literature highlighting AI's capability in enhancing caries detection using convolutional neural networks, improving radiographic interpretation through automated lesion recognition, and aiding in patient-specific risk prediction. It also discusses limitations in existing research, including small sample sizes, lack of randomized controlled trials, inconsistent outcome measures, and limited generalizability across diverse clinical settings. Methodological and publication biases are identified as key concerns, and the need for standardized clinical guidelines is emphasized.

Conclusion: AI holds considerable promise in elevating diagnostic dentistry, offering tools that can complement clinical expertise and enhance patient care. However, current evidence, while promising, remains preliminary. Robust clinical trials and interdisciplinary collaboration are essential to validate AI's real-world effectiveness and ensure ethical, equitable integration into dental practice.

Keywords: Artificial Intelligence, Diagnostic Dentistry, Caries Detection, Radiographic Analysis, Radiographic Analysis, Narrative Review.

INTRODUCTION

Artificial intelligence (AI) is rapidly transforming the landscape of modern healthcare, including the field of dentistry, where it has begun to redefine diagnostic precision, efficiency, and patient-centered care. With the increasing global burden of oral diseases—affecting approximately 3.5 billion people worldwide as of the latest World Health Organization reports—timely and accurate diagnosis has become a cornerstone of effective dental management. Dental caries alone, the most prevalent chronic disease globally, affects over 2.5 billion people, while periodontal diseases remain a leading cause of tooth loss in adults. These statistics underline the urgency for innovative solutions to enhance diagnostic accuracy and clinical decision-making in routine dental practice (1,2). Traditionally, dental diagnostics have relied on clinician expertise combined with radiographic interpretation, manual probing, and subjective assessments. However, this reliance often introduces variability in diagnosis due to human error, fatigue, and inconsistencies in training or experience. Radiographic evaluation, for instance, remains limited by its two-dimensional nature and the interpretive burden placed on dental professionals (3). In this context, AI—particularly machine learning and deep learning algorithms—offers a promising alternative by enabling automated detection, segmentation, and classification of dental pathologies with remarkable accuracy. Several studies have demonstrated that convolutional neural networks (CNNs) can achieve sensitivity and specificity in caries detection comparable to or even exceeding that of human practitioners (4,5).

Despite these advances, several critical gaps persist in the current literature. Most existing AI models have been trained and validated on small, homogeneous datasets, often lacking external validation across diverse populations and clinical settings. Furthermore, regulatory, ethical, and interoperability challenges hinder the widespread adoption of AI in dental diagnostics (6). Concerns regarding algorithm transparency, data privacy, and the legal implications of AI-driven decisions remain largely unresolved. Additionally, many studies focus predominantly on the technical performance of AI models rather than their integration into clinical workflows or their impact on patient outcomes. These limitations highlight the pressing need for comprehensive, human-centered research that addresses not only the capabilities but also the constraints of AI technologies in dentistry (7,8). The objective of this narrative review is to explore the current applications and emerging possibilities of artificial intelligence in diagnostic dentistry, with a specific focus on caries detection, radiographic image analysis, and the development of personalized dental care plans. By synthesizing the existing body of knowledge, this review aims to identify prevailing trends, highlight critical gaps in evidence, and discuss the practical implications of integrating AI into dental practice. Emphasis is placed on studies published in the last five years to ensure relevance to contemporary technologies and clinical environments (9,10).

This review covers various facets of AI integration, including the performance of diagnostic algorithms in identifying dental caries and periapical lesions, the role of AI-assisted radiographic interpretation in reducing diagnostic variability, and the emerging concept of personalized dental care using predictive modeling and risk stratification. Studies involving machine learning, deep learning, and hybrid AI frameworks are considered, particularly those evaluating the clinical feasibility, accuracy, and acceptability of these technologies. While randomized controlled trials in this field remain scarce, the review incorporates high-quality observational studies, validation studies, and expert commentaries to construct a comprehensive understanding of the topic. The significance of this review lies in its timely exploration of a rapidly evolving technological frontier within dentistry. By consolidating recent advancements and evaluating their clinical relevance, this review provides dental practitioners, researchers, and policymakers with a nuanced understanding of how AI can augment current diagnostic capabilities and shape the future of dental care delivery. In an era characterized by digital transformation, this synthesis is intended to support informed decision-making, foster cross-disciplinary collaborations, and ultimately contribute to safer, more precise, and equitable dental health services.

THEMATIC DISCUSSION

Artificial Intelligence in Caries Detection

One of the most actively explored applications of artificial intelligence in dentistry is the detection of dental caries. Traditional diagnostic methods, such as visual-tactile examination and radiography, are prone to interobserver variability and limited sensitivity, particularly in detecting early lesions. AI-based systems, especially those utilizing convolutional neural networks (CNNs), have shown considerable promise in enhancing diagnostic consistency. Recent studies have demonstrated that deep learning models trained on intraoral photographs and bitewing radiographs can achieve diagnostic accuracies comparable to or exceeding those of experienced clinicians (1,2). A comparative analysis of AI-driven caries detection tools revealed that their sensitivity ranges from 85% to 96% and specificity from 81% to 94%, depending on the dataset used and the model architecture (3). However, challenges persist regarding the generalizability of these models across different populations, as most datasets are geographically or demographically limited. Moreover, ethical concerns related to data privacy and algorithmic bias have yet to be comprehensively addressed.

AI-Assisted Radiographic Interpretation

Radiographic analysis forms the backbone of dental diagnostics, especially in identifying periapical pathologies, bone loss, and impacted teeth. AI technologies have been increasingly integrated into interpreting panoramic and periapical radiographs, enhancing both speed and accuracy. Studies show that CNNs and region-based convolutional neural networks (R-CNNs) are capable of detecting apical periodontitis and marginal bone loss with high precision (4). One multicenter trial reported that an AI algorithm achieved an F1 score of 0.91 in detecting periapical lesions, compared to 0.86 for human radiologists (5). These systems can also highlight areas of interest automatically, potentially reducing diagnostic oversights. Despite these advancements, there remains a lack of clinical trials validating AI applications in real-world settings. Additionally, the integration of AI tools into routine radiographic software platforms is still in its infancy, limiting widespread adoption.

Predictive Modeling and Risk Stratification in Dental Care

Beyond diagnostics, AI is making strides in predictive analytics and risk stratification, helping to tailor individualized dental care plans. Machine learning algorithms have been developed to forecast the likelihood of disease progression in periodontitis and caries, based on patient-specific factors such as genetic markers, oral hygiene practices, diet, and socioeconomic status. A recent study utilized gradient boosting machines to predict caries risk with an accuracy of 88%, highlighting the potential for proactive and preventive dental care models (6). Similarly, decision tree models have shown value in identifying high-risk patients for periodontal disease progression, aiding clinicians in making evidence-based recall and treatment decisions (7). However, these models require robust and diverse training datasets to be clinically applicable across different populations, which remains a significant barrier.

Integration of AI in Clinical Decision Support Systems

Clinical decision support systems (CDSS) powered by AI have begun to emerge in dentistry, offering recommendations based on aggregated patient data and established clinical guidelines. These systems can assist in treatment planning by synthesizing radiographic findings, clinical history, and laboratory data. In orthodontics, for instance, AI-driven CDSS have been used to predict treatment duration and recommend bracket positioning, with promising results (8,9). These tools not only enhance diagnostic accuracy but also improve workflow efficiency and reduce clinician workload. Nevertheless, their effectiveness depends on seamless interoperability with electronic health records (EHRs), which is not yet standardized in most dental settings. Furthermore, clinician skepticism and lack of AI literacy may hinder the adoption of these systems.

Challenges and Controversies in AI Implementation

Despite its vast potential, the implementation of AI in dentistry is met with notable challenges. A major concern is the ‘black box’ nature of deep learning models, which makes it difficult to interpret how decisions are made. This opacity can erode clinician and patient trust, especially in high-stakes scenarios. Moreover, variability in imaging equipment, data annotation standards, and population diversity introduces inconsistencies in model performance. Regulatory frameworks for AI in dentistry are still evolving, and very few AI-based dental tools have received regulatory approval for clinical use (10). There is also a dearth of longitudinal studies evaluating the impact of AI integration on treatment outcomes, cost-effectiveness, and patient satisfaction. These gaps highlight the need for more collaborative research, involving clinicians, data scientists, and policymakers.

CRITICAL ANALYSIS AND LIMITATIONS

While the existing literature on artificial intelligence in diagnostic dentistry presents encouraging findings, a critical analysis reveals several limitations that constrain the strength and applicability of current evidence. A major concern lies in the study designs employed in most investigations. Many of the included studies rely on retrospective datasets with limited sample sizes, which compromises the statistical power and increases susceptibility to overfitting in AI models (11,12). Randomized controlled trials, which are the gold standard in clinical research, are virtually absent in this domain, leaving a significant gap in high-level evidence needed to confirm the clinical utility and effectiveness of these technologies. Additionally, several methodological biases are evident across the reviewed studies. Selection bias is particularly problematic, as many models are developed using datasets drawn from academic institutions or single-center sources, often limited to specific age groups, ethnicities, or diagnostic criteria. This narrow sampling restricts the diversity of training data, which is essential for developing generalizable AI tools (13). Furthermore, performance bias is introduced by the lack of blinding during outcome assessments or annotation phases, especially when ground-truth labels are provided by single experts without cross-validation. This increases the risk of subjective interpretation influencing the model training process, ultimately compromising the reliability of results (14).

Publication bias also emerges as a concern, with a disproportionate focus on studies that report high accuracy or favorable outcomes. Negative or inconclusive results are underreported, creating an overly optimistic view of AI's capabilities in diagnostic dentistry. This bias not only skews the perceived success rate of these technologies but also hinders a balanced understanding of their limitations (15). The absence of rigorous peer review and the growing trend of publishing preprints without critical appraisal further compounds this issue. Another challenge pertains to the inconsistency in measurement outcomes across studies. There is no standardized metric for evaluating AI performance in dental diagnostics. While some studies report sensitivity and specificity, others focus on area under the curve (AUC), precision-recall, or F1 scores, making direct comparisons difficult and potentially misleading (16). Furthermore, the lack of uniformity in defining disease presence or severity—such as variations in radiographic criteria for caries or periodontitis—limits the capacity to benchmark AI systems effectively against each other or against clinical gold standards.

The generalizability of current findings also warrants caution. Although certain AI systems have shown impressive diagnostic capabilities in controlled settings, their performance in diverse, real-world clinical environments remains largely untested. Many algorithms are trained on high-quality, annotated datasets that may not reflect the variability encountered in daily practice, such as differences in radiographic equipment, image quality, and operator technique (17,18). As a result, their translation from research to routine care is not guaranteed. Moreover, the absence of longitudinal studies tracking AI impact over time prevents conclusions about long-term effectiveness, cost-efficiency, or influence on patient outcomes. In conclusion, while the integration of AI in diagnostic dentistry holds transformative potential, the current literature is limited by methodological weaknesses, biases, and inconsistent reporting practices. Future research must prioritize well-designed, multicenter clinical trials with standardized protocols and diverse populations to validate the efficacy, safety, and real-world applicability of AI systems in dental care.

IMPLICATIONS AND FUTURE DIRECTIONS

The integration of artificial intelligence into diagnostic dentistry holds meaningful implications for clinical practice, with the potential to revolutionize how oral diseases are detected, monitored, and managed. By offering increased diagnostic precision and consistency, AI tools can support clinicians in making timely and evidence-based treatment decisions. Automated caries detection, for instance, can help identify early-stage lesions that might otherwise be overlooked, allowing for preventive interventions rather than restorative treatment, thereby improving patient outcomes and reducing healthcare costs (19). Similarly, AI-enhanced radiographic interpretation can streamline the workflow, reduce clinician fatigue, and potentially minimize diagnostic discrepancies among practitioners with varying levels of experience (20). These applications signify a shift towards more data-driven, personalized, and efficient dental care models. From a policy and regulatory standpoint, the growing use of AI technologies underscores the need for standardized clinical guidelines to govern their ethical and safe application. Currently, there is an absence of universally accepted frameworks for validating and integrating AI algorithms into routine dental settings. Establishing such guidelines would ensure the reliability, reproducibility, and transparency of AI-assisted diagnostics, especially in relation to data privacy, algorithm accountability, and patient consent (21). Moreover, integration with existing health information systems, such as electronic health records, will require policy-level support to promote interoperability and continuity of care.

Despite promising developments, several important questions remain unanswered. Many studies focus primarily on algorithm performance metrics without assessing how AI impacts real-world clinical outcomes, decision-making behavior, or patient satisfaction. Furthermore, little is known about how dental professionals interact with these systems in practice, or the extent to which they rely on or override AI-generated recommendations (22). The long-term effects of incorporating AI into dental care—whether it reduces diagnostic errors, enhances preventive care, or improves treatment adherence—are yet to be evaluated through robust prospective studies. Future research should focus on addressing these gaps through more rigorous and clinically oriented study designs. Large-scale, multicenter randomized controlled trials are urgently needed to validate AI tools in diverse populations and practice settings. These trials should include longitudinal follow-up to assess the sustainability of clinical benefits and the potential for unintended consequences. Moreover, mixed-methods research incorporating qualitative assessments could offer valuable insights into user acceptance, clinician trust, and the impact of AI on the dentist–patient relationship (23,24). Standardization in outcome measures and data labeling protocols would also enhance comparability across studies and contribute to the development of consensus benchmarks for AI performance. As AI becomes more embedded in the fabric of dental diagnostics, it is essential that its development remains aligned with the core principles of patient safety, clinical effectiveness, and ethical responsibility. Continued investment in interdisciplinary research and collaboration between dental professionals, computer scientists, ethicists, and policymakers will be key to shaping an AI-enabled future that enhances rather than complicates oral healthcare delivery.

CONCLUSION

The integration of artificial intelligence into diagnostic dentistry represents a transformative advancement, with substantial potential to enhance the accuracy, efficiency, and personalization of dental care. This review highlights key applications of AI in caries detection, radiographic interpretation, and risk-based treatment planning, demonstrating promising diagnostic performance that rivals or complements human expertise. While the current literature supports the feasibility of AI-assisted tools, the evidence base remains limited by methodological constraints, including small sample sizes, lack of clinical trials, and insufficient real-world validation. Nonetheless, the consistency of findings across different AI models suggests a growing reliability of these technologies when appropriately developed and applied. For clinicians, incorporating AI into diagnostic workflows may offer significant benefits, provided ethical considerations and regulatory standards are upheld. Researchers are encouraged to prioritize high-quality, multicenter studies with standardized methodologies to bridge the gap between experimental performance and clinical utility. Future investigations must also explore the long-term effects of AI integration on patient outcomes, practitioner behavior, and healthcare equity to fully harness the promise of this evolving technology.

AUTHOR CONTRIBUTION

Author	Contribution
Aleeza Sana*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Alizeh Abbas Gardezi	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
Ayesha Ikram Malik	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Aleshba Saba Khan	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Areeba Zubair	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Khizra Aleena	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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