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Artificial Intelligence in Dentistry: A Comprehensive Review of Diagnostic, Predictive, and Personalized Treatment Applications

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ABSTRACT

Aim: This study aimed to comprehensively review the applications of artificial intelligence (AI) in dentistry, focusing on diagnostic, predictive, and personalized treatment approaches to assess performance, trends, and clinical implications.

Methodology: A systematic search of PubMed, Scopus, Web of Science, and Google Scholar (2015–2025) identified 125 relevant studies, including original research, reviews, clinical trials, and in vitro/in silico investigations. Data on AI applications, performance metrics, methodologies, and clinical outcomes were extracted and analyzed.

Results: AI was predominantly applied in diagnostics (68%), followed by predictive modeling (20%) and personalized treatment (12%). Diagnostic systems demonstrated high sensitivity (88–96%) and specificity (85–94%), predictive models showed 82–91% accuracy, and personalized applications improved planning efficiency while reducing clinician workload.

Conclusion: AI demonstrates substantial potential to enhance diagnostic accuracy, support predictive analytics, and enable personalized treatment in dentistry. Its integration can improve workflow efficiency, standardize care, and serve as a reliable adjunct to clinical decision-making.

KEYWORDS: *Artificial intelligence, Dentistry, Diagnostic accuracy, Predictive modeling, Personalized treatment, Deep learning, Clinical decision support*

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1. INTRODUCTION

Artificial intelligence (AI) has emerged as a transformative technology in dentistry, offering innovative approaches to diagnostics, treatment planning, and patient care. Recent years have seen a rapid proliferation of AI-driven tools capable of analyzing complex dental datasets, ranging from radiographic images to clinical parameters, with the potential to enhance precision and efficiency in dental practice [1]. AI applications in diagnostics facilitate automated detection of dental caries, periapical lesions, periodontal bone loss, and abnormalities in dental anatomy, often surpassing conventional manual interpretation in terms of speed and reproducibility [2]. These advancements are supported by deep learning algorithms, convolutional neural networks, and machine learning models, which can learn intricate patterns from large datasets and generate accurate predictions for diverse clinical scenarios [3].Moreover, AI has begun to play a significant role in predictive dentistry, enabling practitioners to forecast treatment outcomes, risk of disease progression, and long-term prognosis for interventions such as orthodontics, implant therapy, and periodontal management [4]. By integrating patient-specific data, AI-driven predictive models facilitate proactive and individualized treatment planning, aligning with the broader trend of precision medicine in dentistry. Descriptive reviews highlight that AI implementation in routine clinical workflows can reduce diagnostic errors, streamline treatment protocols, and provide decision support for clinicians across various specialties [5].Importantly, the accessibility of AI tools is expanding globally, including applications in lower-middle-income countries, where resource limitations often restrict access to specialized dental expertise [6]. AI has the potential to bridge these gaps, offering scalable solutions for both diagnostics and patient management in diverse socioeconomic settings. Additionally, AI-assisted approaches have demonstrated utility in periodontal maintenance and preventive dentistry, supporting continuous monitoring, early detection of disease, and optimization of treatment intervals [7]. Collectively, these developments underscore AI's capacity to enhance diagnostic accuracy, predictive analytics, and personalized care, positioning it as a vital adjunctive technology in modern dental practice.

2. METHODOLOGY

This study was designed as a comprehensive, observational review to evaluate the current applications of artificial intelligence (AI) in dentistry, with a focus on diagnostic, predictive, and personalized treatment approaches. A systematic search of electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar, was conducted for articles published between 2015 and 2025. Keywords used included "artificial intelligence," "machine learning," "deep learning," "dentistry," "dental diagnostics," "predictive dentistry," and "personalized treatment." Inclusion criteria comprised peer-reviewed studies, narrative reviews, systematic reviews, meta-analyses, clinical trials, and in vitro or in silico studies that investigated AI applications in dental diagnostics, treatment planning, predictive modeling, or personalized patient care. Exclusion criteria included non-English publications, conference abstracts without full-text availability, and studies unrelated to clinical or translational dental applications. Data were extracted regarding study design, sample size, type of AI algorithm or model used, dental specialty application, diagnostic or predictive accuracy, and clinical outcomes. The quality of included studies was assessed using standardized appraisal tools appropriate for the study design, such as the Newcastle-Ottawa Scale for observational studies and the AMSTAR 2 tool for systematic reviews. Descriptive analysis was performed to categorize AI applications according to their clinical function—diagnostic, predictive, or personalized treatment support—and to summarize reported performance metrics including sensitivity, specificity, accuracy, and predictive value. Additionally, emerging trends, challenges, ethical considerations, and integration strategies of AI in clinical dentistry were critically evaluated. This methodological approach allows for a comprehensive overview of how AI technologies are being implemented across dental specialties, highlighting both their potential and limitations in enhancing clinical decision-making and patient care.

3. RESULTS

A total of 125 studies were included in this review, comprising 42 original research articles, 38 narrative reviews, 25 systematic reviews, 12 clinical trials, and 8 in vitro or in silico studies. The majority of AI applications were reported in diagnostic dentistry, with 68% of studies focusing on radiographic analysis, including caries detection, periapical lesion identification, periodontal bone loss assessment, and implant planning. Predictive applications accounted for 20% of studies, primarily involving orthodontic treatment outcome prediction, risk assessment for caries and periodontal disease, and implant success forecasting. Personalized treatment applications were less common, representing 12% of studies, and included AI-assisted prosthodontic design, customized orthodontic treatment planning, and patient-specific preventive strategies.Diagnostic AI systems demonstrated high performance, with reported sensitivities ranging from 88% to 96% and specificities from 85% to 94%, often surpassing conventional manual interpretation in speed and consistency. Predictive models showed promising accuracy in forecasting treatment outcomes and disease progression, with predictive values ranging from 82% to 91%. Studies on personalized treatment reported improved treatment planning efficiency and reduced clinician workload, though these applications were limited by smaller sample sizes and early-stage clinical validation.Most studies highlighted the integration of deep learning, convolutional neural networks, and machine learning algorithms as the primary AI methodologies. Implementation of AI significantly reduced interpretation time in diagnostic workflows, increased reproducibility, and enhanced clinician decision-making. However, variability in dataset size, imaging modality, and algorithm training was noted as a limiting factor affecting generalizability. Ethical considerations, data privacy, and clinician oversight were emphasized as essential for safe clinical adoption.Overall, the findings indicate that AI has substantial potential to enhance diagnostic accuracy, predictive analytics, and personalized treatment planning in dentistry, supporting its growing role as an adjunctive tool in modern dental practice (Table 1).

Table 1: Summary of AI Applications and Performance in Dentistry (n = 125 studies)

AI Application Area	Number of Studies (%)	Key Applications	Reported Performance
Diagnostic	85 (68%)	Radiographic analysis: caries detection, periapical lesions, periodontal bone loss, implant planning	Sensitivity: 88–96%, Specificity: 85–94%, Reduced interpretation time
Predictive	25 (20%)	Orthodontic treatment outcome prediction, caries & periodontal disease risk, implant success forecasting	Predictive accuracy: 82–91%
Personalized Treatment	15 (12%)	AI-assisted prosthodontic design, customized orthodontic planning, patient-specific preventive strategies	Improved planning efficiency, reduced clinician workload, early-stage clinical validation
Methodologies	—	Deep learning, convolutional neural networks, machine learning	Increased reproducibility, enhanced decision-making, faster workflow
Limitations	—	Dataset variability, imaging modality differences, small sample sizes	Generalizability affected, need for clinician oversight

4. DISCUSSION

The integration of artificial intelligence (AI) into dental medicine has demonstrated substantial benefits across diagnostic, predictive, and personalized treatment domains. Critical reviews have highlighted the capacity of AI to analyze complex datasets derived from radiographic imaging, electronic health records, and patient histories, thereby enhancing both the accuracy and efficiency of routine dental assessments [8]. By automating the interpretation of radiographs and clinical data, AI systems can reduce human error, minimize interobserver variability, and provide consistent diagnostic outputs that support clinician decision-making. Furthermore, AI applications in public health dentistry have shown promise in identifying population-level trends in oral diseases, optimizing dental screening programs, and enabling targeted preventive interventions [9]. These tools can help identify high-risk populations for caries, periodontal disease, and other oral health conditions, allowing resources to be allocated more effectively. Systematic reviews of AI-assisted dental tools indicate that these technologies can reliably detect carious lesions, periapical pathology, and periodontal bone loss with reported sensitivities and specificities often exceeding 90%, underscoring their utility as robust decision-support systems [10].Personalized diagnostics is a rapidly evolving area in which AI shows particular potential. In periodontology, AI-assisted predictive models can forecast disease progression and evaluate treatment response, enabling individualized maintenance schedules and tailored interventions [11]. Narrative reviews emphasize that AI not only synthesizes large volumes of heterogeneous data but also reduces the cognitive load on clinicians, providing standardized outputs that improve the quality and reproducibility of care [12]. This capability is particularly valuable in complex clinical scenarios where multiple variables, such as bone density, periodontal status, and systemic health conditions, must be considered concurrently. Additionally, AI integration with advanced imaging modalities, such as cone-beam computed tomography (CBCT), has enhanced visualization of anatomical structures, improved artifact reduction, and facilitated volumetric analyses, all of which contribute to better preoperative planning and postoperative evaluation [13,14].AI also plays a significant role in optimizing diagnostic workflows. Deep learning algorithms can rapidly interpret radiographs, thereby reducing the time required for analysis while maintaining or improving diagnostic accuracy [15]. By automating routine assessments, AI allows clinicians to dedicate more time to patient consultation and treatment planning, ultimately enhancing overall clinical efficiency. In orthodontics, dynamic AI-driven treatment management systems can monitor patient progress, predict future tooth movement, and adjust treatment plans in real time, supporting personalized care and potentially reducing treatment duration [16]. Moreover, AI can be applied to large-scale epidemiological datasets, identifying trends and high-risk populations, and recommending preventive strategies to improve population oral health outcomes [17].Despite these promising advances, several challenges remain in the clinical adoption of AI in dentistry. Variability in training datasets, limited diversity of patient populations, and inconsistencies in imaging protocols can affect the generalizability and reliability of AI models [18]. Ethical considerations are also critical, including data privacy, informed consent, and algorithmic transparency, all of which must be addressed to ensure safe, equitable, and responsible deployment of AI technologies [19]. Furthermore, many AI applications, particularly in predictive modeling and personalized treatment planning, require extensive clinical validation through multi-center trials and long-term outcome studies to ensure their accuracy and robustness [20]. Nevertheless, existing systematic reviews and narrative analyses confirm the potential of AI to significantly enhance diagnostic precision, improve workflow efficiency, and support personalized dental care [21,22].Overall, AI serves as a powerful adjunct to traditional dental practice, offering improvements in diagnostic accuracy, predictive insights, and individualized treatment planning. By integrating AI into clinical workflows, dental professionals can achieve more standardized care, optimize patient outcomes, and reduce the workload associated with routine image interpretation and data analysis. As AI continues to evolve, its implementation promises to transform the practice of dentistry, bridging gaps in expertise, improving preventive strategies, and supporting evidence-based, patient-centered care. These developments represent a meaningful step forward in the modernization of dental practice, with the potential to redefine standards of care and clinical efficiency in the 21st century.AI can identify histological slides more accurately than the human eye because it can process large amounts of data, recognise small morphological patterns, and reduce differences between observers. Deep learning algorithms can find very small differences in the structure of tissues that doctors might miss because they are tired, biassed, or can't see well enough. Research indicates that AI diagnostic systems consistently achieve sensitivities ranging from 88% to 96% and specificities from 85% to 94%, surpassing conventional manual interpretation and enhancing reproducibility and efficiency in histopathological assessment.AI reads CT, MRI, and cytology slides more accurately because it can process high-dimensional imaging data and find small details that the human eye might not be able to see. Convolutional neural networks and other advanced deep learning models are trained on thousands of labelled images, which lets them find small differences in tissue density, texture, and shape. AI improves artefact reduction, anatomical visualisation, and consistent volumetric analyses in CT and MRI. This lowers the chance of human error and differences between observers. AI systems can also classify cells, find abnormal nuclei, and find early signs of cancer in cytology, with higher reproducibility and sensitivity and specificity levels that are often over 90%. AI combines data from different sources to give standard, unbiased, and faster interpretations that are much better than manual assessments.

Artificial intelligence is very important for figuring out diagnostic problems when two or more diseases have similar clinical or radiological features. AI systems can compare findings from individual patients to thousands of previous cases with known outcomes by using large annotated datasets and advanced machine learning models. This method lets the algorithm give each possible diagnosis a probability score, which makes the results less subjective and less likely to differ between observers. These decision-support systems make sure that the most likely diagnosis is highlighted, which helps doctors make better, more confident, and more evidence-based decisions when they aren't sure what to do. In histopathology, AI mostly uses convolutional neural networks (CNNs) and deep learning frameworks to look at whole-slide images that have been digitised. The first step in the workflow is image preprocessing, which turns slides into high-resolution digital formats. Next comes feature extraction, where the algorithm finds small changes in cell size, nuclear atypia, tissue texture, and architectural organisation. These features are then put through multi-layered neural networks that can find complicated, non-linear patterns that the human eye might miss. Lastly, the model classifies by giving different histological diagnoses, like benign, premalignant, or malignant lesions, probability values. This method, which is structured and can be repeated, improves the accuracy of diagnoses, reduces human error, and speeds up the process of interpreting histopathology. There are already a few AI-based platforms that can be used in oral and maxillofacial pathology, and more are being made. PathAI is a clinical-grade platform that uses deep learning to find cancer, even in its early stages in the mouth. Aiforia® is cloud-based software that lets researchers and pathologists analyse whole-slide images automatically. It can be used in studies of oral cancer. Visiopharm® is a digital pathology tool that uses AI to analyse tissues quantitatively. It can be used to check for oral cancer and dysplasia. QuPath is a free digital pathology program that is widely used in academic research, including finding oral squamous cell carcinoma and precancer. Google Health AI models are algorithms that have been trained on histopathology data and have promising uses in oral pathology datasets.AI prototypes for detecting oral cancer – These tools were made in academic and clinical research settings to help find and grade oral epithelial dysplasia and carcinoma early on.

Limitations of AI in Oral Pathology and Histology

Bias and Dependence on Data AI algorithms need big, varied, and high-quality datasets to learn from. If datasets are small, biassed towards certain groups of people, or don't include people with rare conditions, the diagnostic results may not be accurate or useful for a wide range of people. This limitation is particularly pertinent in oral pathology, where datasets are frequently smaller than those in general medicine.

No Clinical Validation AI is very accurate in controlled research settings, but many models haven't been tested in a lot of different clinical settings. Their dependability in actual oral pathology practice is still unknown without strict testing.

Problems with understanding (the "black box" problem) Deep learning models frequently produce outcomes without clear reasoning, complicating pathologists' comprehension of the decision-making process. This "black box" quality can make people less likely to trust it and make it harder to use in clinical practice.

Barriers to Technology and Infrastructure To use AI, you need advanced digital pathology infrastructure, high-resolution scanners, and a lot of computing power, which may not be available in places with few resources. High costs are also a problem for dental schools and smaller practices that want to use it more widely.

Risk of Dependence Too Much If clinicians rely too much on AI outputs, they may not be as careful, which could lead to missed mistakes if the algorithm misclassifies a case. AI should be used to help make decisions, not to replace the judgement of trained professionals.

Concerns about ethics and the law Unresolved issues include data privacy, informed consent, and ownership of patient histological images. There are also ethical problems with medical and legal responsibility in cases of AI-driven misdiagnosis.

5. CONCLUSION

Artificial intelligence in dentistry demonstrates significant potential to enhance diagnostic accuracy, predictive analytics, and personalized treatment planning. AI applications improve efficiency, reduce clinician workload, and offer consistent decision support across radiographic and clinical workflows. Despite promising results, careful consideration of dataset quality, algorithm validation, and ethical oversight is essential. Overall, AI serves as a valuable adjunct in modern dental practice, supporting precision and improved patient care.

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