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ARTIFICIAL INTELLIGENCE IN ENDODONTICS: A SYSTEMATIC REVIEW OF DIAGNOSTIC APPLICATIONS AND CLINICAL PERFORMANCE

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ABSTRACT

Background: The integration of Artificial Intelligence (AI) in endodontics has gained substantial attention in recent years, offering innovative solutions for diagnosis, treatment planning, and clinical decision-making. Given the increasing complexity of endodontic procedures and the limitations of human analysis in imaging, AI systems present a promising alternative to support dental professionals. ***Objective:*** This systematic literature review aimed to synthesize current scientific evidence regarding the accuracy, performance, and applicability of AI models in endodontic diagnosis and treatment, with a focus on periapical lesion detection, root morphology analysis, and decision-making support. ***Methods:*** A comprehensive search was conducted in databases such as PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect for articles published between 2018 and 2024. The PRISMA methodology was followed for study selection, and 45 relevant articles were included based on predefined inclusion and exclusion criteria. ***Results:*** The findings reveal that AI algorithms, especially those based on deep learning and convolutional neural networks, demonstrate high accuracy in detecting periapical lesions,identifying root canal morphology, and predicting treatment outcomes. Most studies reported performance metrics comparable or superior to those of human examiners. Despite these advances, challenges remain in data standardization, external validation, and ethical regulation. ***Conclusion:*** AI has significant potential to enhance diagnostic precision and clinical outcomes in endodontics. However, further multicenter trials, real-world validations, and ethical frameworks are needed to support its routine clinical implementation

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INTRODUCTION

Endodontics is a demanding branch of dentistry that requires a combination of analytical reasoning, manual dexterity, and evidence-based decision-making. Accurate diagnosis, especially in the interpretation of radiographic images, is essential for treatment planning and long-term prognosis. However, even experienced clinicians may face difficulties due to the inherent limitations of human perception, fatigue, and the complexity of anatomical structures.

In this context, artificial intelligence (AI) has emerged as a promising tool to support clinical decision-making, increase diagnostic accuracy, and reduce variability in endodontic outcomes (Setzer *et al*., 2024; Saghiri *et al*., 2023). AI refers to the development of computer systems capable of performing tasks that traditionally require human intelligence, such as pattern recognition, prediction, and adaptive learning. Within dentistry, and more specifically in endodontics, AI has been increasingly integrated through machine learning (ML) and deep learning (DL) algorithms—particularly convolutional neural networks (CNNs)—that are able to analyze and classify radiographic images with high precision (Ahmed *et al*., 2020; Pauwels *et al*., 2020). These systems have been applied to the detection of periapical lesions, classification of root canal morphology, identification of vertical root fractures, and estimation of working length, among other tasks (Kasi *et al*., 2024; Mupparapu *et al*., 2023). Recent studies demonstrate that AI can outperform general dentists and even specialists in specific diagnostic scenarios. For instance, CNN models trained to detect periapical pathoses on periapical radiographs and CBCT images have achieved sensitivity and specificity scores exceeding 90%, in some cases surpassing the performance of human raters (Shah *et al*., 2024; Mahmoud *et al*., 2023). In addition to diagnostic accuracy, AI offers advantages in terms of speed, scalability, and consistency, making it a valuable asset in high-volume clinical settings. Moreover, AI has shown potential in prognostic modeling. Algorithms trained on clinical and radiographic data have been used to predict the likelihood of treatment success or failure over time, allowing clinicians to identify high-risk cases and tailor interventions accordingly (Chakir *et al*., 2023; Lee *et al*., 2022). In microendodontic surgery, for example, AI models such as XGBoost have been applied to predict surgical outcomes with promising results (Kim *et al*., 2023). Despite these advances, several limitations hinder the widespread clinical adoption of AI in endodontics. Many AI models are trained on small or homogeneous datasets, which may limit their generalizability across diverse patient populations. Moreover, concerns regarding the interpretability of DL models—often referred to as "black-box" systems—raise ethical questions about transparency, accountability, and trust in automated decision-making (Khoshbin *et al*., 2023; Lin *et al*., 2024). Data privacy, algorithmic bias, and the lack of regulatory frameworks further complicate the translation of AI technologies into routine clinical practice. Additionally, most current studies are in vitro or retrospective in nature. There is a critical need for prospective, multicenter clinical trials to validate the safety, efficacy, and reproducibility of AI applications in real-world dental environments. Without this translational bridge, the gap between technological innovation and clinical impact will remain wide (Setzer *et al*., 2024; Pauwels *et al*., 2020). Given the rapid evolution of AI applications and the increasing body of evidence supporting its clinical utility, a comprehensive synthesis of current knowledge is necessary. This systematic review aims to analyze and categorize the main contributions of AI to endodontics, particularly regarding diagnostic applications, predictive analytics, technological integration, limitations, and future directions. By critically evaluatingthe literature, this review seeks to clarify the true potential—and current constraints—of AI in modern endodontic practice.

MATERIALS AND METHODS

Study Design and Review Protocol: This study was conducted as a systematic review of the literature, in accordance with the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page *et al*., 2021). The objective was to identify, organize, and synthesize the available evidence on the use of artificial intelligence (AI) in endodontics, particularly in diagnostic and predictive applications. The review protocol followed the PICO strategy to formulate the research question:

- ***P (Population):*** Patients undergoing endodontic evaluation or treatment
- ***I (Intervention):*** Use of artificial intelligence tools (e.g., deep learning, machine learning, convolutional neural networks)
- ***C (Comparison):*** Conventional diagnostic or planning methods, when applicable
- ***O (Outcome):*** Diagnostic performance, treatment prediction, image segmentation, clinical decision support.

Information Sources and Search Strategy: A comprehensive literature search was carried out between March and April 2025 in the following databases: PubMed/MEDLINE, Scopus, Web of Science, ScienceDirect, and Google Scholar. In addition, gray literature sources were considered to identify potentially relevant non-indexed studies. Boolean operators were applied to combine controlled vocabulary terms and free-text keywords in English.

The primary search terms included:

- ("Artificial Intelligence" OR "Machine Learning" OR "Deep Learning") AND
- ("Endodontics" OR "Root Canal Treatment" OR "Endodontic Diagnosis") AND
- ("Radiographs" OR "CBCT" OR "Image Segmentation" OR "Prediction")

Search filters were applied to select full-text, peer-reviewed articles published between 2010 and 2024.

Eligibility Criteria

Inclusion criteria were defined as:

- Original studies or systematic reviews published in English;
- Articles involving human data, in vitro datasets, or simulation models applicable to clinical endodontics;
- Studies that applied artificial intelligence methods (e.g., supervised learning, CNN, XGBoost) for diagnostic or predictive purposes in endodontics;
- Studies with clearly defined outcomes related to diagnostic performance, image analysis, treatment planning, or prognosis.

Exclusion criteria included

- Case reports, editorials, letters, and opinion papers;
- Studies unrelated to endodontics or lacking a clear AI component;
- Articles without accessible full text;
- Duplicated publications.

Study Selection and Data Extraction: All references identified through the search were imported into Mendeley for citation management and duplicate removal. Two independent reviewers screened titles and abstracts for relevance. Full-text articles were subsequently reviewed for eligibility. Any disagreements were resolved through discussion or consultation with a third reviewer.

A standardized data extraction sheet was created to collect the following information from each included study:

- Authors and year of publication;
- Country of origin;
- Study design and sample size;
- AI model(s) used;
- Imaging modality (e.g., 2D radiographs, CBCT);
- Type of endodontic application (diagnosis, prognosis, segmentation);
- Reported outcomes (accuracy, sensitivity, specificity, AUC, etc.);
- Validation methods (cross-validation, test sets, clinical validation).

Data Synthesis: Given the methodological heterogeneity among studies (e.g., different AI architectures, datasets, and outcome measures), a narrative synthesis approach was adopted. The included studies were grouped thematically according to the AI application in endodontics, and the findings were analyzed in terms of performance metrics, clinical relevance, and limitations.

Study Selection Process: A total of 3,200 records were identified through electronic database searches conducted in PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar. After the removal of 1,100 duplicates, 2,100 records remained for title and abstract screening.

Following the screening process, 1,985 articles were excluded for not meeting the inclusion criteria. The full texts of the remaining 115 articles were retrieved and assessed for eligibility.

After a detailed review, 70 articles were excluded due to one or more of the following reasons:

- Absence of artificial intelligence application;
- Irrelevance to endodontics;
- Lack of extractable outcomes;
- Unclear methodology or unavailable full text.

Ultimately, 45 studies were included in the qualitative synthesis and organized into thematic categories for narrative analysis.

RESULTS

This systematic review included 45 studies published between 2010 and 2024, investigating the application of artificial intelligence (AI) in various areas of endodontics. The majority of these studies employed deep learning techniques, particularly convolutional neural networks (CNNs), to interpret imaging modalities such as periapical radiographs and cone-beam computed tomography (CBCT). AI applications were grouped into the following major categories: diagnostic support, treatment planning and outcome prediction, radiographic image segmentation, anatomical classification, and technological innovation.

AI-Assisted Detection of Periapical Lesions: Multiple studies focused on the detection of periapical radiolucencies using AI. Shah *et al*. (2024) demonstrated that CNN models applied to periapical radiographs achieved high sensitivity (up to 0.92) in detecting apical periodontitis, often outperforming general practitioners. Similarly, Mahmoud *et al*. (2023) and Kasi *et al*. (2024) showed that AI-based CBCT interpretation resulted in significantly higher interobserver agreement than manual evaluation, with accuracies exceeding 90%. Saghiri *et al*. (2023) employed deep learning architectures to identify lesion severity in CBCT scans and reported AUC values above 0.95, confirming the model's reliability. Pauwels *et al*. (2020) also emphasized the ability of CNNs to localize early periapical changes with high spatial resolution. In a comparative study, Kaya *et al*. (2022) demonstrated that AI performance was similar to that of endodontic specialists and significantly better than that of general dentists.

Vertical Root Fractures and Root Morphology Recognition: The identification of vertical root fractures (VRFs) and anatomical anomalies is another area where AI has demonstrated clinical utility. Kwon *et al*. (2022) applied ensemble deep learning methods to segment VRFs on CBCT images and reported a diagnostic accuracy of 0.88. Pinto *et al*. (2023) used AI to assess root canal morphology and found that CNNs could reliably classify canal curvature and the number of roots with over 90% accuracy. These capabilities are especially relevant in molars and premolars, where anatomical complexity often leads to treatment failure if undetected.

Prognostic Modeling and Treatment Outcome Prediction: Chakir *et al*. (2023) and Kim *et al*. (2023) developed machine learning models such as XGBoost and random forest to predict treatment success and complications in microendodontic surgery. Their models incorporated both clinical and radiographic data and achieved predictive accuracies ranging from 82% to 87%. Lee *et al*. (2022) used preoperative data to forecast the likelihood of treatment failure and demonstrated the value of AI in stratifying patient risk profiles. Setzer *et al*. (2024) provided a broader perspective, suggesting that AI tools could eventually aid in prognosis determination during initial patient consultations, allowing for more personalized and data-driven treatment strategies.

Working Length and Anatomical Landmark Identification: Ahmed *et al*. (2020) explored the use of deep learning for estimating working length in digital periapical radiographs and reported high concordance with manual measurements. Lin *et al*. (2024) showed that AI-based image segmentation could effectively identify apical foramina and canal endpoints, even in complex cases. These findings suggest that AI has the potential to improve the accuracy of endodontic instrumentation and reduce iatrogenic errors.

Comparative Performance with Human Experts: Several studies directly compared the performance of AI systems with that of dental professionals. In a multicenter study, Mupparapu *et al*. (2023) found that CNNs achieved similar or superior diagnostic accuracy compared to experienced endodontists when interpreting periapical radiographs. Kaya *et al*. (2022) also reported that AI models reduced diagnostic time by 35% while maintaining a high degree of reliability.

Technological Innovation and Ethical Considerations: Beyond clinical applications, the reviewed studies discussed the integration of AI with augmented reality, real-time navigation, and robotics. Lin *et al*. (2024) emphasized the role of explainable AI (XAI) in promoting transparency and clinician trust. However, Khoshbin *et al*. (2023) and Pauwels *et al*. (2020) highlighted challenges such as algorithmic bias, lack of standardized datasets, and ethical concerns related to data security and informed consent.

DISCUSSION

This systematic review provides compelling evidence that artificial intelligence (AI), particularly deep learning models such as convolutional neural networks (CNNs), is reshaping diagnostic and prognostic paradigms in endodontics. Across the 45 studies analyzed, AI demonstrated high performance in radiographic interpretation, anatomical assessment, and outcome prediction, often matching or surpassing human experts. These findings support the growing consensus that AI holds transformative potential in endodontic practice (Setzer *et al*., 2024; Shah *et al*., 2024; Saghiri *et al*., 2023).

Diagnostic Superiority and Clinical Efficiency: One of the most consistent findings across studies was the high accuracy of AI models in detecting periapical lesions. Shah *et al*. (2024) and Mahmoud *et al*. (2023) reported that AI-assisted radiographic analysis achieved sensitivities and specificities exceeding 90%, particularly in CBCT imaging. These results align with Pauwels *et al*. (2020), who emphasized that AI's capacity for spatial recognition enhances early diagnosis, potentially reducing the risk of late-stage endodontic complications. The superiority of AI over general practitioners, and its equivalence to experienced endodontists, reflects its diagnostic consistency and resistance to fatigue-related error. AI also proved effective in complex anatomical assessments. Studies by Pinto *et al*. (2023) and Kaya *et al*. (2022) demonstrated that AI reliably identified root canal morphologies and vertical root fractures—both of which are commonly missed or misinterpreted in conventional exams. Such capabilities can significantly reduce iatrogenic errors during instrumentation and obturation, thereby improving treatment outcomes.

Prognostic Utility and Risk Stratification: The integration of AI into predictive modeling marks a new frontier in personalized endodontic care. Kim *et al*. (2023) and Chakir *et al*. (2023) applied machine learning techniques like XGBoost and random forest to predict surgical outcomes and failure risks. These models, trained on radiographic and clinical features, enabled early identification of high-risk cases, allowing clinicians to modify treatment plans proactively. While promising, the generalizability of these models is still limited by training on homogeneous datasets. Nonetheless, these prognostic tools align with broader movements toward data-driven, personalized dentistry. As suggested by Lee *et al*. (2022), the ability to predict patient-specific outcomes may also enhance communication with patients and improve informed consent processes.

Technical and Ethical Limitations: Despite these strengths, multiple studies identified barriers to clinical integration. Khoshbin *et al*. (2023) and Lin *et al*. (2024) underscored the lack of explainability in most AI models. "Black-box" systems may yield high performance metrics but offer little insight into the rationale behind specific outputs, challenging their integration into medico-legal frameworks. The incorporation of explainable AI (XAI), still in early development stages, will be crucial to bridge this trust gap between algorithmic decision-making and human oversight. Data privacy, algorithmic bias, and the reproducibility crisis in AI research also present ethical and methodological concerns. Many of the reviewed models were trained on institution-specific or small datasets without external validation (Pauwels *et al*., 2020). This raises questions about the applicability of AI across diverse patient populations, particularly in underrepresented regions or healthcare systems with limited digital infrastructure.

Clinical Translation and Future Perspectives: The reviewed literature suggests that AI integration in endodontics is progressing from proof-of-concept toward clinical adoption. Studies such as those by Mupparapu *et al*. (2023) and Kasi *et al*. (2024) demonstrated that AI can reduce diagnostic time by over 30%, improving workflow efficiency in high-volume clinical environments. Moreover, the combination of AI with other technologies—such as augmented reality, robotics, and real-time imaging—has the potential to support intraoperative decision-making, particularly in complex procedures like microsurgeries (Setzer *et al*., 2024). Nevertheless, the path forward requires a multipronged approach: (1) developing large, diverse, and annotated datasets; (2) adopting ethical frameworks for data use and model deployment; (3) fostering interdisciplinary collaboration between engineers, data scientists, and clinicians; and (4) conducting multicenter clinical trials to validate outcomes in real-world settings.

CONCLUSION

This systematic review demonstrated that artificial intelligence, particularly deep learning models, plays a promising role in enhancing diagnosis, anatomical assessment, and outcome prediction in endodontics. AI systems have shown accuracy levels comparable to specialists and offer efficiency gains in clinical workflows. However, limitations such as lack of standardization, limited external validation, and ethical concerns must be addressed. Future efforts should prioritize robust clinical trials, explainable models, and equitable access to ensure safe and effective integration of AI into routine endodontic care.

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