

Artificial Intelligence in Endodontics: A Comprehensive Literature Review

Dr. Vidhi Thakur

Dept. of Conservative Dentistry and Endodontics, Maulana Azad Institute of Dental Sciences, Delhi

ABSTRACT

Artificial Intelligence (AI) has emerged as a transformative force in healthcare, including dentistry, by enhancing diagnostic accuracy, optimizing clinical decision-making, and improving treatment outcomes. Endodontics, a specialty heavily reliant on imaging, diagnosis, and procedural precision, has witnessed rapid integration of AI-based technologies such as machine learning (ML), deep learning (DL), and convolutional neural networks (CNNs). These technologies have demonstrated promising results in tasks including detection of periapical lesions, identification of root canal morphology, working length determination, vertical root fracture detection, prognosis prediction, and outcome assessment of endodontic treatments. This literature review critically examines the evolution, applications, performance, limitations, ethical considerations, and future directions of AI in endodontics. Evidence from recent in-vitro, in-vivo, retrospective, and prospective studies suggests that AI systems can match or exceed human performance in several diagnostic domains, particularly when trained on high-quality datasets. However, challenges related to dataset bias, explainability, clinical validation, regulatory approval, and integration into routine practice remain. This review concludes that AI is poised to play a complementary role in endodontics, augmenting clinician expertise rather than replacing it, and highlights the need for standardized protocols and longitudinal clinical trials.

Keywords: Artificial Intelligence; Endodontics; Machine Learning; Deep Learning; Cone Beam Computed Tomography; Periapical Lesions; Root Canal Morphology; Prognosis Prediction.

INTRODUCTION

Endodontics is a specialized branch of dentistry concerned with the study and treatment of diseases affecting the dental pulp and periapical tissues. The primary objective of endodontic therapy is the prevention and elimination of pulpal and periradicular infection, followed by the restoration of the tooth to full form and function. Despite significant advances in instruments, materials, magnification, and imaging technologies, endodontic diagnosis and treatment planning continue to pose considerable challenges due to the inherent complexity of root canal anatomy, limitations of conventional imaging, and the subjective nature of clinical decision-making.

Accurate diagnosis is the cornerstone of successful endodontic treatment. Clinicians rely on a combination of patient history, clinical examination, pulp sensibility tests, and radiographic evaluation to diagnose pulpal and periapical pathologies. However, conventional diagnostic tools such as periapical radiographs provide only two-dimensional representations of three-dimensional anatomical structures, often resulting in superimposition, distortion, and underestimation of disease extent. Even with the introduction of cone-beam computed tomography (CBCT), which offers three-dimensional visualization, interpretation remains operator-dependent and subject to variability in experience and training. These limitations contribute to diagnostic uncertainty, missed canals, delayed detection of periapical lesions, and inappropriate treatment decisions, which are among the leading causes of endodontic failure.

In parallel with these clinical challenges, dentistry has undergone a rapid digital transformation over the past two decades. Digital radiography, CBCT, operating microscopes, electronic apex locators, rotary and reciprocating instrumentation systems, and computer-assisted documentation have become integral components of modern endodontic practice. The widespread adoption of digital imaging and electronic health records has resulted in the generation of vast amounts of structured and unstructured clinical data. This data-rich environment has created an ideal foundation for the application of Artificial Intelligence (AI) technologies in endodontics.

Artificial Intelligence refers to the capability of computer systems to perform tasks that typically require human intelligence, including learning, reasoning, pattern recognition, and decision-making. In healthcare, AI has gained prominence for its ability to analyze complex datasets, identify subtle patterns, and provide decision support with a level of consistency that is often difficult to achieve through human interpretation alone. In dentistry, AI has been successfully applied in fields such as orthodontics, oral radiology, prosthodontics, and periodontology. More recently, endodontics has emerged as a particularly suitable domain for AI integration due to its heavy reliance on imaging, pattern recognition, and outcome prediction. The application of AI in endodontics has been driven largely by advances in machine learning (ML) and deep learning (DL), particularly convolutional neural networks (CNNs), which have demonstrated exceptional performance in medical image analysis. These algorithms can be trained on large datasets of annotated radiographs or CBCT scans to automatically detect periapical lesions, identify root canal morphology, recognize vertical root fractures, and assess treatment outcomes. Several studies have reported that AI-based systems can achieve diagnostic accuracy comparable to, and in some cases exceeding, that of experienced endodontists, especially in tasks involving radiographic interpretation. Beyond diagnosis, AI has shown potential in multiple stages of the endodontic workflow. Machine learning models have been developed to assist in working length determination, detection of procedural errors, prediction of treatment success, and evaluation of periapical healing following root canal treatment or endodontic surgery. In educational settings, AI-driven platforms are being explored for automated assessment of student performance and simulation-based training. Collectively, these applications suggest that AI has the capacity to enhance precision, reduce variability, and support evidence-based clinical decision-making in endodontics.

Despite the growing body of research, the clinical translation of AI in endodontics remains in its early stages. Most published studies are retrospective or in-vitro in nature, often using limited datasets obtained from single institutions. Variability in study design, imaging protocols, annotation standards, and outcome measures makes it difficult to directly compare results across studies. Furthermore, concerns related to data privacy, algorithmic bias, lack of explainability, and regulatory approval pose significant barriers to widespread adoption. Importantly, AI systems function as supportive tools rather than autonomous decision-makers, and their effectiveness depends on the quality of input data and the clinician's ability to interpret and apply AI-generated outputs appropriately. Given the rapid pace of technological advancement and the increasing interest in AI-assisted dentistry, a comprehensive and critical review of the current literature on artificial intelligence in endodontics is timely and necessary. Understanding the scope of existing applications, their diagnostic and predictive performance, limitations, and future potential is essential for clinicians, educators, and researchers alike.

Therefore, the aim of this literature review is to systematically examine the current evidence on the application of artificial intelligence in endodontics, with a focus on diagnostic imaging, anatomical assessment, treatment planning, prognosis prediction, outcome evaluation, and educational tools. Additionally, this review discusses ethical, legal, and practical considerations associated with AI integration and outlines future research directions required for the responsible and effective implementation of artificial intelligence in endodontic practice.

FUNDAMENTALS OF ARTIFICIAL INTELLIGENCE

Definition and Scope

Artificial Intelligence refers to computational systems capable of performing tasks that typically require human intelligence, such as learning, reasoning, pattern recognition, and decision-making. In healthcare, AI primarily functions as decision-support systems.

Machine Learning (ML)

Machine Learning is a subset of AI where algorithms learn patterns from data without explicit programming. ML models improve performance as they are exposed to more data.

Common ML techniques:

Support Vector Machines (SVM)

Random Forests

k-Nearest Neighbors (k-NN)

Logistic Regression

Deep Learning (DL)

Deep Learning is a subset of ML that uses artificial neural networks with multiple hidden layers to process complex data. DL excels in image analysis, making it particularly suitable for dental radiology.

Convolutional Neural Networks (CNNs)

CNNs are a class of DL models specifically designed for image recognition and segmentation. They are widely used in:

Periapical radiograph interpretation
CBCT image analysis
Lesion detection and classification

RATIONALE FOR AI IN ENDODONTICS

Endodontics presents unique challenges:

- Complex root canal anatomy
- Subtle radiographic changes
- Operator-dependent diagnosis
- High reliance on imaging
- Variability in clinical expertise

AI systems address these challenges by:

- Enhancing diagnostic consistency
- Detecting features invisible to the human eye
- Supporting evidence-based decision-making

AI IN ENDODONTIC DIAGNOSIS

Detection of Periapical Lesions

One of the earliest and most extensively studied applications of AI in endodontics is the detection of periapical pathology.

Periapical Radiographs

Studies using CNN-based models have demonstrated high sensitivity and specificity in identifying periapical radiolucencies, often outperforming general dentists and matching specialist performance.

Advantages:

- Reduced false negatives
- Improved early lesion detection
- Objective interpretation

Limitations:

- Dependence on image quality
- Difficulty distinguishing healing vs scar tissue

CBCT-Based Diagnosis

AI applied to CBCT data provides volumetric lesion detection, superior to 2D imaging. Deep learning models can segment lesions and calculate lesion volume, aiding treatment planning and prognosis.

Detection of Vertical Root Fractures (VRF)

Vertical root fractures are notoriously difficult to diagnose. AI models trained on CBCT images have shown improved accuracy compared to human observers, especially in early or incomplete fractures.

Clinical significance:

- Prevents unnecessary endodontic retreatment
- Improves treatment decision-making
- Reduces diagnostic delay

Identification of Root Canal Morphology

AI has been used to:

- Detect extra canals (e.g., MB2 canals)
- Classify root canal configurations (Vertucci classification)
- Identify C-shaped canals

CNN-based models trained on CBCT datasets demonstrate high accuracy in recognizing complex anatomical variations, significantly reducing missed canals—a major cause of endodontic failure.

AI IN ENDODONTIC TREATMENT PLANNING

Working Length Determination

AI algorithms have been applied to digital radiographs and electronic apex locator data to estimate working length.

Benefits:

- Reduced reliance on subjective interpretation
- Improved consistency
- Potential integration with rotary endodontic motors

Detection of Procedural Errors

AI systems have been trained to detect:

- Ledge formation
- Instrument separation
- Canal transportation
- Root perforations

Such systems are particularly valuable in educational settings, providing real-time feedback to students.

AI IN ENDODONTIC PROGNOSIS AND OUTCOME PREDICTION

Prediction of Treatment Success

Machine learning models incorporating variables such as:

- Lesion size
- Tooth type
- Quality of obturation
- Coronal restoration

Periodontal status have demonstrated promising accuracy in predicting healing outcomes following root canal treatment and endodontic surgery.

Assessment of Healing

AI has been used to longitudinally analyze radiographs and CBCT scans to classify healing as:

- Complete
- Incomplete
- Uncertain
- Failure

This reduces observer bias and improves reproducibility in clinical studies.

AI IN ENDODONTIC EDUCATION AND TRAINING

AI-based platforms are increasingly used in:

- Preclinical simulation
- Radiographic interpretation training
- Automated assessment of student performance

Benefits:

- Objective evaluation
- Immediate feedback
- Standardized assessment criteria

ETHICAL, LEGAL, AND PRACTICAL CONSIDERATIONS

Data Privacy and Security

AI systems require large datasets, raising concerns regarding:

- Patient confidentiality
- Data ownership
- Cybersecurity

Bias and Generalizability

Models trained on limited or homogeneous datasets may not perform well across diverse populations, equipment types, or clinical settings.

Explainability and Trust

“Black box” AI decisions challenge clinician trust. Explainable AI (XAI) models are increasingly emphasized to ensure transparency.

Regulatory and Legal Issues

AI tools must comply with:
Medical device regulations
Clinical validation standards
Medico-legal accountability frameworks

LIMITATIONS OF CURRENT AI APPLICATIONS

Despite promising results, AI in endodontics faces several limitations:

Predominantly retrospective studies
Limited prospective clinical trials
Small dataset sizes
Lack of standardized evaluation metrics
High cost of implementation
AI should currently be viewed as assistive, not autonomous.

FUTURE DIRECTIONS

Key areas for future research include:

Multicenter prospective clinical trials
Integration of AI with dental operating microscopes
Real-time intraoperative AI guidance
Federated learning to improve data diversity
AI-driven personalized endodontic care
The convergence of AI with digital dentistry, robotics, and augmented reality may redefine endodontic practice.

CLINICAL IMPLICATIONS

For clinicians:

AI can enhance diagnostic confidence
Reduces inter-observer variability
Supports evidence-based treatment planning

For educators:

Improves training efficiency
Provides objective assessment tools

For researchers:

Enables large-scale data analysis
Facilitates predictive modeling

CONCLUSION

Artificial Intelligence represents a paradigm shift in endodontics, offering powerful tools to enhance diagnosis, treatment planning, prognosis prediction, and education. Current evidence supports the use of AI as a reliable adjunct to clinician expertise, particularly in radiographic interpretation and anatomical analysis. However, widespread clinical adoption requires rigorous validation, ethical governance, and seamless integration into clinical workflows. As technology advances, AI is expected to play an increasingly central role in precision endodontics, ultimately improving patient outcomes while preserving the clinician’s central role in decision-making.

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