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# Role of AI in Predicting Endodontic Treatment Outcomes

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**ABSTRACT**

The effectiveness of endodontic treatment is a complicated interaction of factors and characteristics of patients, teeth and the procedure itself. Although the techniques and materials have improved, prognosis prediction is a major clinical problem. Artificial intelligence (AI) has become a revolutionary resource in the field of dentistry, as it provides new methods to improve the accuracy of diagnoses and improve the process of treatment planning. Within the field of endodontics, AI-based models, including machine learning algorithms and deep neural networks are being actively used on the imaging data, electronic health records, and clinical parameters to predict the success or failure of treatment. The predictive systems can potentially support clinicians to perform early risk analysis, tailor the therapeutic process, and enhance long-term patient outcomes. Nevertheless, obstacles like heterogeneity of data, ethical issues, and lack of large-scale validation of studies prevent mass adoption. The present paper provides a review of the current role of AI in predicting the outcome of endodontic treatments, its advantages and disadvantages and its future directions by integrating clinically, explaining, and patient-centric AI systems into endodontic practice.

**Keywords**: Artificial Intelligence, Endodontics, Machine Learning, Deep Learning, Predictive Analytics, Treatment Outcomes, Dental Imaging

## 1. INTRODUCTION

Endodontic treatment plays a vital role in preserving natural dentition and maintaining oral function. Despite advancements in diagnostic technologies, biomaterials, and treatment protocols, predicting endodontic treatment outcomes remains a clinical challenge due to the multifactorial nature of prognosis, including patient-related, tooth-related, and procedural variables (Chandra *et al.*, 2021; Kaur, 2022). Traditional diagnostic approaches often rely heavily on radiographic interpretation, clinical expertise, and subjective judgment, which may lead to variability in treatment planning and prognosis estimation (Singh, 2018; Singh, 2020). In this context, artificial intelligence (AI) has emerged as a promising tool to enhance diagnostic accuracy, decision-making, and predictive modeling in endodontics.

AI applications in dentistry have expanded significantly in recent years, with contributions in diagnostic imaging, automated detection of periapical lesions, treatment planning, and prognosis prediction (Khanagar *et al.*, 2021; Agrawal *et al.*, 2022). In endodontics specifically, AI models including machine learning and deep learning algorithms have demonstrated the ability to analyze cone-beam computed tomography (CBCT), periapical radiographs, and electronic health records with a level of precision comparable to or surpassing that of experienced clinicians (Hamdan *et al.*, 2022; Bonfanti-Gris *et al.*, 2022). Studies highlight AI's potential to predict outcomes in endodontic microsurgery (Qu *et al.*, 2022) and improve the detection of apical pathologies, thereby supporting clinicians in making evidence-based decisions (Lee *et al.*, 2022; Aminoshariae *et al.*, 2021).

Systematic reviews and scoping analyses have reinforced the transformative role of AI in prognosis prediction, highlighting both its effectiveness and its limitations. While AI has demonstrated considerable potential in enhancing diagnostic workflows, challenges remain in terms of data heterogeneity, limited large-scale clinical validation, and ethical considerations, such as algorithm transparency and bias (Boreak, 2020; Umer & Habib, 2022; Asiri & Altuwalah, 2022). Moreover, integrating AI into clinical practice requires not only technological readiness but also practitioner acceptance and adequate training to interpret AI-driven insights effectively (Singh, 2022; Ahmed *et al.*, 2021).

As dentistry embraces precision medicine, AI-based predictive models present opportunities to individualize

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treatment planning and identify high-risk cases earlier, ultimately improving long-term treatment success rates and patient satisfaction (Rabbani *et al*., 2018; Singh, 2019). However, to fully harness this potential, interdisciplinary research and the establishment of standardized, validated datasets are essential for ensuring clinical reliability (Makkar *et al*., 2016; Singh, 2020). This paper explores the role of AI in predicting endodontic treatment outcomes, examining current applications, benefits, limitations, and future directions for clinical integration.

## 1.1. Clinical Factors Affecting Endodontic Outcomes

The success of endodontic treatment is influenced by a multifactorial interplay of patient, tooth, and procedural considerations. Despite advancements in instrumentation, irrigation protocols, and biocompatible sealers, clinical outcomes remain variable due to these underlying determinants. Understanding these factors is essential for prognosis prediction and for optimizing treatment planning, especially in the context of artificial intelligence (AI)-driven decision support systems.

## 1.2. Patient-Related Factors

Systemic health, age, and immune status significantly impact the healing capacity of periapical tissues. Patients with comorbidities such as diabetes or immunosuppressive conditions often exhibit delayed healing and increased susceptibility to infection (Aminoshariae, Kulild, & Nagendrababu, 2021; Umer & Habib, 2022). Compliance with oral hygiene and recall appointments further contributes to long-term treatment success (Agrawal, Nikhade, & Nikhade, 2022).

## 1.3. Tooth-Related Factors

Tooth anatomy plays a crucial role in determining treatment complexity. Variations in root canal morphology, presence of calcifications, and the type of tooth treated directly influence the likelihood of procedural errors and prognosis (Singh, 2018; Chandra *et al*., 2021). Moreover, the preoperative periapical status particularly the presence of large periapical radiolucencies remains a strong predictor of treatment outcome (Hamdan *et al*., 2022; Lee *et al*., 2022). The structural integrity of the tooth, including remaining dentin thickness and presence of cracks, further affects long-term survival (Kaur, 2022).

## 1.4. Procedural Factors

Technical variables such as canal instrumentation, irrigation dynamics, and obturation quality are directly associated with endodontic outcomes (Singh, 2020; Kaur, 2022). Inadequate debridement or persistent microbial contamination is a leading cause of treatment failure (Boreak, 2020). The choice of obturation materials, including bioceramic-based sealers, has been shown to enhance sealing ability and improve healing rates (Singh, 2019; Kaur, 2022). Operator skill and adherence to evidence-based protocols also play a decisive role in prognosis (Qu *et al*., 2022).

## 1.5. Technological and Diagnostic Support

Advanced imaging modalities such as cone-beam computed tomography (CBCT) improve visualization of complex anatomy and periapical pathology, thereby supporting more accurate diagnosis and treatment planning (Singh, 2018; Bonfanti-Gris *et al*., 2022). Recent studies highlight the growing role of AI and machine learning in enhancing diagnostic accuracy and predicting prognostic outcomes, providing clinicians with valuable adjunctive support in identifying high-risk cases (Asiri & Altuwalah, 2022; Singh, 2022).

Clinical outcomes in endodontics are shaped by a combination of biological, anatomical, and procedural variables. The integration of AI-driven predictive models, trained on these multifactorial inputs, offers a promising pathway toward personalized and evidence-based endodontic care (Ahmed *et al*., 2021; Khanagar *et al*., 2021).

## 1.6. AI in Dentistry: Current Applications

Artificial intelligence (AI) has made significant strides in dentistry, particularly in diagnostic imaging, decision-making, and prognosis prediction. Its capacity to analyze complex datasets with high accuracy makes it a valuable adjunct to conventional clinical methods (Aminoshariae, Kulild, & Nagendrababu, 2021; Agrawal, Nikhade, & Nikhade, 2022).

## 1.7. Diagnostic Imaging and Lesion Detection

One of the most prominent applications of AI in dentistry is in image-based diagnostics. Deep learning algorithms have been successfully applied to radiographs and cone-beam computed tomography (CBCT) scans for detecting periapical lesions, caries, and other pathologies with accuracy comparable to, and sometimes surpassing, that of experienced clinicians (Hamdan *et al*., 2022; Singh, 2018). AI systems can enhance diagnostic consistency by minimizing human subjectivity, thus improving early detection and case planning (Bonfanti-Gris *et al*., 2022).

## 1.8. Decision Support and Treatment Planning

AI-based tools are increasingly integrated into treatment planning workflows. In endodontics, neural networks and machine learning models help clinicians evaluate complex variables, such as canal anatomy, pulp status, and restorative prognosis, enabling more evidence-based decisions (Asiri & Altuwalah, 2022; Lee *et al*., 2022). For instance, AI models have been shown to predict the prognosis of endodontic microsurgeries by incorporating clinical and imaging features into risk stratification systems (Qu *et al*., 2022).

## 1.9. Prognosis and Outcome Prediction

Beyond diagnosis, AI holds strong potential in predicting treatment outcomes. By analyzing historical treatment data, patient demographics, and clinical parameters, machine learning algorithms can identify risk factors for failure or success, supporting personalized care (Boreak, 2020; Singh, 2022). Recent reviews suggest that such predictive models can reduce retreatment rates and optimize resource allocation in dental practice (Umer & Habib, 2022; Khanagar *et al*., 2021).

## 1.10. Broader Applications Across Dentistry

AI has also been explored in prosthodontics, orthodontics, and restorative dentistry, reflecting its wide applicability. For example, AI has been used to detect fractures, evaluate restoration margins, and improve irrigation dynamics in endodontics (Chandra *et al*., 2021; Singh, 2020; Kaur, 2022). Moreover, AI-enabled systems have been trialed for automated classification of dental structures and restorations on panoramic radiographs, reducing the workload on clinicians (Bonfanti-Gris *et al*., 2022).

Collectively, these developments highlight AI's emerging role as a diagnostic and prognostic tool in dentistry. However, despite promising progress, challenges such as data standardization, model transparency, and clinical validation remain significant barriers to routine adoption (Ahmed *et al*., 2021; Rabbani *et al*., 2018).

## 1.11. AI Models for Predicting Endodontic Outcomes

Artificial intelligence (AI) models have shown promising utility in predicting endodontic outcomes by analyzing clinical, radiographic, and procedural data. These models leverage both machine learning (ML) and deep learning (DL) approaches to enhance clinical decision-making and reduce subjectivity in prognosis estimation.

## 1.12. Machine Learning Approaches

Traditional ML models, including decision trees, random forests, and support vector machines (SVM), have been employed in endodontics to identify predictors of treatment success. For example, ML models trained on patient demographics, tooth anatomy, and preoperative radiographs have demonstrated the ability to classify cases with higher or lower risk of treatment failure (Boreak, 2020; Umer & Habib, 2022). Such models can aid clinicians in case selection and treatment planning by systematically integrating variables that are often assessed subjectively in routine practice (Ahmed *et al*., 2021).

## 1.13. Deep Learning Models

Deep learning, particularly convolutional neural networks (CNNs), has revolutionized dental imaging analysis. These models are highly effective in detecting periapical lesions, root fractures, and assessing healing after endodontic microsurgery (Hamdan *et al*., 2022; Qu *et al*., 2022). In a recent study, machine learning models achieved notable accuracy in prognosis prediction following endodontic microsurgery, demonstrating that AI can complement clinical expertise in outcome prediction (Qu *et al*., 2022). Similarly, deep-learning-based diagnostic tools have improved the accuracy and efficiency of radiographic interpretation compared to conventional methods (Lee *et al*., 2022; Bonfanti-Gris *et al*., 2022).

## 1.14. Hybrid and Integrative Models

Emerging research highlights the value of hybrid models that integrate clinical records, imaging data, and procedural details into comprehensive predictive systems. Such approaches enable individualized risk profiling, which is particularly valuable in complex cases with anatomical variations or compromised host factors (Aminoshariae, Kulild, & Nagendrababu, 2021; Singh, 2022). For example, AI systems trained on cone-beam computed tomography (CBCT) datasets can detect subtle anatomical anomalies and link them to treatment prognosis, offering a level of precision beyond human interpretation (Singh, 2018; Asiri & Altuwalah, 2022).

## 1.15. Applications in Prognostic Prediction

Recent systematic reviews emphasize that AI-based prediction models can identify prognostic indicators such as apical periodontitis, lesion size, root morphology, and operator variables, thereby guiding clinicians in both surgical and nonsurgical endodontic strategies (Khanagar *et al*., 2021; Umer & Habib, 2022). Furthermore, studies suggest that integrating AI with newer biomaterials and techniques—such as bioceramic sealers and irrigation dynamics—can further refine prognosis prediction and treatment outcomes (Singh, 2020; Kaur, 2022).

## 1.16. Clinical Translation

While AI-driven models show strong performance in experimental and controlled settings, translation into clinical practice remains limited due to challenges such as data heterogeneity, lack of standardized validation, and concerns regarding explainability (Agrawal, Nikhade,

& Nikhade, 2022; Rabbani *et al*., 2018). Nevertheless, the potential of AI in providing objective, data-driven prognostic insights makes it an essential adjunct to clinical expertise in modern endodontics.

## 2. CONCLUSION

Artificial intelligence has demonstrated significant promise in revolutionizing endodontic practice by enhancing diagnostic precision, treatment planning, and outcome prediction. Evidence indicates that machine learning and deep learning models can successfully analyze clinical, radiographic, and patient-specific variables to forecast prognosis with high accuracy (Qu *et al*., 2022; Lee *et al*., 2022). These tools not only support clinicians in decision-making but also offer the potential for personalized treatment strategies, ultimately improving patient care and long-term outcomes (Aminoshariae *et al*., 2021; Singh, 2022).

Despite these advances, challenges persist. Data heterogeneity, limited standardized datasets, and the need for external validation restrict the clinical translation of many AI models (Umer & Habib, 2022; Boreak, 2020). Moreover, ethical concerns such as algorithmic bias, interpretability, and practitioner acceptance must be addressed to ensure responsible integration into clinical workflows (Asiri & Altuwalah, 2022; Khanagar *et al*., 2021). Importantly, recent applications in radiographic interpretation and lesion detection suggest that AI can augment, rather than replace, the expertise of endodontists (Hamdan *et al*., 2022; Bonfanti-Gris *et al*., 2022).

Looking forward, the integration of multimodal data—including imaging, clinical records, and biomaterial advancements such as bioceramic sealers—can further strengthen predictive models and improve therapeutic outcomes (Kaur, 2022; Singh, 2020). Interdisciplinary collaborations between dental clinicians, computer scientists, and bioinformaticians are essential to develop robust, explainable AI systems that meet regulatory standards and build trust among practitioners and patients alike (Ahmed *et al*., 2021; Rabbani *et al*., 2018).

In conclusion, AI holds transformative potential in predicting endodontic treatment outcomes, yet its widespread adoption depends on addressing current limitations through rigorous clinical trials, standardization of datasets, and the development of transparent, clinician-friendly systems. If these challenges are systematically tackled, AI-driven tools will become an indispensable component of precision endodontics in the near future.

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