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AI FOR CHAIRSIDE PATIENT-SPECIFIC ENDODONTIC PLANNING

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ABSTRACT

Artificial intelligence (AI) has emerged as a transformative tool in endodontics, offering new possibilities for chairside, patient-specific treatment planning. Traditional approaches to endodontic decision-making rely heavily on clinician expertise, imaging interpretation, and empirical guidelines, which may be subject to variability and human error. By integrating machine learning (ML) and deep learning (DL) algorithms with diagnostic imaging modalities such as cone-beam computed tomography (CBCT) and periapical radiographs, AI enables rapid, data-driven analyses to guide treatment strategies. Chairside applications of AI can assist clinicians in real-time by evaluating tooth morphology, predicting treatment outcomes, identifying risks such as instrument separation or canal transportation, and optimizing individualized treatment plans. This personalized approach not only improves accuracy and efficiency but also enhances patient trust and communication. Despite promising advances, challenges remain in clinical integration, data standardization, and validation of AI models in diverse populations. This paper explores the role of AI in chairside patient-specific endodontic planning, its benefits, limitations, and future implications for precision dentistry.

KEYWORDS: *Artificial intelligence; Endodontics; Chairside Planning; Patient-Specific Treatment; Cone-Beam Computed Tomography (CBCT); Machine Learning; Deep Learning; Precision Dentistry.*

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INTRODUCTION

Endodontic treatment planning is a complex clinical process that requires careful assessment of patient-specific factors, including tooth anatomy, pathology, systemic health, and procedural risks. Conventional planning approaches depend largely on clinician experience and diagnostic imaging interpretation, which can lead to variability in decision-making and treatment outcomes. The emergence of artificial intelligence (AI), powered by machine learning (ML) and deep learning (DL) algorithms, has introduced novel opportunities for enhancing precision and consistency in dental care. AI systems are capable of processing large volumes of clinical and radiographic data with high accuracy, providing real-time insights that support patient-specific endodontic planning at the chairside. Through advanced image recognition, predictive modeling, and risk assessment, AI can identify anatomical complexities, anticipate potential complications, and recommend optimized treatment strategies tailored to the individual patient. Integration of AI into clinical practice has the potential to improve efficiency, reduce errors, and facilitate shared decision-making with patients by offering evidence-based, personalized treatment recommendations. Recent studies highlight the growing utility of AI in diagnostic imaging, outcome prediction, and clinical decision support within endodontics. However, widespread implementation remains limited due to challenges related to model training, clinical validation, data standardization, and ethical considerations. As technology advances, AI-driven chairside systems are expected to play a pivotal role in precision endodontics, shifting the paradigm from generalized treatment protocols toward personalized care pathways.

IMPORTANCE OF INDIVIDUALIZED ENDODONTIC PLANNING

Individualized endodontic planning is essential for predictable treatment outcomes and long-term tooth preservation (Nguyen et al., 2023). Each patient's unique anatomical variations, systemic health factors, and biological responses directly influence the complexity and prognosis of root canal therapy. Conventional approaches, which often rely heavily on generalized guidelines and clinician expertise, may fail to fully account for these patient-specific differences, potentially leading to variability in outcomes and even treatment failures. By adopting a precision-based approach, clinicians can tailor treatment plans to address variations in root canal morphology, degree of curvature, presence of periapical pathology, and patient-related risk factors such as age, immune status, and systemic health conditions. This individualized planning not only improves case selection but also minimizes procedural complications, ensuring more predictable outcomes (Kumar et al., 2023). Furthermore, it enhances communication between clinicians and patients, helping patients better understand their diagnosis, associated risks, and the rationale for recommended treatments. As dentistry continues to evolve toward a precision medicine model, individualized endodontic planning bridges the gap between evidence-based protocols and real-world patient needs, resulting in care that is both scientifically rigorous and patient-centered.

LIMITATIONS OF CONVENTIONAL APPROACHES

Conventional approaches to endodontic planning have traditionally relied on two-dimensional (2D) radiographs, empirical guidelines, and practitioner experience. While these methods have played a key role in the evolution of endodontics, they present notable limitations when applied to complex or patient-specific cases (Silva et al., 2023). Two-dimensional imaging often fails to capture the intricate three-dimensional (3D) anatomy of the root canal system, making it difficult to accurately identify canal configurations, curvatures, and accessory canals (Kumar et al., 2023). This limitation increases the risk of missed canals, procedural errors, or incomplete cleaning and shaping, ultimately compromising treatment success. Another challenge is the subjective nature of diagnostic interpretation. Variability in clinician expertise, differences in training, and reliance on personal judgment can result in inconsistent treatment planning and variable outcomes. Moreover, traditional protocols often follow standardized approaches that fail to adequately address individual patient differences, such as unique anatomical features, systemic health considerations, and healing capacities (Wang et al., 2023). Additionally, conventional planning lacks predictive analytics or real-time decision-support tools, making it difficult to anticipate complications and provide proactive care (Zhu et al., 2023). These constraints highlight the need for advanced technologies, including artificial intelligence (AI), to improve diagnostic accuracy, reduce clinician variability, and support fully individualized treatment planning at the chairside.

EMERGENCE OF AI IN PRECISION DENTISTRY

The integration of artificial intelligence (AI) into dentistry represents a transformative shift toward precision-based care, enabling treatments that are tailored to the unique needs of each patient (Silva et al., 2023). Advances in machine learning (ML) and deep learning (DL) have empowered AI systems to analyze complex datasets including clinical records, radiographs, and three-dimensional (3D) imaging with speed and accuracy that often surpass traditional diagnostic methods. In endodontics, these advancements are particularly impactful, as they address the challenges posed by intricate root canal anatomy and patient-specific biological variability, both of which strongly influence treatment outcomes. AI technologies have shown remarkable potential in automated image interpretation, disease detection, and predictive risk modeling, helping to minimize reliance on subjective clinical judgment (Wang et al., 2023). By integrating AI with advanced chairside technologies such as cone-beam computed tomography (CBCT) and digital intraoral scanning, clinicians can access real-time diagnostic insights and evidence-based treatment recommendations. This integration not only improves diagnostic precision but also supports personalized planning strategies that consider anatomical complexity and patient risk profiles (Santos et al., 2023). The emergence of AI in precision dentistry aligns with a broader movement toward data-driven healthcare, where predictive analytics and clinical decision support systems are central to improving patient outcomes. In this evolving paradigm, AI serves as a bridge between large-scale clinical evidence and individualized care delivery, laying the foundation for a new era of patient-centered endodontics (Patel et al., 2023).

AIM OF THE PAPER

The aim of this paper is to investigate the transformative role of artificial intelligence (AI) in advancing chairside, patient-specific endodontic planning, with a focus on its applications, benefits, and limitations within the framework of precision dentistry. This paper seeks to demonstrate how AI-driven technologies can enhance diagnostic accuracy, predict treatment outcomes, and facilitate individualized clinical decision-making. Furthermore, it addresses the challenges of integrating these technologies into routine dental practice, emphasizing their potential to improve workflow efficiency, patient outcomes, and the overall quality of care. Ultimately, this work aims to provide a comprehensive perspective on how AI can revolutionize endodontic planning by shifting it toward a more data-driven, accurate, and patient-centered model.

ROLE OF DIGITAL WORKFLOWS IN PATIENT-SPECIFIC CARE

Digital workflows have significantly transformed dentistry by providing precise, efficient, and individualized treatment strategies that enhance patient-specific care (Silva et al., 2023). In endodontics, advanced technologies such as cone-beam computed tomography (CBCT), intraoral scanners, and computer-aided design/computer-aided manufacturing (CAD/CAM) systems have introduced detailed three-dimensional visualizations that surpass the limitations of traditional two-dimensional imaging (Kumar et al., 2023). These innovations allow clinicians to accurately analyze root canal anatomy, assess periapical lesions, and plan interventions tailored to each patient’s unique anatomical and clinical characteristics. The integration of these digital tools into a unified workflow also improves case predictability by consolidating radiographic data, clinical records, and diagnostic findings, enabling a comprehensive approach to treatment planning. This interconnected system reduces procedural risks, enhances diagnostic accuracy, and equips clinicians with actionable insights to anticipate potential complications. Additionally, digital workflows promote more effective patient communication through visual treatment presentations, fostering better understanding and involvement in care decisions (Nguyen et al., 2023). When combined with artificial intelligence (AI), digital workflows advance precision dentistry by delivering real-time, data-driven recommendations that optimize both clinical efficiency and treatment outcomes. This synergy between AI and digital tools represents a pivotal step toward a fully personalized approach in endodontics, where every decision is informed by comprehensive, patient-specific data.

AI INTO DENTAL IMAGING AND DIAGNOSTICS

The incorporation of artificial intelligence (AI) into dental imaging and diagnostics represents one of the most transformative technological advancements in modern dentistry (Silva et al., 2023). Traditional diagnostic methods, while effective, are often limited by human interpretation, operator variability, and the inherent constraints of two-dimensional imaging, which may hinder the accurate detection of complex anatomical details. AI, particularly through machine learning (ML) and deep learning (DL) algorithms, has demonstrated the ability to process vast amounts of radiographic and clinical data with remarkable speed and precision, significantly enhancing diagnostic reliability and reducing subjectivity. In dental imaging, AI-based systems have been successfully applied to various diagnostic tasks, including the detection of periapical lesions, assessment of root canal morphology, identification of vertical root fractures, and differentiation between healthy and diseased tissues. When integrated with cone-beam computed tomography (CBCT) and periapical radiographs, AI enables three-dimensional analysis and automated recognition of anatomical structures that may otherwise be overlooked during manual interpretation. This integration not only minimizes diagnostic errors but also supports early detection and intervention, both of which are essential for achieving predictable endodontic outcomes (Kumar et al., 2023). Moreover, AI-powered diagnostic tools provide real-time, chairside assistance, delivering evidence-based insights that enhance clinical decision-making and enable individualized treatment planning. As ongoing research continues to validate these technologies, AI is steadily transforming conventional diagnostic workflows into data-driven systems that underpin the future of precision endodontics.

CORE FUNCTIONS OF AI IN ENDODONTICS: IMAGE ANALYSIS, PATTERN RECOGNITION, AND PREDICTIVE MODELING

Artificial intelligence (AI) has emerged as a transformative tool in endodontics, performing essential functions that significantly enhance diagnostic accuracy and clinical decision-making (Silva et al., 2023). Among these functions, image analysis, pattern recognition, and predictive modeling represent the foundation of AI-driven innovations in chairside, patient-specific care. Image analysis enables AI systems to process and interpret radiographic and cone-beam computed tomography (CBCT) images with exceptional precision (Kumar et al., 2023). Unlike traditional visual assessment, AI algorithms are capable of evaluating complex three-dimensional anatomical structures, identifying intricate root canal morphology, and detecting subtle periapical pathology while minimizing operator bias. This automation addresses the limitations of human perception, such as the tendency to overlook fine details or early-stage lesions (Nguyen et al., 2023). Pattern recognition further strengthens AI's role by identifying recurring anatomical and pathological features within vast datasets. Trained on thousands of annotated dental images, AI models can accurately distinguish between normal and abnormal findings, identify anatomical variations, and flag procedural risk factors, thereby supporting diagnostic consistency across clinicians with varying expertise levels (Singh et al., 2022). Predictive modeling leverages machine learning (ML) and statistical algorithms to anticipate treatment outcomes using patient-specific data (Kumar et al., 2023). By integrating imaging findings, medical history, and procedural factors, AI can forecast the likelihood of complications such as canal transportation, instrument separation, or post-operative pain, enabling proactive planning and patient counseling (Rodriguez et al., 2023). Together, these three core functions image analysis, pattern recognition, and predictive modeling demonstrate how AI reduces diagnostic variability, supports precision treatment planning, and enhances patient-specific care, establishing its role as a cornerstone of modern endodontics.

HOW AI INTEGRATES WITH CBCT AND RADIOGRAPHIC DATA

Artificial intelligence (AI) integrates seamlessly with cone-beam computed tomography (CBCT) and conventional radiographic imaging to enhance diagnostic precision and enable personalized endodontic care. CBCT provides detailed three-dimensional visualization of dental and maxillofacial structures, while periapical and panoramic radiographs remain critical for initial assessment and follow-up evaluations (Jones & Patel, 2022). However, interpretation of these imaging modalities often depends on clinician expertise and is subject to variability, making automated, AI-assisted analysis a valuable tool in modern practice (Lee et al., 2021). AI algorithms address these limitations by automating image evaluation, extracting clinically relevant features, and providing real-time diagnostic support. In particular, convolutional neural networks (CNNs) trained on CBCT datasets can segment intricate anatomical structures, such as root canals, periapical tissues, and surrounding bone, with exceptional accuracy (Kumar et al., 2022). This technology facilitates precise mapping of canal morphology, detection of accessory canals, and early identification of periapical pathology, reducing the risk of oversight during manual interpretation (Chen & Park, 2023). Similarly, AI applied to two-dimensional radiographs improves diagnostic reliability by detecting subtle radiolucencies, apical lesions, or early signs of structural compromise that may be missed by the human eye.

DIAGNOSTIC SUPPORT: AUTOMATED INTERPRETATION OF PERIAPICAL AND CBCT IMAGES

Artificial intelligence (AI) provides significant diagnostic support in endodontics through the automated interpretation of periapical radiographs and cone-beam computed tomography (CBCT) images (Smith et al., 2023). Conventional diagnostic approaches rely heavily on clinician expertise, but visual interpretation can be influenced by fatigue, variability in experience, and the inherent limitations of two-dimensional imaging (Jones & Patel, 2022). AI systems, particularly those leveraging deep learning algorithms, are capable of analyzing imaging data with high precision, offering consistent and objective assessments that improve diagnostic accuracy. In periapical radiographs, AI has demonstrated the ability to detect subtle radiolucencies, periapical lesions, early-stage infections, and trabecular bone pattern changes that may be difficult for clinicians to identify unaided (Lee et al., 2021). Early detection enabled by AI contributes to timely intervention, reducing the risk of disease progression and improving overall prognosis (Brown et al., 2022). With CBCT imaging, AI further enhances diagnostic reliability by segmenting complex three-dimensional anatomical structures, mapping canal morphology, and identifying pathological changes such as periapical cysts, granulomas, and root fractures (Kumar et al., 2022). Automated CBCT analysis minimizes the likelihood of missed canals or overlooked anatomical variations, which are common contributors to endodontic treatment failure (Nguyen & Zhao, 2023). By delivering rapid, objective, and reproducible image interpretation, AI strengthens clinical decision-making and significantly reduces diagnostic errors. Integrating AI-driven diagnostic tools into chairside workflows improves efficiency, supports clinician-patient communication, and promotes a more personalized approach to endodontic care.

IMPROVED ACCURACY AND EFFICIENCY

The integration of artificial intelligence (AI) into endodontic planning significantly enhances both accuracy and efficiency, addressing limitations commonly associated with conventional diagnostic and treatment approaches (Smith et al., 2023). Traditional interpretation of radiographs and cone-beam computed tomography (CBCT) scans relies heavily on clinician expertise, which can introduce variability and lead to inconsistent outcomes (Jones & Patel, 2022). AI systems, particularly those employing deep learning algorithms, reduce this variability by providing standardized, objective, and highly precise analyses of imaging data (Wang et al., 2023). This results in more reliable identification of canal morphology, detection of periapical pathology, and recognition of subtle anatomical variations that may be overlooked by human assessment (Lee et al., 2021). Beyond diagnostic accuracy, AI improves efficiency by processing large volumes of imaging and clinical data in seconds, whereas manual evaluation is time-consuming and prone to oversight (Brown et al., 2022). Automated segmentation of CBCT images, identification of treatment risks, and prediction of clinical outcomes can now be integrated directly into chairside workflows, providing real-time support during decision-making (Kumar et al., 2022). This streamlined process reduces chairside time, enhances procedural predictability, and improves the overall patient experience (Nguyen & Zhao, 2023). By simultaneously advancing diagnostic precision and accelerating clinical workflows, AI enables clinicians to deliver highly personalized and outcome-driven care with greater confidence.

REDUCED OPERATOR VARIABILITY

One of the most significant advantages of integrating artificial intelligence (AI) into endodontic planning is its ability to reduce operator variability, a common challenge in traditional diagnostic and treatment workflows (Singh et al., 2022). Conventional approaches rely heavily on the clinician's training, experience, and subjective interpretation, which can lead to inconsistent diagnoses and treatment strategies. Variability in interpretation of radiographs or cone-beam computed tomography (CBCT) scans not only affects treatment planning but also contributes to unpredictable patient outcomes (Lee et al., 2021). AI addresses this limitation by providing consistent, objective, and reproducible analyses of imaging and clinical data (Wang et al., 2023). Using advanced machine learning algorithms trained on large datasets, AI systems accurately identify anatomical features, detect pathologies, and predict treatment outcomes with minimal bias. This standardization ensures that both novice clinicians and experienced endodontists receive uniform, evidence-based diagnostic support (Kumar et al., 2022). By reducing reliance on subjective interpretation, AI enhances precision, improves quality of care, and increases patient trust in treatment recommendations. Ultimately, the integration of AI promotes consistency across practitioners, elevating the overall standard of care in modern endodontics.

DISCUSSION

The integration of artificial intelligence (AI) into chairside patient-specific endodontic planning represents a pivotal advancement in precision dentistry. Traditional approaches to treatment planning have long relied on clinician expertise, empirical guidelines, and conventional imaging techniques, all of which are subject to variability and limitations in diagnostic accuracy. AI, particularly through machine learning (ML) and deep learning (DL) models, has the capacity to transform these workflows by providing real-time, evidence-based, and individualized support for clinical decision-making. One of AI's most significant contributions lies in its ability to analyze diagnostic imaging, especially periapical radiographs and cone-beam computed tomography (CBCT). Automated interpretation enhances diagnostic precision by detecting subtle periapical lesions, root fractures, and anatomical complexities that might otherwise be overlooked during visual assessment. In CBCT applications, AI-driven segmentation allows for precise mapping of root canal morphology, identification of accessory canals, and recognition of severe curvatures. These capabilities not only improve treatment planning but also reduce the likelihood of procedural complications, thereby enhancing patient outcomes. AI also plays an essential role in predictive analytics, where algorithms integrate patient-specific data including imaging features, systemic health factors, and treatment history to forecast risks and outcomes. Such predictive modeling helps clinicians anticipate complications like instrument separation, canal transportation, or post-operative pain. This proactive approach enhances treatment predictability and strengthens patient counseling, as risks and expected outcomes can be communicated more clearly. Beyond diagnostic accuracy, AI improves efficiency by dramatically reducing the time required for image interpretation and treatment planning. Automated systems are capable of processing large imaging datasets within seconds, thereby delivering actionable insights directly at the chairside This acceleration of workflows optimizes chairside time, fosters patient engagement, and enables immediate discussions regarding tailored treatment strategies.

CONCLUSION

Artificial intelligence (AI) is rapidly emerging as a transformative tool in chairside patient-specific endodontic planning, bridging the gap between conventional diagnostic methods and the demands of precision dentistry. By leveraging machine learning and deep learning algorithms, AI enhances the interpretation of periapical and CBCT images, supports accurate identification of anatomical complexities, and provides predictive insights into treatment risks and outcomes. These capabilities not only improve diagnostic accuracy and efficiency but also reduce operator variability, ensuring more consistent and evidence-based care across clinicians. While the benefits of AI integration are clear, challenges such as data standardization, model validation, ethical considerations, and clinical adoption remain significant barriers to widespread implementation. Addressing these limitations will be critical in translating AI from research environments into routine chairside practice. Overall, AI has the potential to redefine endodontic treatment planning by enabling personalized, proactive, and patient-centered strategies. As technological advances continue, AI-driven decision-support systems are expected to become an integral part of precision endodontics, ultimately improving treatment predictability, patient trust, and long-term clinical outcomes.

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