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Editorial

Artificial Intelligence in Endodontics: Redefining Precision and Possibilities

Labishetty Karthik[1], Manoj Kumar Reddy Gade[2] and Tejaswi Kala[3]*

[1]*Professor HOD, Department Conservative and Endodontics, Tirumala Institute of Dental Sciences and Research Centre, India*

[2]*Dental Health Informatics and Technology Specialist, Oral Surgery and Implant Centre – Pennsylvania, USA*

[3]*Associate Professor, Department of Public Health Dentistry, Tirumala institute of dental sciences and research centre, Nizamabad, India*

***Corresponding Author:** Tejaswi Kala, Associate Professor, Department of Public Health Dentistry, Tirumala institute of dental sciences and research centre, Nizamabad, India.

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Endodontics has always been a specialty of precision. From diagnosing subtle periapical pathoses to negotiating complex root canal anatomies, clinicians have traditionally relied on their experience, intuition, and radiographic interpretation. Yet, these processes are prone to human error, inter-observer variability, and limitations of human perception. In recent years, artificial intelligence (AI) has emerged as a transformative force across healthcare, and endodontics is no exception. By harnessing the power of machine learning, deep learning, and image recognition, AI is reshaping how clinicians diagnose, plan, and execute treatment while simultaneously influencing education and research.

This editorial explores the applications, benefits, and challenges of AI in endodontics, emphasizing its role as a complement-not a replacement-for clinical expertise.

AI in diagnosis

The accuracy of diagnosis underpins the success of endodontic therapy. Conventional radiographic interpretation often struggles to detect small periapical lesions, vertical root fractures, or complex canal configurations, especially in their early stages. AI, particularly through convolutional neural networks (CNNs), has demonstrated diagnostic accuracies comparable to, and in some cases superior to, human experts.

For instance, AI algorithms have shown high sensitivity and specificity in detecting periapical pathoses from periapical radiographs and cone-beam computed tomography (CBCT) scans, significantly reducing inter-observer variability [1-3]. These systems can identify subtle radiolucencies and patterns imperceptible to the human eye, facilitating earlier diagnosis and intervention. Similarly, AI-based platforms can assist in detecting vertical root fractures, a notoriously challenging condition for clinicians due to radiographic superimposition and the subtlety of fracture lines.

The potential of AI goes beyond replication of clinician performance-it lies in pattern recognition at scale. By analyzing thousands of images, AI can learn features that may escape human perception, thereby enhancing diagnostic precision.

AI in treatment planning and execution

While diagnosis forms the first step, treatment planning is equally critical. AI-based decision-support systems are being developed to integrate clinical findings, radiographic data, and patient-specific variables to recommend treatment modalities-whether nonsurgical root canal therapy, retreatment, or surgical endodontics [4]. Such systems aim to standardize treatment decisions, particularly in borderline or complex cases, thereby reducing inconsistencies across practitioners.

In the operatory, AI is extending its influence into real-time procedural support. Research into AI-assisted navigation systems suggests that clinicians may soon receive guidance for locating calcified or aberrant canals. This is particularly relevant in cases where canal calcification obscures traditional access, often increasing the risk of perforation or excessive dentin removal. Early trials demonstrate that AI-supported navigation can reduce iatrogenic errors while improving efficiency and confidence.

Furthermore, AI holds potential in predicting treatment outcomes. By integrating factors such as tooth morphology, lesion size, patient demographics, and systemic health parameters, AI could one day provide personalized prognostic models, helping clinicians counsel patients more accurately about expected outcomes and risks.

AI in education and training

Endodontic education is another domain where AI is making a strong impact. Simulation-based learning, long used in dental education, is now being enhanced by AI. Intelligent tutoring systems can analyze a student's performance in virtual root canal procedures and provide tailored feedback, accelerating skill acquisition and reducing the learning curve [5].

AI-driven platforms can adapt to individual learners, offering case difficulty based on proficiency levels and even simulating rare or complex cases that students may not otherwise encounter in clinical training. This not only ensures exposure to a broad range of scenarios but also cultivates confidence and competence in young practitioners.

AI in Research

AI is also accelerating progress in endodontic research. One of the most time-consuming aspects of clinical research lies in data annotation and image interpretation. AI systems, once trained, can perform these tasks with high reliability and speed, enabling larger datasets to be analyzed in shorter times [6,7]. For example, automated segmentation of CBCT images for periapical lesion assessment saves significant effort and ensures reproducibility.

Moreover, AI tools can aid in meta-analyses and systematic reviews by rapidly screening literature and extracting data, streamlining evidence synthesis. These applications not only enhance research efficiency but also strengthen the evidence base upon which clinical decisions are made.

Challenges and Ethical Considerations

Despite these advancements, several challenges remain before AI can be fully integrated into routine endodontic practice.

First, algorithm transparency is a major concern. Most AI systems, particularly deep learning models, function as "black boxes," producing outputs without easily interpretable reasoning. Clinicians may hesitate to trust recommendations without understanding the underlying rationale [5,8].

Second, data bias threatens the reliability of AI outputs. If training datasets are not diverse, AI models may underperform when applied to populations or imaging modalities different from those used during training. This could perpetuate diagnostic errors or inequities.

Third, issues of data privacy and medico-legal responsibility require careful regulation. Patient radiographs and clinical data used to train AI models must be anonymized and secured to prevent breaches. Furthermore, in cases of misdiagnosis or treatment failure, it remains unclear whether liability lies with the clinician, the AI developer, or the institution deploying the tool.

Finally, there is the concern of overreliance. While AI can augment clinical reasoning, it cannot replace the nuanced judgment, empathy, and ethical considerations that only a human clinician can provide. The challenge, therefore, lies in balancing technological reliance with human expertise.

The road ahead

The question facing endodontics is not whether AI will be integrated, but how. Responsible adoption requires robust validation, ethical guidelines, and regulatory frameworks that ensure AI en-

hances rather than compromises patient care. Training programs should introduce young clinicians to AI, not as a replacement for skill, but as a partner in decision-making.

As AI tools mature, they are likely to move beyond single-task applications toward comprehensive digital ecosystems that span the diagnostic, treatment planning, and follow-up continuum. This integration could pave the way for precision endodontics, where every treatment is guided not only by clinical expertise but also by data-driven insights tailored to the individual patient.

AI may not replace the endodontist. But the endodontist who embraces AI-leveraging its strengths while safeguarding the irreplaceable human elements of care-will help redefine the standards of excellence in the specialty. In doing so, AI offers not just efficiency, but the potential to transform endodontics into a truly patient-centered, precision-driven field.

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