

Artificial intelligence in endodontics: a systematic review.

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Abstract

Background: In recent years, Artificial Intelligence (AI) has emerged as a transformative force across various healthcare domains, offering innovative tools to support clinical decision-making and improve patient outcomes. In dentistry, especially in endodontics, AI is gaining increasing attention for its ability to enhance diagnostic precision and streamline therapeutic workflows. Endodontic procedures often require high-resolution imaging and accurate interpretation of complex anatomical structures. Empowered by machine learning and deep learning algorithms, AI can analyse large datasets derived from radiographic sources, such as Cone Beam Computed Tomography (CBCT), periapical intraoral radiographs, and panoramic images, with the potential to assist in detecting root canal calcifications, segmenting periapical lesions, assessing treatment quality, and predicting prognosis. Despite promising preliminary findings, a systematic evaluation of AI's practical applications and performance in endodontics is needed to understand its true clinical value and future integration into routine practice.

Conclusions: Artificial Intelligence (AI) demonstrates strong potential in endodontics, offering diagnostic accuracy comparable to that of expert clinicians and enabling personalized treatment planning through advanced image analysis. Its potential extends to education, supporting students and practitioners in interpreting complex cases. Nonetheless, widespread adoption remains limited by challenges such as the need for robust datasets, technical and financial demands, and the predominance of retrospective studies. Future research should focus on prospective validation, improved model transparency, and ethical integration to fully realize AI's potential to enhance clinical outcomes.

Keywords: Artificial Intelligence; Endodontics; Dental Radiology

Introduction

In recent years, Artificial Intelligence (AI) has been transforming various sectors of modern society. The medical field, in particular, is seeing the introduction of innovative AI-driven solutions to enhance diagnostic accuracy and therapeutic outcomes. Dentistry is no exception, and the field of endodontics is beginning to reap the benefits from these emerging digital tools (1).

Endodontics demands a high level of diagnostic precision, technical expertise, and advanced instrumentation to treat pulpal and periapical pathologies effectively. AI, through its capabilities in data analysis and machine learning, is a valuable tool for supporting clinicians in selecting the most effective, personalized treatment strategies. By rapidly processing large volumes of data derived from commonly used radiographic examinations, such as Cone Beam Computed Tomography (CBCT) (2, 3, 4), intraoral periapical radiographs (5, 6, 7, 8), and panoramic imaging (8, 9, 10, 11), alongside clinical studies, AI can significantly optimize clinical decision-making processes.



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Moreover, machine learning algorithms have the potential to enhance diagnostic workflows by detecting root canal calcifications (12), assessing the quality of root canal fillings (13), identifying early signs of vertical root fractures (14, 15, 16, 17, 18, 19) segmenting and characterizing periapical lesions (20, 21, 22, 23), predicting post-operative pain (24), and recognizing complex anatomical variations (2, 8, 25, 26).

This experimental scientific work also aims to evaluate the practical applications, benefits, and future perspectives of AI in endodontics. The ultimate goal would be to highlight the potential of AI technologies to reduce clinical errors and support dental professionals in formulating treatment plans tailored to each case.

Materials and Methods

This review has been registered in the PROSPERO database: ID 1115754.

Methodological Framework

This systematic review was conducted in accordance with the PRISMA guidelines to address the following research question:

“Which types of Artificial Intelligence (AI) approaches are applied in endodontics, and to what extent and in what ways does AI improve diagnostic accuracy, decision-making quality, and treatment outcomes in endodontic procedures?”

PICOS, which stands for population, intervention, comparison, outcome, and study design, was used to formulate this systematic review.

Digital computerized dental technologies, representations of the clinical environment, apical, bitewing, orthopantomographic, and CBCT radiographs, are increasingly integrated into endodontic diagnostics and treatment planning. This review’s core focus is the application of artificial intelligence (AI), including natural language processing and deep learning algorithms, in endodontics, particularly for image segmentation, treatment planning, assessment of treatment quality, and prognosis prediction.

This PICOS-based analysis takes into account:

- Population (P): Adult patients requiring or having undergone endodontic treatment.
- Intervention (I): Use of AI-based tools for the evaluation and segmentation of dental radiographs (orthopantomographs, periapical intraoral images, CBCT), and for aiding clinical decisions related to treatment planning, quality assessment, and prognosis estimation.
- Comparison (C): Semi-automated AI methods with human supervision, fully automated AI approaches without human supervision, traditional diagnostic techniques, or no direct comparison (in performance-assessment studies).
- Outcomes (O):
 - Primary outcomes: sensitivity and diagnostic accuracy.
 - Secondary outcomes: prognostic performance, intersection over union (IoU), Dice similarity coefficient (DSC), execution time, precision, and specificity.

- Study design (S):
 - Systematic Review: the included evidence is derived from retrospective studies, in vivo retrospective studies, and pilot retrospective studies, providing a broad spectrum of data on the application of AI in endodontics.

By focusing on these outcomes, the review aims to evaluate the diagnostic and prognostic value of AI technologies in endodontics and to assess their impact on clinical decision-making and efficiency across different imaging modalities and clinical workflows.

Search Strategy

To evaluate machine learning applications in dentistry, particularly neural networks in endodontics, this systematic review was conducted between December 2024 and June 2025 using the following electronic databases: MEDLINE/PubMed, Scopus, Cochrane Library, and ISI Web of Science. The search strategy included the following keywords and terms, adapted to the specific indexing rules of each database: “AI,” “Endodontics,” “AI networks,” “Artificial Intelligence,” “Deep learning,” “Periapical lesions,” “Pulp cavity segmentation,” “Machine learning,” and “Tooth segmentation.”

The studies have been selected based on publication type—randomized controlled trials (RCTs) and experimental studies—considering factors such as sample size, citation count, and the number of contributing authors. Graphical data representation was performed using RStudio, version 5.4.1.

The review thus included 13 studies that met the inclusion criteria, as depicted in Figure 1.

Criteria of exclusion and inclusion

Criteria for Inclusion

- (a) Scientific studies focused on the application of Artificial Intelligence in endodontics;
- (b) Articles published between January 1, 2015, and June 2025;
- (c) Studies with clearly defined interventions aimed at the development, training, validation, and testing of AI models;
- (d) Studies that reported quantifiable outcome measures to evaluate the performance of the AI system.

Criteria for Exclusion

- (a) Articles not available in full text;
- (b) Publications not peer-reviewed (e.g., conference abstracts, unpublished theses);
- (c) Review articles, editorials, and letters to the editor;
- (d) Studies not directly relevant to the field of endodontics;
- (e) Studies focusing exclusively on Artificial Intelligence without application to endodontics;
- (f) Studies dealing solely with endodontics without any reference to AI applications.

Results

In this systematic review, 392 articles were initially identified through searches across several databases,

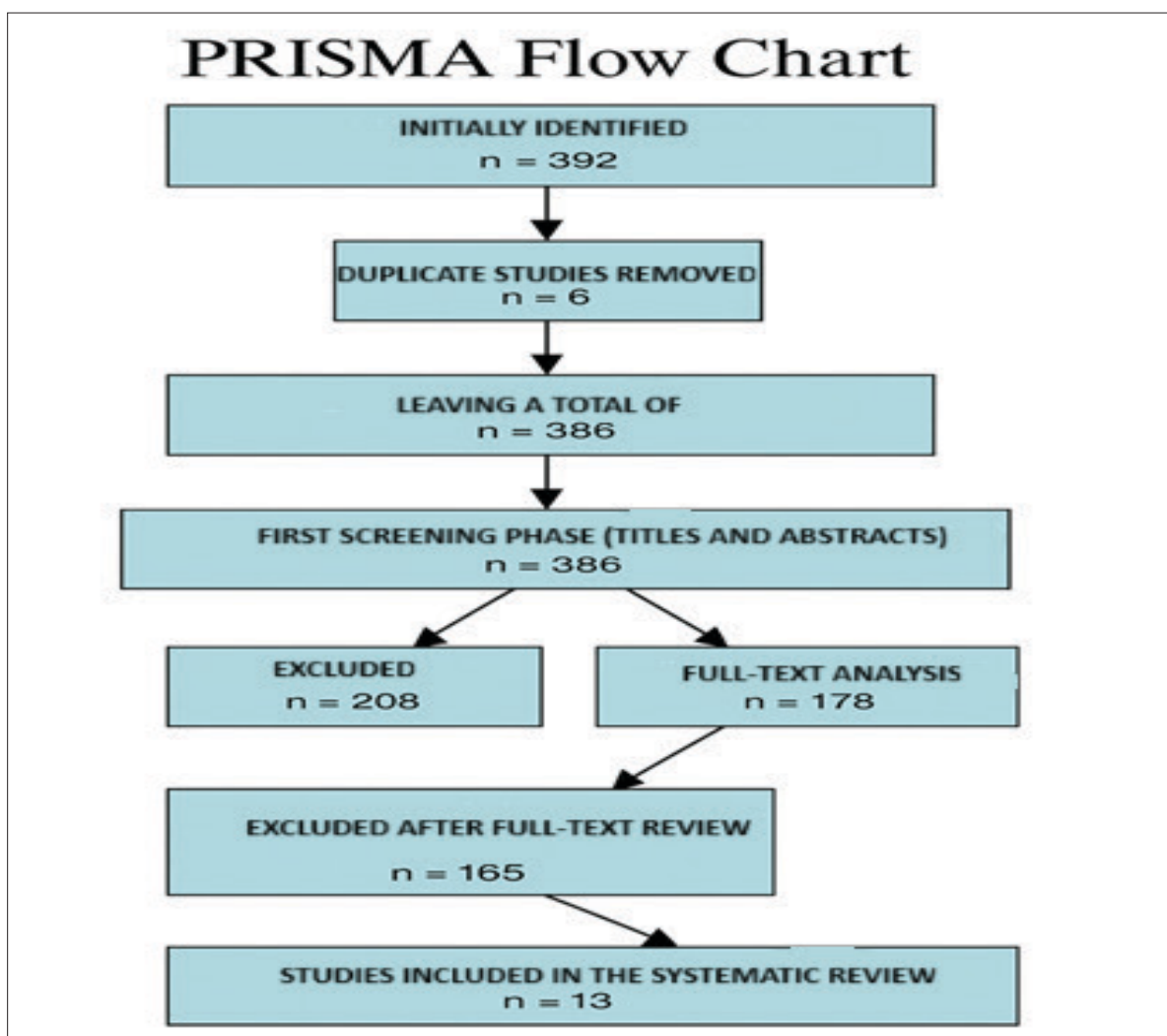


Figure 1. The Prisma flow chart was employed to identify pertinent studies for this review.

including PubMed, Scopus, the Cochrane Library, and ISI Web of Science. After removing 6 duplicate studies, 386 articles remained for evaluation.

The first screening phase involved analysing titles and abstracts, during which 208 articles were excluded because they did not meet the predefined inclusion criteria. The remaining 178 articles underwent a full-text assessment. In this second phase, 165 articles were excluded for the following primary reasons:

- lack of practical applications or implementation of Artificial Intelligence within the clinical endodontic context,
- studies of a purely theoretical or engineering nature without clinical implications,
- narrative reviews.

At the conclusion of the selection process, 13 studies were deemed eligible and included in this systematic review, as they fully met the inclusion criteria by specifically addressing the application of Artificial Intelligence in endodontics and by presenting a sound scientific methodology (Table 1).

Artificial Intelligence (AI), with its capabilities in data analysis and machine learning, can serve as a

valuable tool to support clinicians in selecting the most effective personalized treatment by processing large datasets derived from commonly used radiographic investigations, such as Cone Beam Computed Tomography (CBCT), intraoral periapical radiographs, and panoramic radiography.

In the present experimental study, has been evaluated the performance of AI models in the field of endodontics by analysing their accuracy and sensitivity. These parameters are essential for validating the clinical reliability of such algorithms and ensuring their utility in diagnostic support and treatment planning.

Three-dimensional segmentation of the pulp chamber and root canal system represents a critical step within the digital endodontic workflow, as it could enable highly accurate automated segmentation with minimal processing time (Figure 2).

In the Figure 2, we compare sensitivity values, which refer to the ability to correctly identify the presence of an anatomical structure or pathology.

The blue icon represent the sensitivity of artificial intelligence (AI), while the green one represent that of dentists.

Table 1. Studies included in the Systematic Review.

| Author and year | Software Used | Study design | Dataset (e.g., number of teeth, radiographs, images, patients) | Aim of the Study | Results |
|-------------------------------|-----------------------|---------------------|--|--|---|
| Karatas E. et al. 2025 (30) | CNN (Yolo8) | Retrospective study | based on 1,527 images | Evaluation of the Diagnostic Performance of Artificial Intelligence (AI) in Detecting Root Canal Orifices Using Images Acquired with an Operating Microscope ⁷ | The study demonstrated an overall diagnostic accuracy of 85%, sensitivity of 93%, and precision of 92%. |
| Allihaibi et al 2025 (27) | Diagnocat | Retrospective study | images from 376 teeth (860 roots) | Evaluation of the Diagnostic Accuracy of an Artificial Intelligence-Based Platform in the Analysis of Endodontic Treatment Outcomes on Periapical Radiographs Using CBCT as Reference Standard | Sensitivity was 67.3% at the tooth and 54.3% at the tooth root area; Specificity was 82.3% at the tooth and 86.7% at the root area; Accuracy was 76.3% at the tooth and 78.5% at the root area. In comparison, the results obtained by clinicians were: Sensitivity of 49.3% at the tooth and 43.8% at the root area; Specificity of 92.5% at the tooth and 94.5% at the tooth root area; Accuracy of 75.3% at the tooth and 81.6% at the root area |
| Ibraheem W.I. et al 2025 (20) | CADe | Retrospective study | 1,030 teeth from 300 intraoral radiographs | Evaluation of the Diagnostic Accuracy of Artificial Intelligence in Identifying Periodontal and Restorative Dental Conditions (Marginal Bone Resorption, Periapical Lesions, Crowns, Restorations, Caries) on Periapical Intraoral Radiographs | Regarding previous endodontic treatments, the model achieved an accuracy of 98.95%, sensitivity of 97.50%, and specificity of 99.25%. For periapical lesions, the model demonstrated an accuracy of 86.6%, sensitivity of 98.3%, and specificity of 94.7%. |
| Shujun R. et al. 2025 (18) | Machine Learning (ML) | Retrospective study | The study included 887 patients and a total of 941 teeth. | In Vivo Detection of Vertical Root Fractures in Endodontically Treated Teeth Using CBCT: A Comparative Analysis of Machine Learning Models | The Logistic Regression (LR) model achieved an accuracy of 79.9%, sensitivity of 79.2%, specificity of 80.8%, and precision of 85.7%. XGBoost showed the best performance in terms of sensitivity (91.5%) and accuracy (86.3%), with a specificity of 78.1% and precision of 85.8%. CatBoost reached an accuracy of 82.7%, sensitivity of 88.7%, specificity of 74.0%, and precision of 83.2%. LightGBM achieved an accuracy of 83.2%, sensitivity of 84.0%, specificity of 82.2%, and precision of 87.3%. |

To be continued

| | | | | | |
|--------------------------------------|----------------|---------------------------|--|--|---|
| Santos-Junior A. O. et al. 2025 (28) | CNN (3D U-net) | Retrospective study | 120 teeth | Automated Segmentation on CBCT Versus Manual Segmentation in Single-Rooted Teeth | Manual segmentation achieved a sensitivity of 87%, precision of 86%, and accuracy of 98%, with an average processing time of 2262.4 ± 679.1 seconds. Automated segmentation, in comparison, showed a sensitivity of 89%, precision of 94%, and accuracy of 99%, with a significantly shorter average processing time of 94 ± 64.7 seconds. Regarding the agreement between the predicted and ground truth masks, the Intersection over Union (IoU) ranged from 80% ± 14 to 86% ± 7, while the Dice Similarity Coefficient (DSC) ranged from 89% ± 6 to 93% ± 4. The model achieved a sensitivity of 75.91 ± 2.84%, specificity of 68.88 ± 2.35%, and accuracy of 72.78 ± 2.13%. Accuracy: 91.3% Precision: 84.4% Sensitivity: Not reported Time: Not reported |
| Li Ye et al 2024 (12) | DNN (U-net) | Retrospective pilot study | 100 images | Automated Detection of Pulpal Calcifications | |
| Boubaris M et al. 2024 (21) | AI (Diagnocat) | Retrospective study | 500 teeth, of which 408 had periapical lesions and 92 were lesion-free | Comparison Between Semi-Automatic and Automatic Segmentation in the Evaluation of Periapical Lesions on CBCT | |
| Kazimierczak W. Et al 2024 (13) | AI (Diagnocat) | Retrospective study | 55 images from CBCT scans of 55 patients | Diagnostic Accuracy of the Diagnocat AI Platform for the Assessment of Endodontic Treatment Outcomes Using Cone-Beam Computed Tomography (CBCT) Images | The study produced the following results: For filling probability, the model achieved 100% accuracy, precision, and sensitivity. For adequate obturation, accuracy was 84.1%, precision 66.7%, and sensitivity 92.3%. Regarding adequate obturation density, accuracy was 95.5%, precision 97.2%, and sensitivity 97.2%. For overextension of the root canal filling beyond the apex, accuracy was 95.5%, precision 86.7%, and sensitivity 100%. For filling discontinuity, accuracy was 88.6%, precision 88.9%, and sensitivity 66.7%. Finally, for underfilling, accuracy was 95.5%, precision 100%, and sensitivity 86.7% |

To be continued

| | | | | | |
|--------------------------------|--------------------|---------------------|--|---|--|
| Slim M. L et al 2024 (29) | CNN | Retrospective study | 90 first and second mandibular molars from 66 CBCT scans | Manual vs. Automated Segmentation on Multirouted Teeth, Including First and Second Mandibular Molars | Manual segmentation achieved an accuracy of 98.3% ± 0.8, precision of 90.3% ± 7.6, sensitivity of 84% ± 8, and required an average time of 2349 ± 444 seconds. AI segmentation showed an accuracy of 99% ± 0.8, precision of 92% ± 4.5, sensitivity of 90% ± 8.2, with a significantly reduced processing time of 4.3 ± 2 seconds. Regarding mandibular molars, sensitivity was 86% ± 9 for the first molars and 88% ± 7 for the second molars; precision was 91% ± 6 for the first molars and 93% ± 4 for the second molars. The overall accuracy reached 99% ± 1% for both first and second mandibular molars. The Intersection over Union (IoU) between predicted and ground truth masks was 80% ± 12 for first mandibular molars and 82% ± 10 for second mandibular molars. The Dice Similarity Coefficient (DSC) was 88% ± 7 for first molars and 90% ± 6 for second molars |
| Junghoon L et al. 2023 (31) | DCNN | Retrospective study | 598 premolars | Prediction of Endodontic Treatment Prognosis Using Preoperative Periapical Radiographs: A Comparison Between Two Deep Convolutional Neural Networks (DCNNs) | ResNet-18 achieved an accuracy of 63.4%, sensitivity of 39.9%, and specificity of 72.6%. Pressan-17 demonstrated an accuracy of 67.0%, sensitivity of 42.0%, and specificity of 78.3%. |
| Yang S. et al. 2022 (8) | CNN(Efficient-Net) | Retrospective study | 740 radiographs | Development of a Deep Learning Model for Classification of C-Shaped Canals in Mandibular Second Molars | Results for the AI on periapical radiographs showed a precision of 90%, sensitivity of 93%, and specificity of 87%. For panoramic radiographs, the AI demonstrated a precision of 85%, sensitivity of 72%, and specificity of 93%. Regarding the specialist's performance, on periapical radiographs, precision was 95%, sensitivity 95%, and specificity 94%. On panoramic radiographs, the specialist achieved a precision of 96%, sensitivity of 97%, and specificity of 95%. |
| Orhan k. Et al. 2020 (22) | CNN (Diagnocat) | Retrospective study | 153 radiographs from 109 patients | Evaluation of Artificial Intelligence for the Detection of Periapical Pathology Using Cone Beam Computed Tomography (CBCT) | The results showed a sensitivity of 89%, precision of 95%, and accuracy was not reported. |
| Johari et al. 2017 (16) | PNN | Retrospective study | The dataset consisted of 240 radiographs of single-rooted teeth. | Detection of Vertical Root Fractures in Premolars | On periapical radiographs, accuracy was 70%, sensitivity 97.78%, and specificity 67.7%. For CBCT images, the values were higher, with an accuracy of 96.6%, sensitivity of 93.3%, and specificity of 100%. |

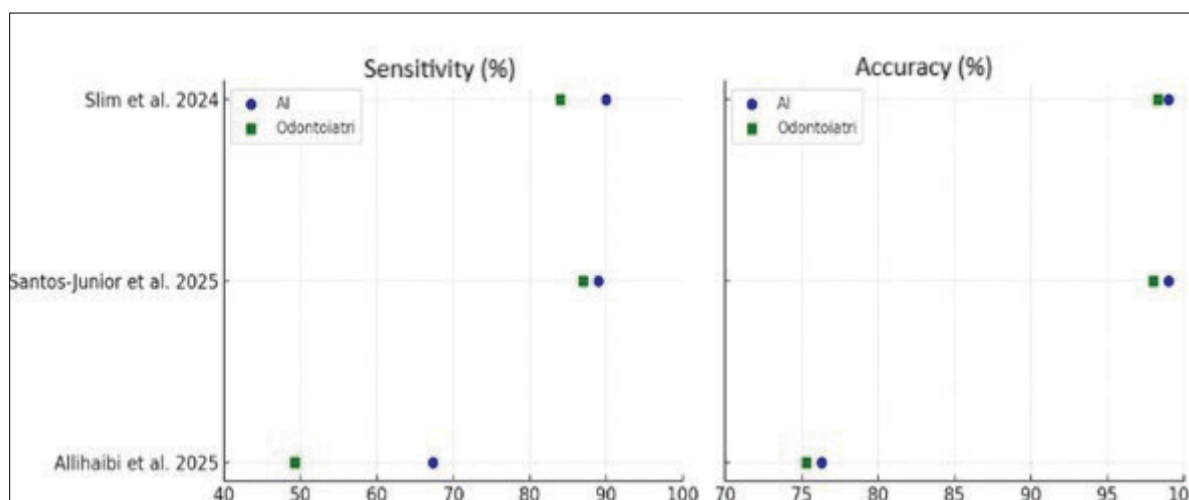


Figure 2. Sensitivity and Accuracy between dentists and Artificial Intelligence in percentage (27, 28, 29).

Across all three studies Slim et al. (29), Santos-Junior et al. (28), and Allihaibi et al. (27), AI demonstrated higher sensitivity compared to human clinicians. Notably, in the study by Allihaibi (27), the greatest difference was observed: AI reached nearly 70% sensitivity, whereas dentists achieved around 50%. These findings suggest that AI systems may provide high-level diagnostic support, particularly in tasks requiring precise detection.

In the graph on the right, accuracy is analysed, defined as the proportion of total cases correctly classified. While the differences between AI and dentists are less pronounced here, the results support AI, which achieved higher accuracy values in each comparison (Figure 3).

Figure 3 presents a comparison of automatic versus manual segmentation performance based on the studies by Slim et al. (29) and Santos-Junior et al. (28), evaluating accuracy, precision, sensitivity, and

segmentation time. Darker colors in the table indicate better numerical performance.

- Accuracy reflects the overall correctness of the method.
- Precision measures how well the segmented areas correspond to the actual anatomical structures.
- Sensitivity indicates the ability to correctly identify all relevant structures.
- Segmentation time is expressed in seconds.

Automatic segmentation has been demonstrated significantly faster, with processing times ranging from 4 to 94 seconds in these studies (28, 29). Despite the much shorter time required, automatic methods achieved accuracy, sensitivity, and precision comparable to or better than manual segmentation, which required approximately 2349 seconds (about 39 minutes) (29). These results highlight the potential of AI-based segmentation to save time and improve the precision of therapeutic planning.

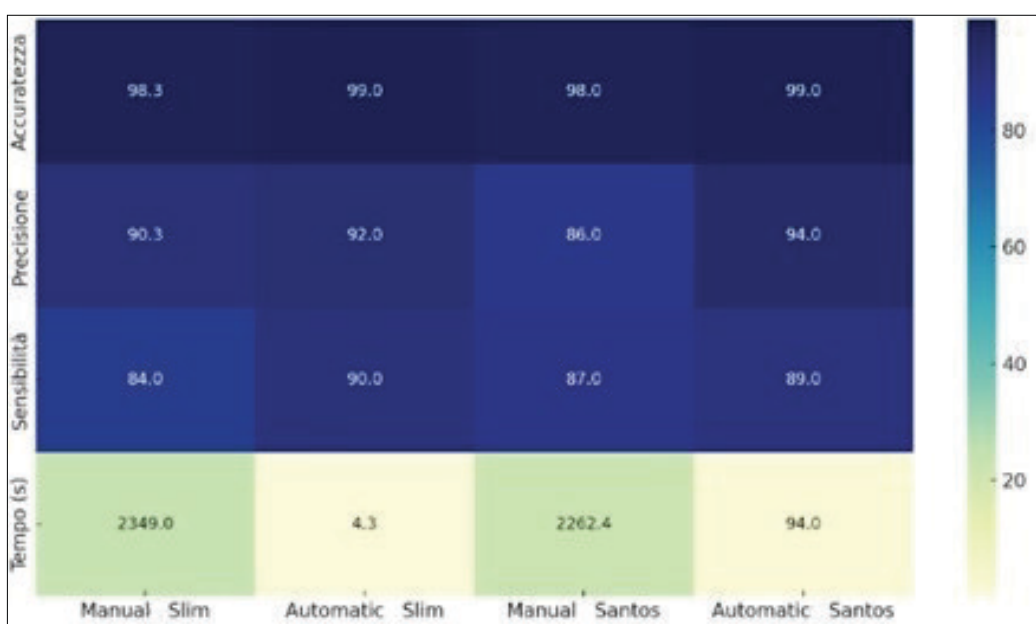


Figure 3. Comparison of automatic versus manual segmentation performance (28, 29).

Relying on these advances in segmentation, artificial intelligence (AI) methods are increasingly applied in endodontics to enhance the detection of critical anatomical structures, which are essential for successful treatment outcomes. For instance, a study (16) focused on identifying canal orifices in maxillary molars with previous root canal therapy. Using CBCT for anatomical confirmation and acquiring 1,527 images via a dental operating microscope, the authors developed a YOLOv8-based AI model implemented in PyTorch, which achieved 85% accuracy, 93% sensitivity, and 92% precision. They noted limitations due to manual labelling accuracy and emphasized the need for further in vivo validation.

Similarly, accurate detection and volumetric quantification of periapical lesions are vital for diagnosis and treatment planning in endodontics. A semi-automatic segmentation technique was compared with a commercial AI platform (Diagnocat) based on deep convolutional neural networks, which assigned CBCTPAVI scores reflecting lesion volume (21). Using this approach on 500 periapical regions, the AI achieved 91.3% accuracy and 84.4% precision, performing faster than the semi-automatic segmentation, which required 15 to 45 minutes per lesion. Challenges were observed in classifying lesions smaller than 1 mm³ and in volumetric discrepancies between the AI and the semi-automatic method (Figure 4).

In the figure 4, each pair of bars in this chart represents a study evaluating a specific imaging modality (such as intraoral radiographs, panoramic radiographs, or CBCT) in relation to a particular clinical condition. The comparison among three different studies (8, 20, 30), highlights how the diagnostic performance of artificial intelligence (AI) systems can vary depending on the type of radiographic imaging used.

Specifically, studies based on CBCT imaging have demonstrated high levels of accuracy, sensitivity (20),

and specificity in the detection of vertical root fractures. In contrast, the use of AI on intraoral periapical radiographs for the same diagnostic purpose has shown a notable reduction in specificity (8, 20).

Furthermore, the lower sensitivity observed in detecting certain anatomical variations may be attributed to the lower resolution of conventional radiographs and the presence of artifacts or overlapping anatomical structures, which can hinder accurate identification.

Intraoral radiographs demonstrated high sensitivity and specificity for detecting anatomical variations and periapical lesions, with reported values ranging from approximately 93% to nearly 100% for sensitivity and 90–95% for specificity (8, 20). Panoramic imaging showed comparable specificity (around 93%), but sensitivity dropped to approximately 75%, suggesting greater difficulty for AI in this modality (8). For the diagnosis of vertical root fractures, intraoral radiographs achieved high sensitivity (98%) but lower specificity (68%), whereas CBCT provided both high sensitivity (93%) and perfect specificity (100%), confirming its superior reliability in this context (8).

Recent advances in artificial intelligence (AI) have enabled more precise detection and quantification of endodontic pathologies using radiographic imaging, including CBCT. A deep convolutional neural network (DCNN) based AI system was evaluated for detecting periapical lesions (22). Lesion presence, localization, and volume were assessed and compared with manual segmentation. The AI correctly identified 142 of 153 lesions, achieving a reliability of 92.8%, and volumetric measurements were comparable to manual methods ($P > 0.05$).

Overall, AI demonstrated high diagnostic performance when applied to intraoral and CBCT imaging, both in terms of sensitivity and specificity, whereas panoramic radiographs proved less accurate. These findings underscore the importance of high-quality imaging data

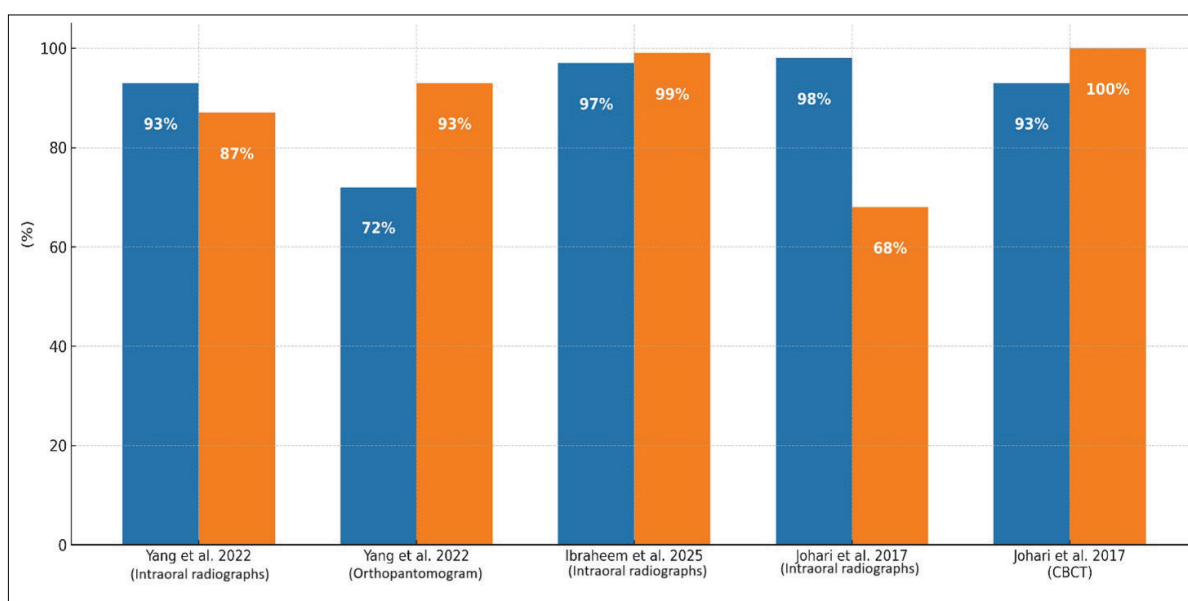


Figure 4. Sensitivity (blue) and Specificity (orange) for intraoral radiographs, panoramic radiographs, or CBCT when using AI (8, 20, 30).

for optimal AI performance in endodontic diagnostics (Figure 5).

The bar plot in Figure 5, illustrates the diagnostic performance of an artificial intelligence (AI) system applied to Cone Beam Computed Tomography (CBCT) imaging for the evaluation of endodontic treatment outcomes (13). The analysis includes five key parameters related to the quality of root canal fillings: adequacy of obturation, filling density, overextension beyond the apex, presence of filling discontinuities, and underfilling. For each parameter, three performance metrics were evaluated: accuracy, precision, and sensitivity.

Regarding the identification of adequately filled root canals, the AI demonstrated high sensitivity (92.3%), suggesting a strong ability to detect true positive cases. However, the lower precision (66.7%) indicates a tendency to overestimate adequacy, potentially misclassifying some suboptimal cases as satisfactory. The overall accuracy for this parameter was 84.1%.

In contrast, when assessing the density of the filling material, the AI system achieved excellent results, with both sensitivity and precision at 97.2%, and an overall accuracy of 95.5%, highlighting its reliability in recognizing appropriate material compaction.

The evaluation of overextended fillings (beyond the apical foramen) revealed perfect sensitivity (100%), meaning that all actual cases of overfilling were correctly identified. Precision remained high at 86.7%, and overall accuracy reached 95.5%, indicating that the AI was highly effective in recognizing this condition, although a small number of false positives may still occur.

For the detection of filling discontinuities, performance was less robust. While precision and accuracy were relatively high (88.9% and 88.6%,

respectively), the sensitivity dropped to 66.7%, suggesting that the AI failed to detect a significant portion of actual discontinuities, thus limiting its clinical reliability in this specific context.

Lastly, the analysis of underfilling cases showed strong performance overall. The AI achieved perfect precision (100%), indicating that all predicted underfilled cases were indeed correct, while sensitivity was slightly lower (86.7%), reflecting a modest rate of false negatives. The overall accuracy was again high, at 95.5%.

In summary, the AI system demonstrated high diagnostic accuracy and robustness across most parameters, particularly in identifying overfilling, underfilling, and evaluating filling density (13). However, its lower sensitivity in detecting filling discontinuities suggests that further refinement may be necessary in this specific application. These results underscore the value of high-resolution imaging modalities such as CBCT in enhancing AI-assisted diagnostics and highlight the potential of such systems to support clinical decision-making in endodontics.

Recent studies have explored the use of artificial intelligence (AI) for predicting endodontic treatment outcomes using periapical radiographs as input.

Preoperative periapical radiographs of premolars were used to develop the Periapical Radiograph Explanatory System with Self-Attention Network (PRESSAN-17) for predicting 3-year endodontic treatment prognosis (31). A total of 598 radiographs were split into training and validation sets using five-fold cross-validation. PRESSAN-17 extends a conventional convolutional neural network (CNN) by adding a self-attention layer after the fifth convolutional layer, allowing the model to better capture complex global patterns and spatially distant relationships within the image.

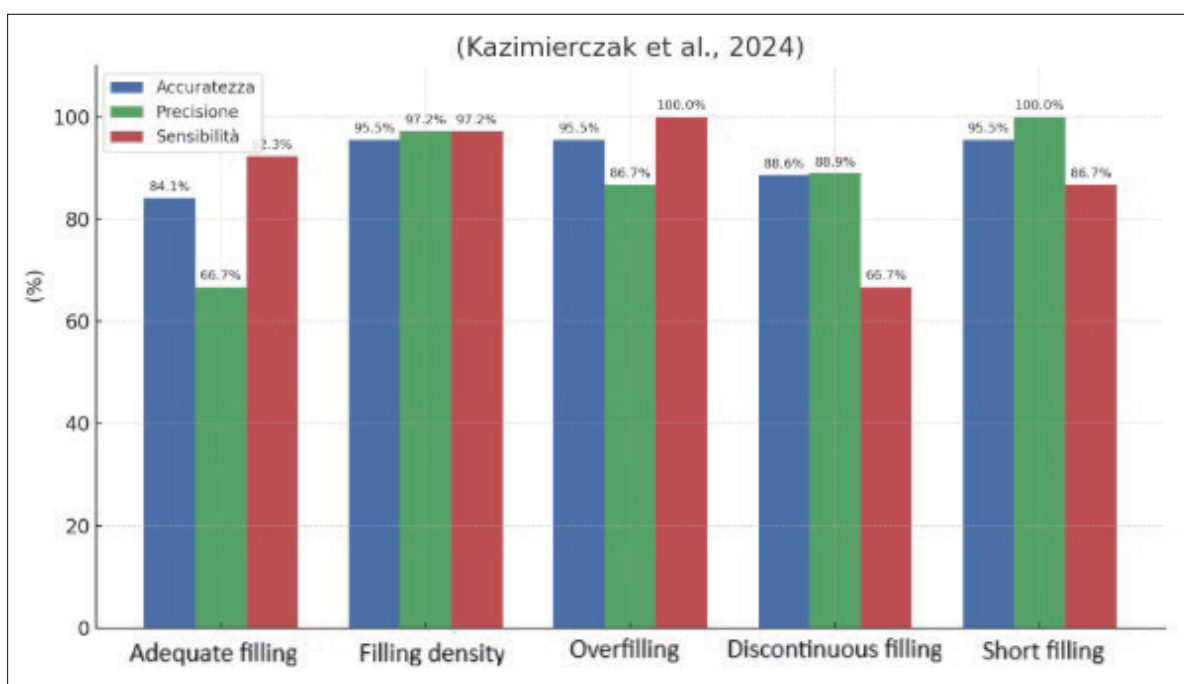


Figure 5. Diagnostic performance of an artificial intelligence (AI) system applied to Cone Beam Computed Tomography (CBCT) imaging for the evaluation of endodontic treatment outcomes (13). Accuracy (blue), Precision (green), Sensitivity (red).

Several clinical features were manually annotated and assessed, including: presence of adjacent teeth, intracanal anatomy, periapical status, periapical radiolucency, full-coverage restorations, canal morphology, coronal defects, and previous root fillings. PRESSAN-17 was compared to RESNET-18 (31), which has a similar number of convolutional layers. Results showed that PRESSAN-17 achieved slightly higher overall performance:

- PRESSAN-17: Accuracy 67.0%, Sensitivity 42.0%, Specificity 78.3%
- RESNET-18: Accuracy 63.4%, Sensitivity 42.0%, Specificity 72.6%.

PRESSAN-17 showed superior specificity and overall accuracy, especially in identifying features like coronal restorations and prior root fillings. However, intracanal features remained difficult to detect, mirroring challenges faced in clinical settings. A notable advantage of this model is its reliance on periapical radiographs, which are routinely acquired during treatment and follow-up. Yet, limitations include variability in image quality, potential projection inconsistency, and reduced ability to detect complex complications such as vertical root fractures or perforations.

Despite encouraging results, limitations include a small dataset, potential confusion with root fillings, and reduced performance in the presence of anatomical variations or imaging artifacts. The study calls for larger, more diverse datasets to improve clinical utility. While both models showed limited sensitivity, PRESSAN-17 performed better in distinguishing true negatives and provided superior overall accuracy. It was also proved to be more effective at detecting features such as full coronal restorations, coronal defects, and previous canal fillings, though intracanal features remained challenging.

One major advantage of PRESSAN-17 is its reliance on periapical radiographs, which can be taken repeatedly during treatment and follow-up, offering more precise views of coronal and periradicular structures than panoramic imaging (31). However, limitations such as radiation angle variability, inconsistent projections, and the inability to detect iatrogenic errors or vertical root fractures may affect reliability.

Despite these constraints, the study supports the potential of DCNN models for feature detection and endodontic prognosis prediction based on periapical radiographs

Periapical radiographs were also analyzed using Diagnocat, a commercial AI platform, with CBCT serving as the reference standard for evaluating endodontic outcomes (27). Diagnocat automatically detected apical radiolucency ($\geq 50\%$ probability) without manual input. In teeth with multiple roots, all affected roots were considered positive.

The AI demonstrated higher sensitivity in detecting positive cases, while specialists achieved higher specificity, especially at the root level of the tooth. Overall, both approaches showed comparable accuracy as for the tooth, with a slight advantage for human experts at the tooth root area. These findings suggest AI may be a valuable adjunct for screening, particularly due to its speed and ability to detect subtle findings,

though expert review remains essential for nuanced clinical decision-making.

A probabilistic neural network was applied to both periapical radiographs and CBCT scans (16). When using periapical radiographs, the system achieved very high sensitivity (97.8%), indicating a strong ability to detect actual fractures. However, this came at the cost of low specificity (67.7%) and moderate accuracy (70.0%), reflecting a considerable number of false positives. In contrast, the performance significantly improved with CBCT imaging, where the model achieved 96.6% accuracy, 93.3% sensitivity, and a perfect specificity of 100%. This confirms the well-documented diagnostic superiority of CBCT over traditional 2D radiographs, particularly in distinguishing between true positives and negatives.

Multiple machine learning algorithms trained on CBCT data from a large patient cohort, and among the models tested, XGBoost yielded the highest sensitivity (91.5%) and accuracy (86.3%), suggesting it was particularly effective in correctly identifying fractured teeth (18). However, its specificity was somewhat lower (78.1%), indicating a slightly increased risk of false positives. The Logistic Regression model, by contrast, demonstrated more balanced performance across all three metrics (accuracy: 79.9%, sensitivity: 79.2%, specificity: 80.8%), though overall slightly lower than XGBoost. These results, show that more advanced ensemble models like XGBoost may offer better detection capabilities, albeit sometimes at the expense of specificity.

Overall, the comparison underscores that CBCT-based AI models outperform those based on periapical radiographs, and that advanced machine learning techniques, such as XGBoost, can significantly enhance fracture detection. Nevertheless, balancing sensitivity and specificity remains a critical consideration depending on the clinical context and the consequences of false positives or negatives.

A U-Net-based deep learning model was developed for the automatic detection of pulp canal calcifications on CBCT scans (12). The model was trained on 150 annotated images, with segmentations performed and verified by expert endodontists using MITK. The U-Net architecture combined encoder, decoder, and classifier modules, with skip connections to enhance feature integration. Training involved 10-fold cross-validation and the use of two RTX3090 GPUs. The model achieved a sensitivity of 75.9% ($\pm 2.8\%$), specificity of 68.9% ($\pm 2.4\%$), and an overall accuracy of 72.8% ($\pm 2.1\%$), demonstrating moderate performance in detecting pulp canal calcifications.

These results provide a comprehensive overview of the diagnostic performance of AI across various endodontic imaging modalities and clinical applications, illustrating both strengths and limitations observed in the collected studies

Discussion

This systematic review analysed the diagnostic performance of artificial intelligence (AI) applications in endodontics, with a focus on radiographic interpretation,

treatment quality assessment, and anatomical structure detection. The evidence collected from multiple studies suggests that AI-based systems show promising diagnostic capabilities across various imaging modalities, particularly when applied to high-resolution tools such as CBCT and intraoral radiographs.

Artificial intelligence can reliably assess multiple parameters of root canal treatment quality (13, 31), including obturation adequacy, material density, overfilling, underfilling, and discontinuities. In most cases, AI systems reached high accuracy and sensitivity values, especially for detecting overextended or underfilled canals and evaluating the density of the filling material. For instance, the perfect sensitivity (100%) in identifying overfilling and the high precision (97.2%) in assessing filling density indicate that AI can contribute meaningfully to post-treatment evaluations, while the reduced sensitivity (66.7%) in detecting filling discontinuities highlights an area where the performance of AI remains suboptimal (13), potentially leading to missed diagnoses in complex cases (8, 16). Comparative studies evaluating different imaging modalities reinforce the importance of image quality in AI performance. AI achieved better sensitivity and specificity when analysing intraoral radiographs compared to panoramic images (8), which led to a notable drop in sensitivity (from 93% to 75%). CBCT imaging was used to detect vertical root fractures (16, 18), achieving both high sensitivity and perfect specificity, indicating that it is a highly reliable modality for this purpose. These results suggest that while AI can assist clinicians in radiographic interpretation, its performance is closely linked to the resolution and diagnostic capability of the imaging modality.

Analysis of radiographic images using artificial neural networks (ANNs) demonstrated the ability of these systems to accurately identify the location of the apical foramen (32, 33), supporting clinicians in working length determination. These findings suggest that ANN-based approaches may serve as reliable decision-support tools in endodontic clinical scenarios. Similarly, artificial intelligence has been applied to images acquired with a dental operating microscope (DOM) for the detection of root canal orifices (30). Using deep learning architectures, AI systems demonstrated a strong ability to recognize and localize canal orifices under high magnification, supporting clinicians during access cavity procedures and enhancing visual interpretation in complex anatomical situations.

In head-to-head comparisons between AI and human clinicians (27, 28, 29), AI systems consistently achieved higher sensitivity in detecting anatomical structures and pathologies. Notably, a nearly 20% difference in sensitivity was observed with AI (27), indicating its potential to reduce underdiagnosis in certain contexts. Even when accuracy was evaluated, AI generally performed at least as well as human operators, reinforcing its potential value as a diagnostic support tool.

One particularly relevant contribution of AI is its ability to accelerate image analysis. Automatic segmentation methods (28, 29), significantly reduced segmentation time (from over 2300 seconds manually to just a few

seconds), without compromising diagnostic quality. This efficiency can be crucial in busy clinical settings and may support the broader implementation of AI-assisted workflows.

When integrated with machine learning approaches, structured endodontic difficulty assessment tools, can support clinicians in the rapid evaluation of case complexity. This approach may be particularly valuable in settings where standardized treatment and referral guidelines are inconsistently applied, and may also assist less experienced practitioners in decision-making (34).

Nevertheless, several limitations must be acknowledged. The performance of AI systems remains highly dependent on the quality, quantity, and representativeness of the training datasets. Incomplete or biased data can reduce model generalizability and lead to performance drops in real-world applications (27). Most included studies were retrospective and based on controlled datasets, which may not accurately reflect the variability encountered in everyday practice. Artifacts from restorations, metal posts, variable exposure levels, and unusual anatomical presentations all represent challenges that can affect AI accuracy and require human oversight (12).

Furthermore, the predominance of studies based on CBCT, a second-level imaging tool, raises questions about the applicability of AI to more widely used, first-line diagnostic tools such as intraoral or panoramic radiographs (20, 31). While CBCT offers superior image quality, its routine use is limited by cost, radiation exposure, and accessibility. Future developments should prioritize AI systems capable of operating effectively with lower-resolution images, to ensure wider clinical utility.

The interpretability of AI systems also remains a critical concern. Many models operate providing results without transparent reasoning, which can hinder clinical acceptance and patient communication. In addition, ethical and legal considerations regarding data handling, patient consent, and algorithm accountability are increasingly relevant as AI becomes more integrated into healthcare (35).

Among the primary challenges associated with the implementation of Artificial Intelligence (AI) in endodontics is the need for large, comprehensive, and high-quality datasets. Insufficient or incomplete data can lead to errors and compromise the reliability of AI models (20). Furthermore, these systems require dedicated hardware platforms (such as GPUs or FPGAs), licensed software, and specialized training with regular updates, which can be costly, particularly for smaller practices.

Another significant concern is the heterogeneity of training data, which often involves limited or non-representative samples (e.g., variations in populations or artifacts from restorations). This may result in overfitting and inconsistent performance across different clinical scenarios (20). Additionally, the majority of studies in this field are retrospective, underscoring the need for prospective research, including randomized controlled trials (RCTs) and longitudinal studies, to validate the clinical effectiveness and real-world benefits of AI in

endodontics.

AI's pattern recognition capabilities may also prove inadequate in complex cases or when imaging is affected by artifacts such as intracanal posts, fillings, unusual anatomical variations, poor-quality radiographs, or variable exposure levels, all of which can reduce sensitivity and specificity (12). These factors necessitate continued human oversight, and outcomes may vary depending on both the algorithm employed and the type of diagnostic imaging used.

Moreover, most research to date has focused on CBCT, a second-level imaging modality. Broader implementation will require the integration of AI techniques that can effectively analyse first-level diagnostic tools, such as panoramic radiographs and intraoral periapical X-rays. Another limitation lies, as mentioned above, in the so-called "black box" nature of many AI models, which often lack interpretable mechanisms for clinicians, thereby reducing transparency and hindering effective communication with patients. Finally, there are ongoing concerns regarding the handling of health data, particularly in relation to ethical considerations, patient consent, and privacy (35).

Conclusions

Artificial Intelligence (AI) is emerging as a valuable tool in endodontics, demonstrating diagnostic accuracy comparable to that of experienced clinicians and the potential to streamline treatment planning through the precise analysis of radiographs and CBCT images. By integrating anatomical and clinical variables, predictive models can support individualized care, leading to faster, more accurate diagnoses and optimized patient outcomes. Furthermore, AI applications hold significant promise for education, offering students and practitioners tools to interpret a broader range of pathological conditions and refine their diagnostic skills. However, the translation of AI into routine clinical practice remains contingent on overcoming critical challenges. Reliable performance requires large, high-quality, and representative datasets, while technical demands, such as specialized hardware, software, and training, may limit accessibility. In addition, the predominance of retrospective studies highlights the need for prospective, high-quality clinical trials to validate its real-world efficacy.

Therefore, while AI has the potential to enhance diagnostic precision, efficiency, and education in endodontics, its widespread adoption will depend on addressing current limitations, improving data quality and model transparency, and ensuring ethical and practical integration into clinical workflows.

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