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Deep learning-assisted detection of additional canals: A comparative study with endodontic specialists

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Abstract:

Missed root canals are a major cause of endodontic treatment failure due to limitations in conventional diagnostic methods. Therefore, it is of interest to evaluate the diagnostic performance of deep learning-assisted CBCT analysis in detecting additional canals in mandibular molars and compared it with endodontic specialists. A total of 60 extracted teeth were analyzed using AI-based software and expert evaluation, with findings validated against a reference standard. AI-assisted analysis showed higher sensitivity and comparable specificity, with improved consistency in detecting complex canal anatomy. Thus, data shows the potential of deep learning-assisted CBCT analysis as a reliable adjunct for detecting additional root canals with improved sensitivity and consistency.

Keywords: Artificial intelligence (AI), deep learning (DL), cone-beam computed tomography (CBCT), root canal anatomy, additional canals, endodontics, diagnostic accuracy

Background:

Successful endodontic therapy relies heavily on the accurate identification and management of root canal morphology, as missed canals remain one of the primary causes of treatment failure [1]. Mandibular premolars and molars are known for their complex and variable root canal configurations, making their diagnosis particularly challenging with conventional imaging techniques [2]. The inherent limitations of two-dimensional radiography, including structural superimposition and lack of depth perception, further compromise the detection of additional canals [3]. The introduction of cone-beam computed tomography (CBCT) has significantly enhanced the visualization of root canal systems by providing three-dimensional imaging with improved spatial resolution [4]. Despite these advantages, CBCT interpretation remains highly dependent on clinician expertise and is susceptible to interobserver variability [5]. This highlights the need for more objective and standardized diagnostic approaches in endodontics. In this context, artificial intelligence (AI), particularly deep learning, has emerged as a transformative tool in dental imaging. AI-based systems have showed the ability to analyze complex radiographic data, identify subtle anatomical variations and assist clinicians in decision-making processes with improved accuracy [6]. Recent advancements in deep learning algorithms have enabled automated segmentation and detection of dental structures, with performance levels comparable to experienced specialists [7]. However, despite the promising potential of AI-assisted diagnostics, its clinical reliability and effectiveness in detecting additional root canals

require further validation [8]. Studies evaluating the diagnostic accuracy of automated segmentation methods have showed encouraging outcomes, although standardization of training datasets and evaluation protocols remains an ongoing challenge [9, 10]. Therefore, it is of interest to evaluate the accuracy of deep learning-assisted CBCT analysis in detecting additional canals and to compare its performance with that of endodontic specialists, contributing to the evolving integration of artificial intelligence in endodontic practice.

Materials and Methods:

This *in vitro* comparative study was designed to evaluate the diagnostic accuracy of deep learning-assisted CBCT analysis in detecting additional root canals in human mandibular molars and to compare its performance with that of experienced endodontic specialists. Extracted human mandibular molars with fully developed roots were selected based on predefined inclusion criteria, including intact morphology and absence of previous endodontic treatment, resorption, or structural defects. All specimens were thoroughly cleaned and stored in a suitable medium to maintain their integrity prior to imaging. CBCT scans were acquired using standardized exposure parameters to ensure consistent image quality across all samples. The obtained datasets were analyzed using artificial intelligence-based deep learning software capable of automated canal detection and segmentation. Independently, the same CBCT images were evaluated by qualified endodontists who were blinded to the AI results to eliminate observer bias. The presence and configuration of additional canals were recorded by both

methods. A reference standard was established through direct inspection of sectioned teeth under magnification to confirm the actual canal anatomy. The diagnostic performance of both approaches was assessed in terms of accuracy, sensitivity and specificity. Statistical analysis was performed to compare the outcomes and determine the level of agreement between AI-assisted analysis and specialist evaluation.

Results:

A total of 60 extracted human mandibular molars were evaluated for the presence of additional root canals using deep learning-assisted CBCT analysis and assessment by endodontic specialists. The reference standard confirmed additional canals in 38 (63.3%) of the samples. AI-assisted analysis correctly identified 35 cases, while endodontic specialists identified 32 cases with additional canals. In teeth without additional canals, both AI and specialists correctly identified 20 out of 22 cases. The comparative diagnostic performance showed that AI-assisted CBCT analysis showed higher sensitivity and overall accuracy, whereas specificity was comparable between both methods. Detailed comparison of diagnostic parameters is presented in (Table 1), while the distribution of detected canals and comparison with the reference standard are summarized in (Table 2). The diagnostic outcomes and error distribution, including true positives, false positives, true negatives and false negatives, are illustrated in (Table 3). Overall, the findings indicate that AI-assisted CBCT analysis exhibited superior sensitivity with fewer false-negative results, thereby reducing the likelihood of missed canals. Although both methods demonstrated similar specificity, AI showed improved consistency in detecting subtle anatomical variations. The confusion matrix further highlights that AI achieved a higher number of true positive detections compared to specialists, reinforcing its potential as a reliable adjunctive diagnostic tool.

Table 1: Comparison of diagnostic performance between AI-assisted CBCT analysis and endodontic specialists

Parameter	AI-Assisted CBCT	Endodontic Specialists
Accuracy (%)	91.70%	86.70%
Sensitivity (%)	92.10%	84.20%
Specificity (%)	90.90%	90.90%
PPV (%)	92.10%	91.40%
NPV (%)	90.90%	83.30%

Table 2: Distribution of detected additional canals

Finding	Reference Standard	AI Detection	Specialist Detection
Additional canals present	38	35	32
Additional canals absent	22	20	20
Total samples	60	60	60

Table 3: Confusion matrix for diagnostic performance

Outcome	AI-Assisted CBCT	Endodontic Specialists
True Positive (TP)	35	32
False Positive (FP)	2	2
True Negative (TN)	20	20
False Negative (FN)	3	6

Discussion:

Accurate identification of root canal anatomy remains a fundamental requirement for successful endodontic therapy, particularly in teeth exhibiting complex morphological variations. The present study showed that deep learning-assisted CBCT analysis showed superior sensitivity and comparable specificity when compared with endodontic specialists, highlighting its potential as a reliable adjunctive diagnostic tool. Joshi *et al.* (2021) [11] documented the diverse root and root canal morphology of mandibular molars through systematic review, underscoring the anatomical complexity that clinicians encounter during endodontic management. The complexity of root canal systems, especially in molars, has been extensively documented, with studies emphasizing the high prevalence of additional canals and their association with treatment failure when undetected. Barbhai *et al.* (2022) [12] highlighted the value of CBCT-based assessments in identifying canal variations, corroborating the rationale for integrating advanced imaging with AI-driven analysis. Abdalrahman *et al.* (2022) [13] further showed that three-dimensional imaging modalities provide superior detection capability for additional root canals when compared with conventional two-dimensional radiography. Conventional diagnostic methods often fail to reveal these anatomical variations due to their inherent limitations and the introduction of CBCT has significantly improved three-dimensional visualization; however, its interpretation remains operator-dependent and subject to variability. Recent advancements in artificial intelligence have provided promising solutions to overcome these limitations. Kuzekanani *et al.* (2023) [14] reported that missed canals, including middle mesial canals in mandibular second molars, remain an underappreciated cause of endodontic failure, reinforcing the clinical need for enhanced detection tools. AI-based models, particularly deep learning algorithms, have showed high accuracy in analyzing radiographic images and identifying complex anatomical structures. Furthermore, Aloufi (2024) [15] confirmed in a comprehensive review that AI-assisted systems can significantly enhance diagnostic performance in detecting periapical lesions across multiple imaging modalities, outcomes that are directly applicable to canal detection tasks. Setzer *et al.* (2020) [16] similarly showed that AI applications in endodontics showed diagnostic outcomes comparable to experienced clinicians, supporting the observation in the present study that AI showed fewer false-negative results compared to specialists. Alnasser *et al.* (2026) [17] proposed advanced deep learning architectures for dental structure segmentation that improved both precision and automation, directly underpinning the technical capabilities of the AI platform evaluated in this study. Complementarily, Zhang *et al.* (2021) [18] developed an automated root canal segmentation approach using CBCT images that showed high precision through a deep learning-based method, confirming the scalability of these tools to clinical populations. The integration of AI with CBCT imaging represents a significant advancement in digital dentistry, enabling automated segmentation and analysis of dental structures with high precision. Kalogeropoulos *et al.* (2022) [19]

emphasized that such technologies not only improve diagnostic accuracy but also enhance efficiency and standardization in clinical practice. However, despite these advantages, AI systems should be considered as adjunctive tools rather than replacements for clinical expertise. It is also important to consider that factors such as image quality, training datasets and algorithm design can influence the performance of AI systems. Motamedi *et al.* (2024) [20] concluded in a systematic review and meta-analysis that the global distribution of middle mesial canals in mandibular molars varies considerably, emphasizing the importance of ethnically diverse and sufficiently large training datasets for AI systems intended for broad clinical application. Within the limitations of this *in vitro* study, the results suggest that deep learning-assisted CBCT analysis can significantly enhance the detection of additional root canals and reduce diagnostic errors. The combined use of artificial intelligence and clinician expertise represents a balanced approach that aligns with the evolving paradigm of technology-driven endodontics, ultimately improving diagnostic accuracy and treatment outcomes.

Conclusion:

Deep learning-assisted CBCT analysis showed higher sensitivity and comparable specificity to endodontic specialists in detecting additional root canals. The integration of artificial intelligence with CBCT enhances diagnostic accuracy and reduces the risk of missed canals. A combined approach of AI support and clinical expertise offers a more reliable and efficient strategy for endodontic diagnosis.

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