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Artificial Intelligence in Endodontics: A Review

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ABSTRACT

Artificial intelligence (AI) has greatly increased its significance and presence across various fields, including dentistry. By emulating human intelligence, AI can perform complex predictions and decision-making in healthcare, especially in endodontics. AI models like convolutional neural networks and artificial neural networks have shown various applications in endodontics, such as studying the anatomy of the root canal system, predicting the viability of dental pulp stem cells, measuring working lengths, identifying root fractures and periapical lesions, and forecasting the success of retreatment procedures. Future potential applications of AI in this area include scheduling, patient care, analyzing drug-drug interactions, prognostic diagnosis, and robotic endodontic surgery. AI has demonstrated high accuracy and precision in disease detection, evaluation, and prediction, indicating it can significantly improve endodontic diagnosis and treatment outcomes. However, it is essential to further confirm the cost-effectiveness, reliability, and practical applicability of these AI models before they are regularly incorporated into clinical practice.

INTRODUCTION

Artificial intelligence (AI), a discipline in applied computer science first outlined by John McCarthy in 1956, is often called the "fourth industrial revolution." AI leverages computer technology to replicate human-like intelligent behavior, critical thinking, and decision-making processes.[1] AI has proven to improve efficiency, accuracy and precision comparable to medical professionals, achieving these results more quickly and at a lower cost.[2] One of its definitions is “the theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision making and translation between languages”.

AI has been adopted across various industries, such as robotics, automotive, smart cities, and financial analysis. In medicine and dentistry, AI is employed for imaging diagnostics, decision support, precision and digital medicine, drug discovery, wearable technology, hospital monitoring, and robotic and virtual assistants. It often acts as a valuable tool to alleviate the workload of dentists and clinicians.

In health care, AI exists in two forms: virtual and physical (robotics). The virtual type uses mathematical algorithms for tasks such as diagnosis and prognosis, imaging and osteoporosis, appointment scheduling, drug dosage calculations, drug interaction checks, and electronic health records management. The physical type includes robotic assistance in surgeries, telepresence, rehabilitation and socially assistive robots for elderly care. In the realm of endodontics, AI models such as convolutional neural networks (CNNs) and artificial neural networks (ANNs) play crucial roles in analyzing the anatomy of the root canal system, ascertaining working lengths, identifying periapical lesions and root fractures, anticipating the outcome of retreatment procedures, and projecting the survival potential of stem cells within dental pulp. The latest progress in digital technology has made it possible to introduce clinical interventions like AI-based diagnosis and aided access cavity preparations. These innovations allow for simplified access to root canals, even when dealing with roots that are difficult to access due to obstructions. Researchers have demonstrated the application of this evolving approach in diagnosing endodontic conditions and devising treatment strategies through numerous studies.[3]

CURRENT APPLICATIONS OF AI IN ENDODONTICS

DETECTION OF PERIAPICAL LESIONS

Clinicians often encounter difficulties when diagnosing and determining treatment for teeth exhibiting periapical lesions and related symptoms. Approximately 75% of radiolucent lesions in the jaw are attributed to apical periodontitis, a prevalent condition. Early detection is crucial for improving treatment outcomes, preventing disease spread to nearby tissues, and reducing potential complications. Panoramic and intraoral periapical radiographs are commonly employed in routine clinical practice as two-dimensional diagnostic tools for detecting apical periodontitis. Periapical lesions typically appear as radiolucent areas on these radiographs. However, these images may not provide precise information as they represent a simplification of the three-dimensional anatomy into a two-dimensional format.[4] Cone-beam computed tomography (CBCT), a three-dimensional imaging modality, was developed to accurately identify periapical lesions and determine their size and location. A meta-analysis indicated that CBCT imaging exhibited superior accuracy (0.96) in detecting periapical lesions compared to conventional periapical radiography (0.73) and digital periapical radiography (0.72). However, CBCT imaging showed reduced accuracy in diagnosing apical periodontitis in teeth with filled roots. Endres et al. demonstrated that a deep learning algorithm could identify periapical radiolucencies on panoramic radiographs with a level of accuracy similar to that of 24 oral and maxillofacial surgeons. Another study evaluated the performance of convolutional neural network (CNN) models in detecting simulated periapical lesions on intraoral radiographs and compared it with the proficiency of three oral and maxillofacial radiologists.[5] The studies showed that interpretations by the CNN group had superior sensitivity, specificity, and area under the receiver operating characteristic curve compared to oral and maxillofacial radiologists. Deep CNNs demonstrated accurate discriminatory ability in detecting apical lesions on panoramic radiographs compared to experienced dentists. However, both studies used panoramic radiography, which is rarely used by endodontists, and had small sample sizes. Discrimination of periapical lesions on radiographs varies widely among examiners and relies heavily on expertise. AI systems offer potential to reduce bias and discrepancies among examiners.[6]

Integrating AI systems into periapical lesion detection from radiographs and CBCT scans has the potential to enhance accuracy, enabling physicians to achieve detection accuracies on par with or surpassing seasoned experts. Moreover, it could streamline assessment processes, reduce evaluation time, and facilitate semi-automated documentation, alleviating diagnostic burdens on dentists. However, to ensure readiness for therapeutic applications, efforts should focus on enhancing the sensitivity of AI systems through further research. Poswar F de et al. conducted research revealing differing gene expressions between periapical cysts and periapical granulomas. They employed a multilayer perceptron neural network to categorize genes and differentiate between these lesions. However, the study faced limitations, including potential missing algorithmic data and the inability of the algorithm to distinguish between inflammatory and physiological cytokines. Nonetheless, the authors proposed that this approach could have broader applications in distinguishing various biological processes, such as cancer biomarkers. In a separate study, Zheng et al. compared lesion identification accuracy and dice coefficient indices using an anatomically constrained Dense U-Net with existing biomedical image analysis techniques. Despite the study's small sample size, the innovative deep learning method enabled CBCT segmentation and improved pathosis detection sensitivity and specificity.

ROOT FRACTURES

Vertical root fractures (VRFs) are concerning, comprising 2%–5% of crown/root fractures and potentially requiring root resection or tooth extraction. Both radiographs and CBCT imaging help in VRF detection, but diagnosis can be challenging. Failing to definitively diagnose VRFs may lead to unnecessary procedures, posing a dilemma for clinicians due to limited sensitivity of traditional radiographs. Talwar et al.'s meta-analysis found CBCT imaging superior for detecting VRFs in unfilled teeth, while radiographs were slightly better in root-filled teeth. With conventional methods' limited accuracy, alternative diagnostic approaches are sought. Fukuda et al. suggested CNNs as a promising tool for VRF detection on panoramic radiographs, showing high sensitivity and positive predictive value. Another study aimed to develop a probabilistic neural network for VRF diagnosis in intact and root-filled teeth using periapical radiographs and CBCT images.[7] They found that identifying root fractures on CBCT scans is more precise, sensitive, and specific compared to 2D radiographs. However, this conclusion was based on studying single-rooted premolar teeth. Additional research is needed to assess the effectiveness of using a probabilistic neural network to detect vertical root fractures in multirooted teeth. Using synthetic data, Shah and colleagues introduced artificial cracks into second molars and examined them using wavelets. These mathematical techniques facilitate the extraction of faint signals from noisy environments within a machine learning context. Despite a small sample size, cracks were consistently detected with great accuracy in CBCT images using steerable wavelets. The authors recommended further validation of this approach through ex vivo and clinical methods.[8] Vicory et al. simulated micro fractures in 22 teeth, using 14 teeth as the negative control group. They utilized wavelets and machine learning methods and discovered that micro-computed tomographic images outperformed CBCT images in pinpointing fractured teeth. While the positive predictive value of machine learning exceeded that of observers' interpretations, the authors proposed further refinement. They advised that future investigations should include a larger sample size.

WORKING LENGTH DETERMINATION

An essential step in root canal therapy involves pinpointing the bottom limit of the root canal system. With precise determination of the working length (WL), the root canal system can be effectively cleansed both mechanically and chemically. Establishing the correct WL not only prevents debris from being pushed out, reducing discomfort after the procedure, but also shields the periodontal tissues from any excessive instrument probing beyond the canal's end. Studies have demonstrated that even a slight reduction in the working length (WL) during the treatment of infected root canal systems can significantly decrease success rates by 12–14%. Furthermore, filling the canals beyond the radiographic apex can have adverse effects on treatment outcomes. Currently, electronic apex locators and periapical radiography are the main techniques used to determine canal length. However, the accuracy of interpretation in digital radiography relies on image clarity and the subjective judgment of the clinician. It's essential for instrumentation to end at the cemento-dentin junction, typically located 0.5 to 2 mm from the radiographic apex. Although apex locators can be highly precise, errors may occur in damp canals, metallic repairs, or damaged wires, resulting in incorrect readings that could impact treatment effectiveness negatively.[9]

Artificial intelligence systems are currently under development to aid clinicians in locating the apical endpoint on radiographs. Saghiri et al. conducted a study using AI to calculate working length measurements on a cadaver model, simulating a clinical scenario. They found that AI achieved 100% accuracy in calculating root length compared to real measurements after tooth extraction. Moreover, they concluded that AI could identify the small apical constriction 96% of the time. Further advancements in this technology may allow AI to extract information from imaging techniques and guide the endodontic handpiece/motor operated by the clinician, thus enabling precise movement of endodontic files to the cemento-dentin junction with minimal operator intervention.[10]

ROOT AND ROOT CANAL SYSTEM MORPHOLOGY

Comprehending the variations in root and root canal systems is crucial for the success of nonsurgical root canal treatment. Traditionally, periapical radiographs and CBCT imaging have been employed for this purpose. Although CBCT imaging offers better precision in assessing root and root canal configurations compared to radiographs, its regular clinical application is restricted due to radiation concerns. Hiraiwa et al. discovered that a deep learning system applied to panoramic radiographs demonstrated high accuracy in distinguishing between single or multiple roots in the distal roots of mandibular first molars. This process involved generating learning models by extracting image patches from panoramic radiographs and feeding them into deep learning systems.[11] The AI algorithm, combined with information analysis, demonstrated effectiveness in assessing root canal curvature and its three-dimensional alterations following instrumentation. However, additional studies are needed to confirm these results. Lahoud et al. introduced an automated technique for three-dimensional tooth segmentation using a CNN approach. They analyzed 433 CBCT radiographic tooth segmentations, offering a fast, accurate, and efficient clinical reference. Their results suggested that AI performed on par with a human operator but with notably faster processing. In a separate investigation utilizing panoramic radiography, researchers integrated two deep convolutional neural networks (CNNs) with expert refinement. Analyzing 153 panoramic radiographs, they observed that the AI tool exhibited high sensitivity and specificity while achieving rapid performance in detecting and segmenting teeth.[12]

PREDICTING THE VIABILITY OF STEM CELLS

Bindal et al. (2022) investigated the application of dental stem cells from dental pulp in regenerative treatments, using a neuro-fuzzy inference system to forecast results. In a simulated clinical scenario, the system evaluated the viability of stem cells following treatment with bacterial lipopolysaccharides, which triggered inflammation. The neuro-fuzzy inference system successfully anticipated cell viability after different regenerative protocols faced microbial infections. The study involved measuring the viability of dental stem cells post-lipopolysaccharide-induced inflammation and analyzing the prediction accuracy of the adaptive neuro-fuzzy inference system regarding the cells' viability after microbial invasion.

DETECTION OF PERIAPICAL CYST OR GRANULOMA

Using artificial intelligence, gene expression analysis was conducted to differentiate between a cyst and a granuloma. Machine learning (ML) and artificial neural networks (ANN) were employed in this process.

RETREATMENT PREDICTIONS

According to the report by Campo et al., a case-based reasoning paradigm was developed to predict the outcomes of nonsurgical root canal retreatment, weighing the risks and benefits. This system provided advice on whether to proceed with retreatment, incorporating statistical probability, performance, and recall data. A notable strength of the system was its high accuracy in forecasting retreatment outcomes. However, its precision was limited by the quality of the data it was based on. Case-based reasoning involves solving problems by applying knowledge and information from similar past experiences. The system's heterogeneity was influenced by variability and the different methods used, which could impact its reliability. To enhance the system's accuracy, sensitivity, and specificity, future research should address the heterogeneity of human methods and consider increasing the sample size.

FOR DIAGNOSIS, TREATMENT, AND PROGNOSIS

The use of artificial intelligence (AI) in diagnosing and treating oral cavity diseases, as well as in detecting and classifying suspicious mucosal changes indicative of premalignant or malignant transformations, can be highly beneficial. AI's capability to detect even minor changes at the single-pixel level, which may be overlooked by the human eye, is particularly valuable. Furthermore, AI can effectively identify genetic predispositions to oral cancer within large populations. An AI-based machine learning system can also serve as a crucial tool in determining dental prognosis based on the treatment strategy. A comprehensive treatment plan must be meticulously evaluated to predict a tooth's long-term health and functionality.

DETECTION OF TOOTH PREPARATION MARGINS

AI automatically orients, scores, and marks preparation margins before sending them to the laboratory for crown design.

CONCLUSION

Endodontics could greatly benefit from the potential of current AI models in detecting periapical pathosis, identifying root fractures, estimating working length, and predicting treatment outcomes. Developing these AI models using data from experienced clinicians is crucial to ensure their accuracy and reliability. Although AI usage in endodontics isn't as widespread as in other dental fields, there are promising opportunities for its expansion. As dentistry progresses, the field of endodontics continues to offer new ways to effectively preserve teeth. Integrating AI into clinical practice in endodontics holds promise for improving the identification of periapical pathosis, root fractures, working length estimation, and disease prediction. However, rigorous research is necessary to assess AI's reliability, applicability, ethical and legal implications, and cost-effectiveness before its widespread adoption in routine clinical settings.

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