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Artificial Intelligence in Endodontics: A Paradigm Shift in Diagnosis and Treatment Planning

[1]Dr. Meba Merin Joy, Post Graduate Student, Department of Conservative Dentistry and Endodontics, Bapuji Dental College and Hospital, Davanagere, Karnataka, India

[2]Dr. Sophia Thakur, Professor, Department of Conservative Dentistry and Endodontics, Bapuji Dental College and Hospital, Davanagere, Karnataka, India

Corresponding Author: Dr. Meba Merin Joy, Post Graduate Student, Department of Conservative Dentistry and Endodontics, Bapuji Dental College and Hospital, Davanagere, Karnataka, India

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Abstract

In the recent years, the field of dentistry has witnessed a growing relevance of artificial intelligence (AI). The ongoing evolution and application of this technology have the potential to bring about positive impacts in the field of endodontics, aiding in the preservation of natural dentition. AI-guided algorithms hold significant potential for improving the diagnosis, treatment planning, and execution of endodontic procedures, along with predicting the outcomes of various endodontic treatments. The objective of this review is to explore the current applications of artificial intelligence in the field of Endodontics, specifically focusing on aspects such as diagnosis, decision-making, and predicting treatment prognosis.

Keywords: Artificial Intelligence, Endodontics, Machine learning, Periapical Lesions, Cone Beam Computed Tomography

Introduction

The integration of artificial intelligence (AI) in the clinical decision-making processes has caused a revolutionary transformation in modern medicine. [1] The Dartmouth Conference in 1956 marked the introduction of the concept of artificial intelligence (AI) by Professor John McCarthy. AI was defined as the creation of intelligent machines that can perceive, understand, reason, learn, and make decisions in a manner akin to humans. Artificial intelligence leverages computers and machines to emulate the problem-solving and decision-making capabilities of the human mind. [2]

AI has developed into a distinct and autonomous discipline that spans a diverse array of areas, including machine learning, deep learning, natural language processing, computer vision, knowledge representation, and reasoning. Machine learning serves as the fundamental approach in achieving AI whose central idea is to allow computers to learn from data rather than by explicitly programming them to perform certain tasks. Deep learning is a technique within machine learning that leverages neural networks, specifically deep neural networks, to comprehend the intricate structure of data. In the realm of AI, natural language processing and computer vision emerge as pivotal research domains focused on aiding humans in the recognition and analysis of both language and images. [3]

Dentistry is witnessing the emergence of AI as a promising field, demonstrating the capability to execute various tasks with heightened precision and fewer errors compared to human counterparts. AI has found application in diverse areas, it is widely employed in endodontics and holds potential in various clinical applications, including the identification of root fractures, identification of periapical pathologies, determination of working length, tracing the apical foramen, analyzing root morphology, and predicting diseases. [4]

The aim of this article is to review the current applications of AI in the field of endodontics.

Functioning mechanism of artificial intelligence models

AI functions through two distinct phases: the initial "training" phase and the subsequent "testing" phase. During training, the model's parameters are established based on the provided training data. In retrospect, the model utilizes data from past examples, such as patient data or diverse examples within datasets. These parameters are subsequently applied to test sets for evaluation. In the past, artificial intelligence models were often perceived as "black boxes" as they provide outputs without elucidating the underlying rationale. In contrast, contemporary AI now takes an input, produces a "heatmap," and delivers a prediction. This generated heatmap serves to visualize the input variables that influenced the prediction, enabling a clearer distinction between reliable and pertinent prediction techniques. [5-7]

Artificial Intelligence for Endodontic Diagnosis

Detection of Periapical Lesions

Radiographically, the presence of periapical pathosis is identifiable as periapical radiolucencies. Apical periodontitis is often found inadvertently on periapical radiographs, panoramic radiographs, and cone-beam computed tomography scans (CBCT).8 Research indicates that, for a periapical radiolucency to be discerned in a two-dimensional radiograph, an average of 7.1% mineral bone loss or a minimum of 12.5% cortical bone loss is typically required. Additionally, the interpretation of radiographs involves a significant degree of subjectivity.[9]

Notably, CBCT generates high-resolution three-dimensional (3D) images, devoid of the deformations and superimpositions of bone and dental structures often encountered in traditional radiography.8 The application of AI technologies for diagnosing periapical pathology through X-rays and CBCT diagnostic tests holds the potential to enhance clinicians' precision in identification, rivalling or even surpassing specialists with substantial experience. Moreover, it has the prospect of reducing dentists' diagnostic time and effort by expediting the evaluation process through semi-automated documentation.[10]

Orhan et al. reported that the AI system accurately detected 142 out of 153 periapical lesions, achieving a detection accuracy of 92.8%. [11] Setzer et al. in his study used a deep learning system on twenty CBCT volumes, encompassing 61 roots with and without periapical lesions. The AI segmentation was applied to categorize each voxel into labels such as "periapical lesion," "tooth structure," "bone," "restorative material," or "background." This deep learning AI system demonstrated a high level of accuracy, achieving 93% accuracy in detecting lesions with a specificity of 88%. [12]

Detection of vertical root fractures

Vertical root fractures (VRFs) are infrequent occurrences in teeth that have undergone root canal treatment. These fractures tend to be subtle, often displaying minor symptoms or, in many instances, no symptoms at all.[13]

In a recent systematic review and meta-analysis, it was found that the accuracy of CBCT imaging in diagnosing vertical root fractures (VRF) is limited to 78%. [14] Fukuda et al. in their study AI for the detection of Vertical Root Fractures (VRF) in panoramic radiographs, revealing a sensitivity of 75% and a positive predictive value of 93% in their detection.[15]

By optimising AI for VRF diagnosis, it is possible to avoid extracting perfectly healthy teeth that were incorrectly diagnosed and treating non-restorable teeth needlessly. [4]

Determination of Working Length

Establishing the apical boundary of the root canal system is a crucial aspect in the course of root canal treatment. Accurately determining the working length (WL) is vital for ensuring comprehensive mechanical and chemical disinfection of the root canal system. A precise WL also safeguards the periodontal tissues by preventing instrumentation beyond the canal terminus, thereby reducing the risk of debris extrusion and minimizing post-operative pain. [4] The existing approaches for determining canal length primarily involve a combination of electronic apex locators and periapical radiographs. The precise interpretation of digital radiographs relies heavily on both image quality and the subjective judgment of the clinician. [16]

In two studies conducted by Saghiri et al., the authors examined the capacity of Artificial Neural Networks (ANN) to identify minor apical foramen on dried skulls and cadavers. In their initial study, they observed that the ANN accurately detected 93% of the apical foramen. Subsequently, in a later study, they found that ANN demonstrated a high accuracy of 96% in detecting minor apical foramen, surpassing endodontists who achieved an accuracy of 76%. This difference was deemed statistically significant. [17,18]

Determination of Root Canal Morphology

Traditionally the assessment of root canal morphology has relied on periapical radiographs, bitewing radiographs, and CBCT imaging. Nevertheless, the assessment of these imaging methods can be subjective, necessitating training and expertise. AI can help identify morphological irregularities and detect number of canals. [4]

Hiraiwa et al reported that the deep learning system demonstrated a high level of accuracy in distinguishing whether the distal root of the mandibular molar was single or multiple. [19] Lahoud et al. In their research on three-dimensional tooth segmentation, observed that artificial intelligence (AI) exhibited comparable accuracy and greater efficiency compared to human evaluators in determining root canal morphology. [20]

Presently, commercial AI software companies like Diagnocat (LLC Diagnocat, Moscow, Russia) assist practitioners in analyzing CBCTs of their patients. This software aids in determining the specific root canal morphology and offers the capability to automatically segment teeth. Additionally, it can generate 3D Standard Tessellation Language (STL) models, enabling dentists to produce printed materials for further examination. [21]

Predicting the Viability of Stem Cells

The AI algorithm was employed to predict the viability of the stem cells. Bindal et al. utilized an adaptive neuro-fuzzy inference system to anticipate the viability of DPSC after treatment with bacterial lipopolysaccharides, offering potential applications in diverse regenerative therapies. [22]

Artificial Intelligence in predicting outcomes

Lee et al. conducted a study aimed at developing an efficient AI-based module for precise clinical decisions regarding tooth prognosis and optimal treatment plans. This research utilized data from a multidisciplinary team at Harvard, comprising specialists from prosthodontics, periodontics, endodontics, and experienced clinician educators. The outcomes demonstrated that the AI-based module achieved accurate clinical decisions on tooth prognosis, comparable to those made by clinicians from diverse disciplines. [23]

In the context of endodontic retreatment cases, Campo et al. utilized a case-based reasoning paradigm to anticipate the outcome of nonsurgical root canal retreatment, taking into account potential benefits and risks. Case-based reasoning is the method of devising solutions to problems by drawing on prior experiences with comparable issues. In this approach, information is gleaned from analogous cases, encompassing diverse clinical approaches. The system incorporates data from various areas, including performance, recall, and statistical probabilities. The constraint lies in the fact that the system's effectiveness is contingent upon the quality of information within the data. The more extensive the data collection, the enhanced sensitivity, specificity, and accuracy of these approaches. [24]

In the context of endodontic microsurgery, Qu et al. investigated various machine learning models for predicting prognosis involving eight common predictors. The study revealed the potential to predict the prognosis of endodontic microsurgery with an accuracy of 80%.[25]

Micro Robotic Technology for Endodontic Procedures

Dr. Hong's proposition for advanced endodontic technology centered around investigating the utilization of micro robots for conducting endodontic procedures, with the objective of enhancing the quality and reliability of endodontic therapy.

The apparatus possess the subsequent characteristics: Micro-adjustment for positioning and orientation to ensure precise tool initiation, Automatic control of feed rate and travel distance to guarantee tools reach the necessary canal depth and halt at specified points, Integrated micro sensors for monitoring the probing and drilling/reaming processes, Apex sensing and control to prevent root perforations or overshooting of the canal apex, Adaptability with flexible drills or files to facilitate cleaning and shaping of curved canals, Vacuum attachments capable of suctioning debris or loose tissue from the root canal, along with pressurized solution jets for chip removal. Further a system interface is also included to allow clinicians to interact with and control the machine.

The utilization of automated treatment with micro endodontic robots circumvents issues typically encountered with conventional techniques, such as insufficient opening and excessive tooth removal. [26]

Conclusion

The application of artificial intelligence (AI) in Endodontics holds great promise for revolutionizing the field and enhancing the quality of patient care. The primary benefit is the enhancement of diagnostic accuracy, achieved within a reduced timeframe for the analysis of X-ray images and clinical data. However, AI models should be viewed as supplementary tools contributing to the potential optimization of the decision-making process in endodontic practice. Nevertheless, further research is necessary before the widespread adoption of AI systems into routine clinical dental practice.

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