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Diagnostic Accuracy of Artificial Intelligence in Endodontics- A Review

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Abstract

Endodontics is a critical branch of dentistry that focuses on diagnosing and treating diseases of the dental pulp and surrounding tissues. It is gradually incorporating artificial intelligence (AI) to improve diagnostics. AI employs algorithms and machine learning to process vast data sets, discern patterns, and deliver precise predictions. Accurate diagnosis and treatment planning depend on a precise understanding of diseases affecting the pulp and periapical tissues. AI models, such as convolutional neural networks and artificial neural networks, are employed to analyze the anatomy of the root canal system, determine working lengths, detect periapical lesions and root fractures, predict the success of retreatment procedures, and estimate the survival of stem cells in dental pulp. The purpose of this review is to assess the precision of artificial intelligence in endodontic dentistry in terms of diagnosis and prognosis. To review the literature, Studies were selected from PubMed, Scopus, Web of Science, and Google Scholar published over the last five decades (January 1975 to March 2024) by using key-words such as artificial intelligence, machine learning, deep learning, Convolutional Neural Networks, Artificial Neural Networks, application, endodontics, and dentistry. Although, it was concluded that the clinical application of AI in dentistry is in the nascent phase, further research is essential to verify its efficacy and precision. Present AI models show potential in endodontics, particularly in identifying periapical pathosis, diagnosing root fractures, determining working lengths, and predicting treatment outcomes.

Keywords: Dental Pulp, Discern Patterns, Periapical Tissues, Root Canal System

Introduction

The concept of artificial intelligence came into the limelight in World War 2 leading John McCarthy to coin this term in 1956, there has been no looking back after that (1). It is, at times, called machine intelligence. The "fourth industrial revolution, "often known as artificial intelligence, employs computer technology to imitate critical thinking, decision-making, and intelligent behavior that is similar to that of humans.

Artificial intelligence already has a direct Impact on our daily lives, thanks to various office and practice management software.

Siri, Alexa, and other voice command devices are just a few examples of applications that have built intelligent conversational user interfaces for any device, application language, or environment using artificial intelligence. Virtual and physical (that is robotics) AI are both applicable in the field of health care. The mathematical formulae for medication dosage, diagnosis and prognosis, appointment scheduling, drug interactions, electronic health records, and imaging are the main arena of the virtual type. The physical aspect includes rehabilitation, telepresence, robotic support in surgery, and companionable robots for elderly care. (2)

In dentistry, AI technology has emerged as a powerful tool, revolutionizing various aspects of oral healthcare. It involves the use of algorithms and machine learning techniques to analyse large volumes of data, identify patterns, and make accurate predictions. By leveraging AI, dentists can enhance diagnosis, treatment planning, patient care, and practice management. In the realm of diagnosis, AI algorithms can analyse radiographs, images, and patient data to detect and diagnose oral diseases. Through machine learning, AI algorithms continually refine their diagnostic accuracy by learning from vast datasets. This not only improves the accuracy of diagnoses but also enables early detection of conditions, leading to more timely interventions and better patient outcomes. (3)

The specialty of endodontics deals with the diseases and conditions that affect the root canal complex and are developed due to untreated or incompletely treated dental carious lesions. Diseases related to the pulp and periapical tissues are most commonly managed by nonsurgical root canal treatment (RCT). The basis of endodontic diagnosis and treatment planning relies on an adequate and accurate understanding of the diseases related to the pulp and periapical tissues. Inaccurate diagnosis may result in unanticipated pain, which may have a negative impact on the therapeutic plan and eventually result in unpleasant experiences among patients. (4) In the field of endodontics, AI models such as convolutional neural networks (CNN) and artificial neural networks (ANN) are being used to study the root canal system anatomy, measure working lengths, find periapical lesions and root fractures, forecast the success of retreatment procedures, and forecast the survival of stem cells in dental pulp (5).

When AI is combined with endodontics, the root canals could be biomechanically prepared with accuracy. The latest advancements in digital applications have also promoted the creation of clinical techniques such as AI-based diagnosis and assisted access cavity preparations to gain easy accessibility to root canals even in obliterated roots. (6) Additionally, the recent approval of several AI tools for dental image analysis by the Food and Drug Administration (FDA) is a significant step forward in the clinical use of AI in dentistry. However, despite these advancements, it is important to note that the clinical use of AI in dentistry is still in its early stages, and more research is needed to establish its effectiveness and accuracy (7).

The current AI models being researched have several promising applications within the field of endodontics including the detection of periapical pathosis, root fractures, determination of working length, and prediction of treatment outcomes. It is critical, however, to build these AI models from data obtained from experienced clinicians to ensure accuracy and consistency (8). In this study we aimed to evaluate the diagnostic accuracy of artificial intelligence applied in endodontics.

Methodology

Purpose of this literature review is to elaborate the applications along with analysing the diagnostic accuracy of artificial intelligence in the field of endodontics. The literature for this review article was recognized and listed by conducting a scrupulous search in electronic data-bases such as Google Scholar and PubMed published over the last five decades (January 1975 to March 2024) by using key-words such as artificial intelligence, machine learning, deep learning, Convolutional Neural Networks, Artificial Neural Networks, application, endodontics, and dentistry. Inclusion criteria involved articles related to AI in endodontics and original research articles on applications of artificial intelligence in endodontics and dentistry. Articles that were unpublished, articles only with abstracts and articles not in English were excluded. Articles for which full texts weren't available or were duplicate and were irrelevant to endodontics and artificial intelligence were excluded. Abstract screening was followed by the screening of the titles of the articles and the screening process was concluded by full text article assessment at last. Decisively, studies that were irrelevant to the inclusion criteria were rejected.

Results

Study Selection

After the initial search, 600 citations were identified as relevant to the review title, however, 25 articles were removed due to duplication. The abstract relevance narrowed down the article number to 200. Further scrutinizing the articles based on the inclusion and exclusion criteria, resulted in 10 studies for systematic reviewing of the implications of AI in endodontic diagnosis and treatment planning.

Study characteristics

the study characteristics of the included material are shown in the given table 1. The table shows the features of the finally eligible studies. Where, out of 12 studies only 10 were selected that were conducted between 2012 to 2022. While the sample sizes of the studies were predominantly based on the number of teeth, in a few studies, it was also based on the number of patients enrolled in the study (Saghiri et al., 2012a, Saghiri et al., 2012b, Miki et al., 2017a). However, there was a wide variability in the sample size based on the number of teeth, ranging from 21 to 3000 teeth, and mainly examined through radiographs of the patients being evaluated in the study. {ref}(role of ai)

The studies report data from different types of radiographic sources including PANs, PAs and CBCT.

Research methodologies of the reviewed studies used various AI models and methods with specified architectures or frameworks but the ones used mostly were CNN and ANN. One study also reported the use of BNN for predicting results.

The study parameters, as reported in the studies were to classify the teeth or diagnose vertical root fractures, periapical lesions, predicting C shaped canals, locating minor apical foramen and predicting results of endodontic retreatment.

Table 1:

Authors (Year)	Country	Sample size	TASK	Type of AI Network	Study parameter(s)	Outcome
Tuzoff et al., 2019	Russia	1574 dental panoramic radiographs.	Teeth detection and numbering.	CNN	Sensitivity, specificity and precision of tooth detection and numbering.	CNN based algorithm achieved a sensitivity of 0.9941 and precision of 0.9945 for teeth detection, and sensitivity of 0.9800 and specificity of 0.9994 for teeth numbering. These results were comparable to that of the experts (teeth detection – sensitivity of 0.9980/precision of 0.9998; teeth numbering – sensitivity of 0.9893/specificity of 0.9997)
Hu et al., 2019	USA	21 patients (mean age – 27.6 ± 3.5 years)	AI based real time pain detection and localization using neuroimaging.	ANN and DCNN based AI algorithm	Classification accuracy of pain and nonpain states.	AI algorithm achieved 80.37% classification accuracy and a positive likelihood ratio of 2.35
Hatvani et al.		17 CBCT radiographs	Root morphology	CNN (U-net)	Detection	The results suggest the superiority of the proposed CNN-based approaches over reconstruction-based methods.
Saghiri et al., 2012a	Iran	50 single rooted extracted teeth	Locating anatomic position of minor apical foramen.	ANN – Multilayer perceptron model	Accuracy of identifying the minor apical foramen.	ANN had greater accuracy (96%) than endodontists (76%)
Orhan et al., 2020	Turkey	153 CBCT images of periapical lesions acquired from 109 patients.	Detection, localization and volume determination of periapical Lesions.	DCNN	Reliability of DCNN for detection, localization and volume determination of periapical Lesions.	Comparing volume determination of the lesions by DCNN and manual segmentation, there was no significant difference (p > 0.05)
Bayrakdar et al.		470 radiographs	Segmentation	470 U-Net	Periapical lesion	The sensitivity, precision and F1-score for segmentation of periapical lesions at 70% IoU values were 0.92, 0.84 and 0.88.
Pauwels et al.		10	Detection	CNN	Periapical lesion	When data were split up by socket, the mean sensitivity, specificity and ROC-AUC values were 0.79, 0.88 and 0.86, respectively; when split up by filter, they were 0.87, 0.98 and 0.93, respectively
Zheng et al.		180 CBCT radiographs	Segmentation	DL(network not mention)	Pulp chamber Segmentation C	In the training and validation sets, the results showed high spatial overlaps between manual and automatic segmentation. For the testing set, the estimated human ages were not significantly different with true human age.
Campo et al.		205 radiographs	Classification	BNNs	Endodontic re Treatment prediction	Prediction on final solution for treatment and retreatment in 84.4% of the cases, by applying the leave-one out techniques
Li et al.		322	Detection	CNNs	Periapical lesion	Accuracy: 92.5%

Discussion

Periapical Pathologies

Accurate assessment of the periradicular status is crucial in diagnosis, treatment, and evaluation of healing in endodontic therapy. However, from some reported studies, it is believed that periapical lesion cannot be detected until a comparatively advanced bone destruction, that is, not until the lesion erodes the junction between cortical and cancellous bone.

Radiographs cannot be relied upon entirely for this information. However studies done by 'LofHag Hansen' et al. and Low et al showed that CBCT can detect apical radiolucency in the cancellous 2 cortical bone that are normally hidden by the superimposition of unrelated structures onto the Features of interest. (21)

Apical periodontitis, a prevalent condition, accounts for approximately 75% of cases involving radiolucent jaw lesions. (22)

Notably, the accuracy of CBCT imaging diminishes in diagnosing apical periodontitis in teeth with filled roots, limiting its use to specific clinical scenarios due to its high cost and radiation exposure. (23)

A study by Orhans revealed that The AI system was able to detect 142 of a total of 153 periapical lesions. The reliability of correctly detecting a periapical lesion was 92.8%. The deep convolutional neural network volumetric measurements of the lesions were similar to those with manual segmentation. There was no significant difference between the two measurement methods. (12) Another study by Pauwels demonstrated that the CNN showed perfect accuracy for the validation data. When data were split up by socket, the mean sensitivity, specificity, and ROC-AUC values were 0.79, 0.88, and 0.86, respectively; when split up by filter, they were 0.87, 0.98, and 0.93, respectively. For radiologists, the values were 0.58, 0.83, and 0.75, respectively. The study also concluded that CNNs show promise in periapical lesion detection. The pre-trained CNN model yielded in this study can be used for further training on larger samples and/or clinical radiographs. (16)

Lee at al also demonstrated that an AI-based machine-Learning algorithms will be a helpful tool for determining tooth prognosis when considering the treatment plan. A comprehensive treatment plan must be considered to diagnose tooth prognosis and ensure long-term oral health and function. (18)

Determination of working length

A too short working length can result in infected tissue being left in the root canal, and this can then continue to damage the periapical tissue. Hence, a correct estimation of working length is crucial for endodontic success. The radiographic apex does not always coincide with true apex (apical foramen). (21)

very few studies have been performed on determination of working length & detecting apical Foramen amongst which one study performed by Saghri suggested that Artificial neural networks can act as a second opinion to locate the AF on radiographs to enhance the accuracy of working length determination by radiography. In addition, ANN can function as a decision-making system in various similar clinical situations. (9)

Decision of retreatment in endodontics

Treatment outcome assessment in Endodontics has been a source of debate since the second half of the XX century. This mainly arises from the complexity of the periapical healing process that, as thoroughly demonstrated, usually takes up 1 year but could require a longer period, even 4 or 10 years. (24.) The presence of a persistent periapical radiolucency has often been used as a criterion of endodontic “failure” and as an indication for endodontic retreatment. As an alternative decision strategy, the use of decision analysis has been proposed. (25.)

Only one study by Campo et al. presented an innovative system specially designed to help odontologists make decisions about retreatment. The results obtained show that, with the CBR analysis, the data obtained were relevant because by ordering the established variables, particularly those with the highest risk factor, we could predict the final solution for treatment and retreatment in 84.4% of the cases. (15)

Pulp chamber segmentation

Compared with the two-dimensional images generated by conventional radiography, the three-dimensional characteristic of CBCT provides more information about the teeth and their surrounding structures, which makes the application of it in endodontics rapidly growing worldwide. However, the image presented to the dentists is blurred and two-dimensional, imagining the 3D structure of the teeth highly depends on the clinical experience, especially the dental pulp reconstruction is one of the most challenging problems for all dentists. (26)

Hence a recent study conducted by Zheng et al. Wherein a total of 180 CBCT studies were randomly divided into 37/10/133 patients for training, validation, and testing data, respectively. In the training and validation sets, the results showed high spatial overlaps between manual and automatic segmentation (dice = 87.8%). For the testing set, the estimated human ages were not significantly different from true human age (p = 0.57), with a correlation coefficient of r = 0.74. this study concluded that an integrated DL and LS method was able to segment the pulp chamber of first molars from 3D CBCT images, and the derived pulp chamber volumes could effectively estimate the human ages. (13)

Conclusion and Future Research

In a nut shell, The Evolution of AI cannot be ignored, and it has already begun showing its wonders in dentistry, where we have examined the efficiency of AI in endodontics. However, one of the biggest drawbacks of the current given literature is the sample data size, the future studies should consider using larger sample sizes.

There are also several models which are not trained based on relevant clinical data, no matter what the accuracy meter says it makes the output of such models unreliable. As of now there are not enough papers to come to a finite conclusion for the practical implementation of AI technologies in routine practice.

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