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Review Article

Artificial Intelligence in Endodontics - A Literature Review

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Abstract

Artificial Intelligence (AI) is revolutionizing endodontics, significantly enhancing the accuracy of diagnoses and the effectiveness of treatments. This literature review examines the methods and applications of AI within endodontics, particularly its role in detecting root fractures, periapical lesions, and evaluating root canal anatomy. AI technologies, such as machine learning and deep learning, have shown remarkable precision in tasks like determining working length and predicting the success of retreatment procedures. The integration of AI into endodontics holds great promise for improving patient care by refining treatment plans, minimizing procedural errors, and advancing robotic-assisted endodontic surgeries. Despite the encouraging outcomes, challenges such as data variability and the necessity for standardized protocols persist. This review underscores the potential of AI to transform endodontic practice and highlights the need for ongoing research and development in this area.

Keywords: Artificial Intelligence; Deep Learning; Machine Learning; Dental Pulp Cavity; Retreatment

Introduction

AI is revolutionizing healthcare by connecting computers and humans more effectively, by demonstrating smart behavior in order to accomplish specific objectives. It promises to bring a paradigm shift in diagnostic accuracy, treatment planning, and clinical decision-making and also can reduce expenses, time, the need for human knowledge, and the number of medical errors [1]. Within the realm of AI, machine learning (ML) serves as a subdomain where algorithms are employed to acquire knowledge of inherent statistical patterns and structures within data. This acquisition of knowledge facilitates the ability to make predictions pertaining to previously unobserved data.

The phrase "Artificial Intelligence" (AI) was originated during the 1950s and constitutes the construction of machines with the ability to execute tasks that are typically carried out by humans.

To understand how AI can be utilized, key aspects such as machine learning (ML), neural networks (NN), and genetic algorithms have to be acknowledged [2].

Machine Learning (ML)

Machine learning (ML) is a part of AI that uses algorithms to predict results from data. It allows machines to analyze and solve problems using large datasets on their own, without needing human help [3].

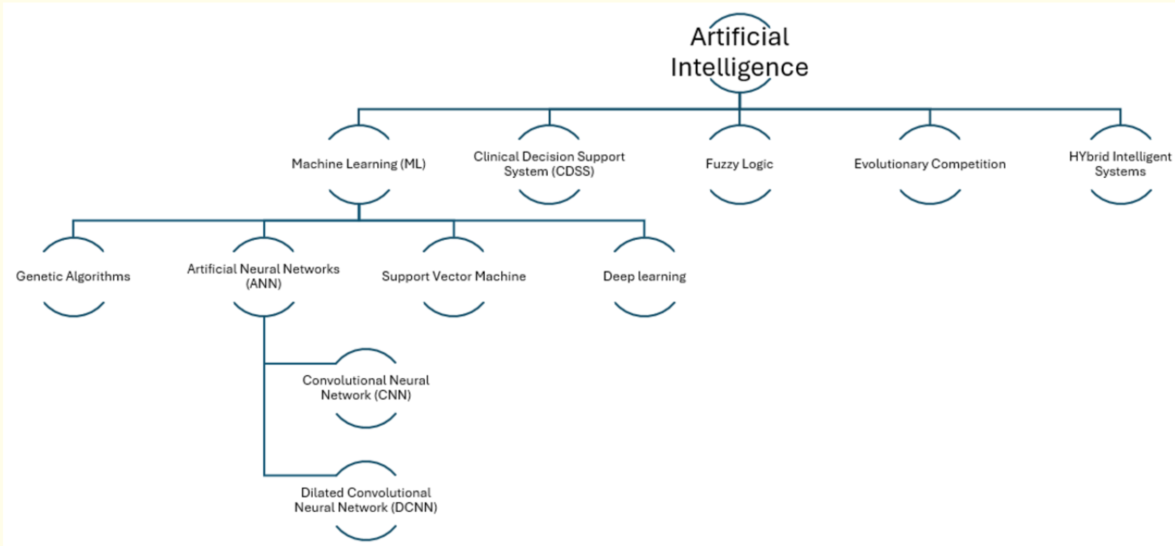

Figure a

Neural networks (NN)

A notable type of ML model is neural networks, composed of multiple algorithms that process signals through artificial neurons, aiming to replicate the functioning of the human brain [3].

There are 2 types of Neural networks

- Convolutional neural networks (CNNs) – For image classification
- Dilated convolutional neural networks (DCNNs)–Image sections are spread out (dilated) to cover more of the image without losing any details.

Convolutional Neural Network (CNN) is a deep learning model designed for grid-like data, such as images. It mimics the animal visual cortex and can automatically learn features from basic to complex patterns. It basically looks at small sections of an image at a time to find patterns, like edges or textures.

Deep Learning (DL)

Deep learning, a subset of machine learning, utilizes multi-layered neural networks to process information and automatically identify patterns. This method improves how features are identified [4].

Clinical decision support systems (CDSS)

Any computer system that aids healthcare providers in making clinical choices by handling clinical data or medical knowledge is referred to as a CDSS [5].

Fuzzy logic:

The branch of logic known as fuzzy logic recognizes and proves that everything is a matter of degree [6]. Fuzzy logic is an easy-to-understand machine learning technique that offers great flexibility in its application.

4 major components of fuzzy logic [7].

- Rule Basse
- Fuzzification
- Inference Engine
- Defuzzification

Applications of ai in endodontics

AI can improve endodontic treatment by providing better insights into root canal anatomy. It can also be a valuable educational tool for interpreting radiographs, making differential diagnoses, exploring treatment options, and tracking student progress.

Various applications of AI in Endodontics are as follows [2]:

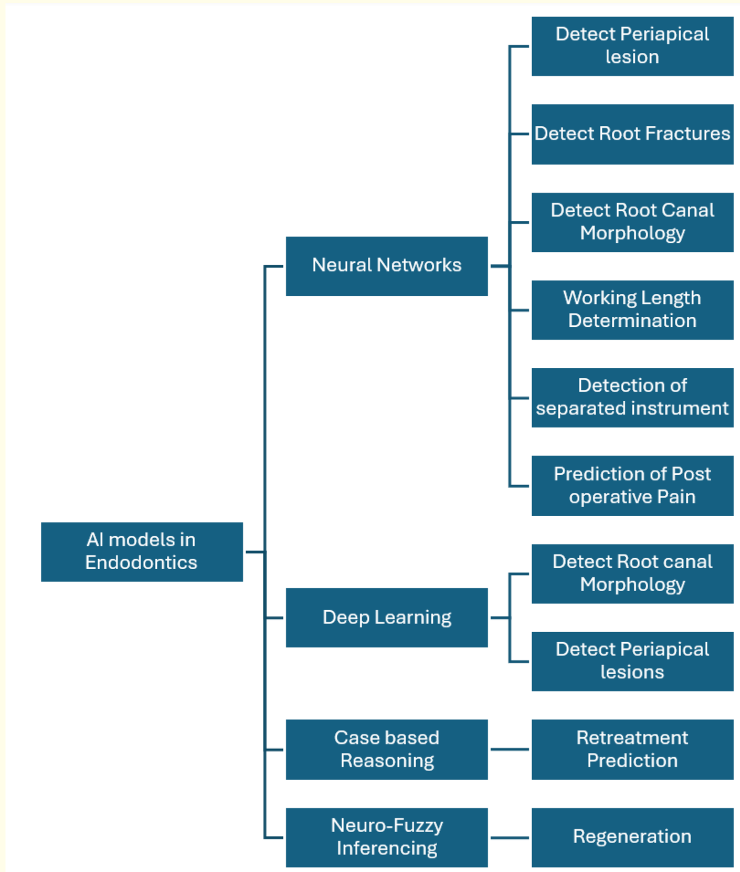

Figure b

Endodontic diagnosis

AI has been used to detect and diagnose a wide range of physiological and pathological abnormalities in the teeth [8].

Caries diagnosis

Accurate diagnosis of dental caries is essential for effective prevention and treatment of tooth decay, but traditional methods can be imprecise and inefficient. AI integration, particularly machine learning and deep learning algorithms, offers significant potential for enhancing the accuracy and efficiency of caries diagnosis. According to a systematic review by Mohamad-Rahimi H., *et al*, deep learning models with various architectures can greatly aid dentists in detecting caries lesions [9].

Caries Net is an advanced deep learning model created to improve the diagnosis of dental caries. This AI system has shown significant promise in improving the accuracy and efficiency of caries detection compared to traditional manual methods [10].

Utilizing deep learning techniques for classifying dental caries with the ICDAS™ scoring system holds significant promise. This approach can substantially enhance the accuracy and speed of caries diagnosis [11].

Periapical lesions

Various authors suggest that a panoramic-based AI model can help minimize misdiagnosis of periapical lesions and provide secondary validation, saving clinician's time for treatment.

Different neural network algorithms, such as CNN, [12] CNN using U-Net, [13] and D-CNN, [14] have been used for lesion detection.

A study on the AI-based U2-Net model showed high sensibility and intermediate precision in detecting periapical lesions on radiographs [15]. Another study with deep learning models (Faster-RCNN and Inception-v3) achieved 84.6% accuracy in classifying periapical regions on OPG radiographs [16].

Pulpal exposure

Preserving pulp vitality is crucial for treating deep caries without severe symptoms. Accurate preoperative radiographic assessment is essential for choosing the right treatment. Altukroni., *et al.* developed the AI tool Make Sure Caries Detector and Classifier (MSc), which reliably detects and differentiates exposed from unexposed pulp on digital radiographs [17]. Another study by S Ramezanzade et al found that AI can predict pulp exposure in vital teeth with deep caries and no severe symptoms, but further explainable AI predictions and a 'learning curve' are needed [18].

Root fractures

"Vertical root fractures (VRFs)" are a very common occurrence in endodontically treated teeth and sometimes are also reported in non-endodontically treated teeth.[19] Identifying vertical root fractures (VRFs) on radiographs is challenging and might require more sophisticated technology. Fukuda and colleagues utilized a convolutional neural network (CNN)-based deep learning model called DetectNet to identify vertical root fractures (VRFs) on panoramic radiographs. However, due to the 2-dimensional imaging of panoramic radiography, the information of images CNNs could extract is limited and the diagnostic efficiency of CNN using panoramic radiography is unsatisfactory [20]. Ziyang Hu., *et al.* investigated the feasibility of CNN models in diagnosing non-endodontically treated VRF teeth on CBCT images in vivo, and reported that CNN model ResNet50 presented higher diagnostic efficiency in diagnosis of in vivo VRF teeth than VGG19, DensenNet169 and radiologist with 2 years of experience [21].

External root resorption

Detecting external root resorption (ERR) at an early stage is vital to prevent progressive and irreversible damage, which can lead to tooth loss in severe instances. The periapical radiograph is a commonly used imaging technique for identifying ERR. Although it provides high-resolution images, it has limitations such as the overlapping of two-dimensional images, which may not accurately depict the full extent of ERR. Studies have found that AI incorporated tools can assist clinicians in early detection of ECR and differentiating it from caries [22]. Another recent study explored the potential of 8 different DLMs algorithms in identifying ERR on CBCT images and demonstrated promising results for future automated ERR identification [23].

AI in treatment planning and execution

Determination of Root canal morphology

Understanding root canal anatomy is crucial for non-surgical root canal therapy. AI helps detect irregularities and locate new canals.

Hiraiwa T et al demonstrated that a deep learning system accurately classifies root morphology of mandibular first molars on radiographs (panoramic radiograph), effectively distinguishing between single or extra canals in distal root [24].

Aminoshariae A reported that AI performs as well as humans in analyzing CBCT radiographic segmentations but much faster [25].

Endodontic retreatment involves treating missed canals, with 93% of all missed canals being on the maxillary first molar and 44% on maxillary second molars [26]. Periapical radiographs are primary, CBCT is recommended for complex cases.

Albitar L et al developed a deep learning model to detect and segment unobturated MB2 canals in endodontically treated maxillary molars using CBCT images, and showed that AI algorithm has potential for identifying both obturated and unobturated canals in such teeth [27].

A visually explainable DLM for classification of C shaped canals was developed and was found to be effective in diagnosing C shaped canals [28].

Another study using a new lightweight CNN structure to detect C shaped canal and found its higher accuracy in detection and lower resource consumption [29].

Verification of working length and tracing the apical foremen

The selection of the correct working length (WL) is critical to ensuring successful root canal treatment outcomes. Inadequate determination of working length (WL) can lead to several issues, including instrumentation beyond the apical foramen, flare-ups, periapical foreign body reactions, and poor microbiological control. Digital technology has shown advantages in locating the apical foramen but also has its own set of errors.

Xiaoyue Qiao et al utilized a multi frequency impedence method based on neural network for precisely locating the position of the apical foramen and found that it exhibited 95% success, thereby eliminating the influence of human and environmental factors on measurement of the root canal length [30].

Retreatment Predictions

In dentistry, endodontic treatment has a 90% success rate, leaving a 10% failure rate. Consequently, a dentist would greatly benefit from using AI to identify and evaluate cases within this 10% failure rate, helping to determine whether extraction or retreatment is the better option.

The case-based reasoning (CBR) paradigm was described by Campo et al. to predict nonsurgical endodontic retreatment outcomes and the benefits and risks, and it determined whether retreatment was necessary [31].

Endodontic surgery

Endodontic microsurgery (EMS) becomes a crucial alternative option when nonsurgical endodontic retreatment is insufficient or its outcome is uncertain.ML has a promising role in various aspects of EMS focusing on diagnosis, including computer-aided detection of periapical lesions in CBCT images, distinguishing cystic periapical lesions from granulomas, identifying cracks, and automating the segmentation of teeth and the mandibular nerve canal as well [32].

Regenerative endodontics

AI can help to enhance the processes of dental pulp tissue repair using stem cells with the help of the analysis of factors that define cells' differentiation, creating an optimal scaffold for cell growth, and predicting the effectiveness of the treatment. Neuro-fuzzy inference technique can be used in examining dental pulp stem cells in multiple rejuvenation treatment modalities, predicting cell viability, following microbial infection [25].

AI in Treatment outcome prediction

AI has been employed to forecast specific results in endodontic treatment. In a study by Lee et al., the authors looked to create an effective AI based module that would allow for accurate clinical decisions on tooth prognosis, in consideration of an ideal treatment plan [33].

Predicting postoperative pain

Studies indicate that ANN holds the potential to identify crucial variables and predict posttreatment pain with remarkable accuracy. Gao et al. emphasize the high prediction accuracy of ANN based on the BP algorithm, suggesting potential benefits for dentists and patients in future root canal therapy [34]. Additionally, as measurement techniques continue to be refined, the accuracy of artificial neural network (ANN) models is anticipated to keep improving, offering better precision in forecasting outcomes for root canal treatments.

Other uses of AI in Endodontics

Detection of separated instruments

A separated endodontic instrument is one of the challenging complications of root canal treatment. Various CNN and LSTM models were found to achieve a high predictive performance on to distinguish separated endodontic instruments in radiographs [35].

Dental education

Studies show that AI software-based model found to be feasible in training dental students in terms of access cavity preparation learning [36].

Recent and Future trends

Photorealistic 3D Reconstructions

An exciting area that has been gaining more interest is the use of AI enhanced algorithms is to create photorealistic 3D reconstructions of the root canal space and the tooth anatomy. This innovative reconstruction technique is known as cinematic rendering (CR). CR can create these photorealistic 3D images based on CBCT data sets by using high dynamic range rendering lightmaps to create a natural lighting environment [37].

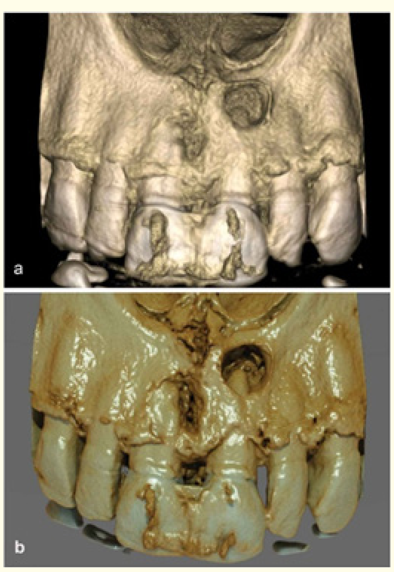

Figure 1: A case highlighting periapical lesions on both teeth #8, and #9. (a) depiction in traditional CBCT vs (b) 3D visualization obtained with CR [37].

Robotics and Microbots

AI-guided robots, already used in neurosurgery and orthopedics, are being developed for implant dentistry to aid in implant placement with accuracy comparable to static and dynamic navigation systems. Future applications are expected to include similar AI-guided systems for endodontic microsurgery and routine endodontic treatments. Besides AI guided robots, AI-guided microrobots have significant potential in endodontics, in improving the strategies for eradicating bacterial biofilm colonies that adhere to dentin in complex root canal areas.

Recently, laser, ultrasound, or light energy-assisted systems combined with self-propelled micro-robots have been introduced in endodontics. These microbots, smaller than a pinhead, convert environmental energy into mechanical energy, increasing their ability to penetrate biofilm. They can be manipulated through augmented reality to deliver disinfectants, drugs, and assist in opening and shaping infected spaces [38].

Artificial intelligence (AI) chatbots

AI chatbots like ChatGPT and Bard have been recognized as transformative tools in various fields, including dental education. Despite AI's significant advancements in dentistry since 2020, especially in diagnostics, treatment planning, and telemedicine, the integration of chatbots in dental education remains limited. This highlights the necessity for curriculum updates to include advanced AI and deep learning methods, as chatbots can support decision-making and improve clinical reasoning skills.

Studies have found that chatbots such as ChatGPT provided more credible information on topics related to endodontics to the general public, thereby protecting their role in awareness regarding endodontics [39].

However, in a study by Yeliz Guven et al, complex situations such as traumatic dental injuries (TDI) chatbots provided some misleading and inaccurate responses to questions about TDIs, thereby proving that no chatbot can replace a dentist for diagnosis, treatment, and follow-up care in complex dental scenarios [40].

Shortcomings and gaps in ai in endodontics

Though AI has been found to be beneficial in a lot of aspects, there have been downfalls associated with it, due to which it has not been widely implemented in endodontics, such as [25].

1. The healthcare system needs standardized programming technology for appointment scheduling, patient management, and periodic recalls. This system must be regularly updated to align with ongoing changes in the healthcare sector.
2. Extensive cost to set up the AI systems
3. Individual health records provide valuable insights for dentists to detect adverse drug reactions and adjust treatments, though they also carry the risk of AI-related information misuse.
4. A standardized protocol for precise diagnosis, which influences outcome predictions and prognosis, is still lacking and depends on clinical findings.
5. The complexity of these applications may be misunderstood by individuals and dentists who lack training in AI.
6. The impact of AI in endodontics may be limited because AI tends to provide a single result, while there could be multiple possible outcomes.

Conclusion

In modern dentistry, vast amounts of data are gathered throughout the treatment process, posing challenges in data collection, analysis, and utilization. Although complex, this data is crucial for addressing clinical issues. AI advancements won't replace dentists but will augment their skills, leading to more precise diagnoses and outcome predictions, ultimately enhancing patient experiences and treatment success.

Additionally, the absence of standardized treatment protocols can be problematic when implementing new technologies. Therefore, AI can be valuable in understanding and identifying scenarios where these technologies can be effectively applied.

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