Artificial Intelligence in Endodontics

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Abstract:
Artificial intelligence (AI) is revolutionizing endodontics as well as other healthcare specialties. This research investigates the use of AI in endodontic practice, which also highlights the technology's potential for increasing diagnostic accuracy, refining treatment plans, and forecasting patient outcomes. Artificial Neural Networks (ANN) and Machine Learning (ML) algorithms are two examples of AI technologies that hold great promise for improving image analysis, streamlining clinical decision-making, and deciphering complex dental data. Even with these developments, problems including poor data quality, moral dilemmas, and the requirement for clinical validation still exist. The goal of this paper is to give a thorough analysis of the advantages, restrictions, and potential uses of AI in the field of endodontics.

Keywords:
Artificial intelligence, Endodontics, Machine learning, computer aided diagnosis, predictive analysis, Automated diagnosis.

Introduction:

Healthcare is changing as a result of artificial intelligence (AI), which closes the communication gap between computers and people. To accomplish certain objectives, it demonstrates clever conduct. Following John McCarthy's formal establishment of AI in

1955, it has developed into a fundamental component of medical care. A new approach in clinical decision-making, planning of treatment, and diagnosis accuracy is expected[1]. The field of precision medicine has led to increased interest in the applications of classical machine learning (ML). They can predict whether a treatment will be successful based on the patient's features. Moreover, medical image processing has been transformed by deep neural networks (DNN). They perform better on activities like using lymph nodes to diagnose cancer. The application of AI can raise patient care overall, lower healthcare expenses, and increase diagnostic precision[2]. This historic endeavor changed quickly and is still having an impact on many areas of our life today. These days, AI is a potent instrument utilized to resolve challenging issues.

As a subset of artificial intelligence, machine learning makes judgments by analyzing and learning from data using algorithms rather than explicit programming. Machine learning uses an experience-based approach to teach computers how to program themselves. Prior to training the machine learning model to identify patterns or make predictions, data must first be collected and prepared. This model could be adjusted by a human programmer to produce more accurate results. After then, the accuracy of the ML model is tested using fresh evaluation data.

The core of Deep learning (DL), a subfield of computational neuroscience that leverages data sets for learning and prediction, is the construction of multi-layered neural networks. Artificial neural networks' architecture is similar to that of the human brain, with hundreds of thousands or millions of interconnected processing nodes arranged into layers. For the processing of complicated imaging data, such biomedical images, DL has been very useful[3].

Advancements in radiography, cardiovascular surgery, neurology, and other health care professions have been made possible by artificial intelligence[4]. AI-based applications have received approval from the Food and Drug Administration (FDA). AI has the potential to enhance pulpal and periapical disease diagnosis, treatment, and prevention in endodontics. While radiologic diagnosis is the primary use of AI in endodontics, other AI-based applications are being developed for clinical treatment and result prediction. But false information about AI fuels sensationalism and exaggerated expectations, underscoring the importance of proper knowledge and awareness in the medical field. With the introduction of AI, healthcare is set to enter a revolutionary era that promises improved treatment for patients, improved productivity, and breakthroughs in the field of medicine as a whole. The many AI-based endodontics technologies will be emphasized, along with some of the challenges, limitations, and ethical quandaries that arise.

AI in dentistry

The area of dentistry has seen a major revolution thanks to AI technology. Artificial intelligence (AI) applications use models like Convolutional Neural Networks (CNN) and Artificial Neural Networks (ANN) to accomplish a variety of tasks in dentistry practices. Artificial intelligence(AI) powered virtual dental assistants guarantee accuracy and productivity in dental clinics by completing activities with less personnel and greater precision. The diagnostic abilities of AI are highly beneficial in dental and oral surgery, supporting treatments like tumor excision and dental implants. Design assistants, like rapid, support prosthetic dentistry by guaranteeing the most aesthetically pleasing prostheses possible using patient preferences and anthropological considerations.

AI also contributes to the provision of individualized orthodontic care by assessing radiographs, forecasting misalignment, identifying cephalometric landmarks, eliminating the requirement for several testing methods, and offering diagnoses that are more accurate than those made just by human judgment. Artificial intelligence(AI) technologies that can assess bite marks and determine biological age and gender are beneficial to forensic odontology. Dental radiology uses artificial intelligence (AI) to identify teeth, identify diseases like caries, and forecast problems like caries in root and TMJ arthritis. Because AI algorithms improve the diagnosis of compromised teeth, they additionally help dental treatment and periodontal therapy[5,6.]

AI's assessment in endodontics

Endodontics is a rapidly evolving subject, demonstrating the transformative potential of AI for patient treatment in such professional field. Specifically, the creation of CNN led to significant advancements in diagnosis precision and treatment planning[7]. In tasks like identifying complex root canal anatomy, calculating a working length, identifying vertical fractures of the root, predicting pressure and force during the canal preparing, and identifying delicate abnormalities indicators in radiography images, for instance, CNNs have demonstrated impressive performance[8]. This developments improve patient outcomes by enabling endodontists to make more accurate diagnosis and create customized treatment regimens.AI provides a number of other advantages in endodontics in addition to improving efficiency and precision. For example, AI-powered algorithms can assist in planning treatment by analyzing patient information while predicting the most effective plan of procedure based on individual characteristics along with treatment objectives. By providing clinicians with immediate information throughout treatments as well as alerting them to potential implications or deviations from advised treatment procedures, AI can also reduce errors. Additionally, AI-driven technologies allow for the early detection of endodontic problems, which facilitates prompt intervention and stops the progression of the disease. Extensive research approaches supporting the assessment of the accuracy and dependability of AI-driven treatment algorithms and diagnostic instruments are used to promote the incorporation of AI. Research leveraging extensive clinical case datasets and applying stringent validation methods, like external validation and cross-validation, offer convincing proof of AI's effectiveness in endodontics.

Interoperability with current dental software systems and user-friendly interfaces further aid in the smooth incorporation of AI into clinical procedures.The application of AI in endodontic treatment is not without difficulties and constraints, despite its revolutionary promise. For instance, in order to guarantee the moral and appropriate use of patient data in AI-driven apps, issues with data security and privacy must be resolved. Furthermore, relying too much on AI algorithms may provide problems when making treatment decisions or interpreting complex clinical settings requires clinical judgment and knowledge.

Automated techniques for detecting tooth morphology, roots, and canals

In endodontics, automated systems have been created to identify tooth morphology, canals, and roots by analyzing dental pictures using sophisticated algorithms. Endodontists can make accurate assessments of tooth anatomy and root canal layouts with the help of these technologies. In one study, Chen et al developed an automatic identification device to identify teeth that undergone root canal therapy using orthopantomograms (OPGs) and a Convolutional

Neural Network (CNN). The significant improvements in picture segmentation and anomaly identification demonstrated by this method held promise for enhancing endodontic treatment planning[9]. Hasan et al employed YOLOv5s and YOLOv5x in a different investigation to distinguish between noisy periapical images and the root canal obturation. They were effective in identifying obturation and errors, indicating the usefulness of these algorithms in evaluating the results of endodontic treatment[10].

Hiraiwa et al. focused on mandibular first molars while analyzing root morphology using OPGs and a Deep Learning Model (DLM). Their study showed how AI may increase diagnostic precision by diagnosing root morphology with great accuracy11. Duan et al. studied tooth and pulp segmentation in CBCT scans using the U-Net algorithm and Feature Pyramid Network. They demonstrated accurate segmentation and highlighted the potential for AI to enhance in-depth diagnostic processes.

Periapical lesion detection

Clinicians often face challenges in diagnosing and scheduling therapy for teeth that exhibit periapical lesions and associated discomfort due to the inherent complexity of this process[13]. Common radiographic modalities used to identify pulp and periapical disorders include Intra Oral Periapical Radiographs (IOPA), Ortho Pantomo Grams including one-Beam Computed Tomography (CBCT) imaging[14]. When it came to detecting periapical lesions, CBCT imaging fared better in terms of accuracy ratings than both digital IOPA (0.72) and conventional IOPA (0.73), according to a meta analysis (0.96)[15]. Notably, when detecting apical periodontitis in teeth with filled roots, CBCT imaging is only helpful in specific clinical circumstances due to its elevated price and radiation risk[13].

The particularities of peripheral radiolucency and resorption of alveolar bones are highly advantageous for artificial intelligence (AI) models intended to detect periapical illness and periodontal disease[16]. Considerable research on artificial intelligence (AI) applications in endodontics, particularly for lesion diagnosis, has been grounded in two-dimensional (2D) radiography, including panoramic and periapical images. Cone-beam computed tomography (CBCT), a type of 3-dimensional (3D) radiography, has greatly increased the detection of Periapical Lesion(PL) in comparison to 2D radiography. However, there is little sensitivity and specificity for PL detection in teeth that have had endodontic treatment, and clinicians' interpretation of CBCT has poor intra- and interobserver agreement[17].

AI-based CBCT solutions are increasingly crucial to fully eliminate observer bias. Based on combined information obtained from 12 research, a comprehensive review and meta-analysis of the testing precision of algorithms using deep learning determined the sensitivity range for radiographic diagnosis of PL to be 0.65 to 0.96. This is equivalent to the lesion detection accuracy of CBCT[18] used by human doctors. Issa et al. assessed the Diagnocat AI system's diagnostic accuracy in identifying apical pathosis on periapical radiographs. The method demonstrated a 97.87% specificity in detecting healthy teeth and a 92.30% sensitivity in identifying periapical lesions[19].

Crack detection

In industrialized nations, tooth decay is primarily caused by dental cracks, which rank third in frequency. One successful method of preventing tooth loss is the early diagnosis of cracks and the implementation of appropriate therapies to stop the cracks from spreading. It is essential to build unbiased and trustworthy AI-based techniques for crack detection. Prior to using fracture detection techniques, early attempts employed segmentation for individual teeth based on convolutional neural networks. However, because clinical scans are frequently obtained using distinct acquisition parameters a phenomenon that the machine learning field refers to as a domain shift this approach was not ideal for handling clinical data. A unique 3D Fourier domain adaptation model was created by Sahu et al. to solve this issue in an unsupervised way for teeth segmentation from a source domain to an adapted target domain (i.e., 2 different CBCT scans and acquisition protocols). Their research showed that the suggested domain adaptation technique can considerably enhance the target domain's segmentation performance. Presently, this method is undergoing additional refinement to boost the prediction validity of CBCT in fracture detection[20].

Caries detection

One crucial area where AI has advanced significantly is caries detection. Carious lesions in dental photographs can now be accurately identified thanks to machine learning algorithms. As an example, CNN utilizes an OPG and a typical dataset using a deep neural network technologies to automatically detect oral health problems. They demonstrated the promise that AI holds in the comprehensive detection of dental problems by using their method to identify damaged, root-canal treated and repaired tooth[21]. Oztekin et al. used pre-trained models and a variety of machine learning models to concentrate on dental caries identification. Using a dataset of 562 participants, they studied OPGs and showed that AI is accurate in identifying teeth decay. These research show how flexible Artificial Intelligence (AI) can be in the dental industry, particularly in the area of caries assessment, where machine learning (ML) models can be used to efficiently and automatically diagnose patients[22]. Models based on Artificial

Intelligence (AI) have demonstrated good diagnostic performance and could be a useful tool for diagnosing caries lesions[23].

Working length determination

The effectiveness of endodontic treatments depends on the accurate determination of the WL. The minor diameter, or the smallest diameter with the lowest degree of perfusion and innervation, is the appropriate apical limit for endodontic treatment[24]. Clinical dentists routinely employ radiography and electronic apex locators as two standard techniques[25]. Artificial Intelligence has significantly improved this process. It has been demonstrated that when it comes to locating an apical foramen on radiography, ANN can act as a very helpful alternative option. This can increase the precision when determining the working length using radiograph[26]. In order to increase the accuracy of WL determination using radiography, the ANN model performed admirably.

Saghiri et al. evaluated the precision of ANN in a cadaver model by using radiographs to locate a file with regard to its apical foramen. The study demonstrated that, when assessed against actual readings, the Artificial Neural Networks (96%) outperformed endodontists (76%) when determining the working length using human cadavers containing fifty single-rooted teeth. This suggests that under some circumstances, AI and ANN in particular may be able to provide WL judgments that are more accurate than human judgment[27]. This demonstrates how ANN can significantly increase the precision of endodontic procedures.

Predicting Postoperative Pain

In the medical domain, artificial neural networks (ANNs) have advanced significantly and are now widely used for prognostication, diagnosis, and clinical decision-making[28,29]. As one of the most recent developments in algorithms inspired by nature, ANN is a fast developing technology[30].

Research suggests that artificial neural networks (ANNs) have the capacity to detect important factors and accurately predict pain after therapy. Notably, this model has been effectively used by researchers to forecast conditions including unstable chest discomfort and Non-ST-Elevation Myocardial Infarction (NSTEMI). In terms of treating acute pain associated with sickle cell disease, the combination of machine learning models and mobile health apps demonstrated predictive power[31,32.]

In the realm of dentistry, Gao et al. emphasize the excellent precision for prediction of ANN depending algorithm, suggesting potential benefits for patients and dentists with regard to root canal therapy in the future[33]. Furthermore, it is expected that the accuracy of ANN models would rise in tandem with ongoing improvements in measuring methodologies, providing better outcomes prediction for root canal therapy.

Decision making for Retreatment

Endodontic therapy has an astounding 90% success rate, with a 10% failure rate. Endodontists can benefit greatly from the inclusion of AI techniques in treating this 10% of patients. This can help with case analysis and help identify whether extraction or retreatment is the better course of action.[34,35,36.] Campo et al. have contributed to this topic by developing a Case Based Reasoning (CBR) decision support system. This method is specifically designed to predict if retreatment would be practical. By precisely predicting the likelihood of either succeeding or failing, this helps to reduce the frequency of failed retreatments and prevent unnecessary removal of teeth. Interestingly, they had an 84.4% accuracy rate in predicting the rehabilitation or final therapeutic success for the subjects under study[37]. Herbst et al. looked into what causes endodontic failure and how to forecast it using machine learning (ML) techniques such XGBoost, The gradient boosting algorithm, Random forest algorithm and Logistic regression[38]. A more detailed understanding of treatment outcomes resulted from the research, which involved 458 participants and 591 teeth. It also showed tooth level characteristics that were substantially connected with failure.

Vertical Fracture of Root

In dental practice, vertical root fractures—defined as fractures that extend vertically from the apex of root to the crown—are very challenging to diagnose[39]. The frequency of VRFs after treatment of root canals varies widely, ranging from 3.7 to 30.8%[13,38]. Among the several diagnostic techniques, conebeam computed tomography (CBCT) has gained popularity for detecting VRFs due to its sub millimeter resolution of spatial detail and threedimension (3D) imaging abilities[40]. A built neural network has been shown to be a potentially useful method for recognizing vertical root fractures on CBCT images, especially in teeth that have undergone endodontic treatment but are still intact[42,43]. Shah and colleagues carried out a noteworthy study whereby they deliberately fractured second molars. When wavelet analysis was used on generated data, it proved useful. Wavelets, as mathematical operations, simplified the process of recovering weak signals in noisy environments inside a machine learning framework. Although a limited number of samples, steerable wavelets were successfully deployed, indicating their efficacy in locating injuries using excellent quality CBCT images[41]. These state-of-the-art methodologies show how diagnostic approaches are evolving, with neural networks and wavelet analysis offering exciting new avenues for increasing the precision of vertical root fracture diagnosis in oral images.

Other applications of AI in dentistry

AI is useful in endodontics for a variety of purposes besides standard diagnostic work. It can help with a variety of clinical practice issues, enhance treatment results, and offer insightful information for thorough endodontic evaluations.
A CNN approach using U Network structure used to identify both filled and unfilled root canals and also CNN network with the Gabor processing and a network with Long Short-Term Memory (LSTM) used to recognize detached endodontic equipment in OPGs42,43. Multiple path NN used for evaluating pulp exposure risk in Bitewing radiography, whereas Multilayer Perceptron to separate stress from electro dermal activity data generated by the Electric Pulp Tester (EPT)[44,45].

While Choi et al developed a conversational computer program for cavities evaluation utilizing 3D models[46], Suárez et al. evaluated the precision as well as consistency of ChatGPT, an AI the conversation with the bot in endodontic treatment[47]. Furthermore, it was observed that ChatGPT has flaws and restrictions when it comes to comprehending the circumstance and coming to treatment planning decisions[48].
These research demonstrate how artificial intelligence (AI) has the potential to revolutionize endodontics and challenge the accepted norms for a dental office. This ensuing a thorough examination of every theme field, stressing important techniques, findings, and the consequences of these investigations for the field of endodontics as a whole.

Perspectives on ethics and future directions

Use of Artificial Intelligence (AI) in endodontic procdure exhibits considerable potential; yet, appropriate and efficient adoption necessitates addressing ethical considerations, constraints, and developing challenges[49]. To protect patient welfare and maintain professional standards, ethical concerns around algorithmic bias, data security, and privacy of patients need to be carefully examined and supported by strong regulatory frameworks. In order to reduce bias and boost model reliability, diverse and inclusive datasets are essential. AI training with previous data sources raises concerns about the authenticity and adaptability. Furthermore, a barrier that prevents AI algorithms from being widely accepted and used by clinicians is their inability to be interpreted. Future studies should place a high priority on explainability and transparency in order to help endodontic practitioners build understanding and trust.

Additionally, there are intriguing opportunities to advance clinical practice by investigating novel applications such patient-centered decision support systems, real-time procedural assistance, and predictive modeling for treatment outcomes. Ethical reflexivity, technological innovation, and continued multidisciplinary debate are necessary to ensure the ethical and beneficial integration of AI into endodontic care meanwhile realizing its transformative potential[50].

Clinical significance

By increasing procedural precision, forecasting treatment results, and boosting diagnostic accuracy, artificial intelligence (AI) in endodontics promises substantial clinical advances. Compared to conventional techniques, AI-driven systems can more consistently identify periapical lesions, root fractures, and canal shape by analyzing complicated imaging data. AI can also help in optimizing individualized treatment regimens and forecasting the effectiveness of root canal procedures. Because of the improved long-term results, decreased procedural errors, and more efficient patient care, artificial intelligence (AI) is a priceless tool in endodontic treatment today.

Conclusion:

In the subject of contemporary endodontics, artificial intelligence offers a useful use with encouraging outcomes. To overcome the lack of heterogeneity and enable generalization of the results, more research including a larger number of datasets must be conducted in the future.

Conflict of interest: No conflicts of interest

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