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Review Article

Artificial Intelligence in Endodontics: A Brief Review

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Abstract

The success of the endodontic treatment depends upon proper understanding of the diseases in depth, accurate diagnosis and the various endodontic diagnostic methods used to identify the nature of the disease. This brief review describes the application, limitations and possible future of AI-based dental diagnostics, treatment planning, and conduct, such as, image analysis, prediction making, record keeping, as well as dental research and discovery in endodontics.

***Keywords**: endodontics diagnostic systems; dental informatics; machine learning.*

Introduction

The branch of Endodontics deals with the diseases and conditions affecting the root canals and diseases originated due to the untreated carious lesions. However, the conditions related to the periapical tissues and pulp are commonly treated and managed by nonsurgical root canal treatments. The success of the endodontic treatment depends upon proper understanding of the diseases in depth, accurate diagnosis and the various endodontic diagnostic methods used to identify the nature of the disease.(1,2)

The most frequently used radiographic techniques for diagnostic purposes for endodontic diseases related to pulp and periapical areas are intraoral periapical radiographs, orthopantomograms, and cone-beam computed tomography (CBCT). It is evident that the periapical and panoramic radiographs generate two-dimensional (2D) images of the maxillofacial structures, with lesser exposure than CBCT imaging. (3) CBCT imaging is used widely by endodontists as it enables more radiological analysis. This technology provides three-dimensional images with more precision. (4) The accuracy in detecting periapical lesions is significantly higher with CBCT imaging in comparison to periapical radiography. The only drawback is that it's expensive and the radiation dose, therefore, the use of CBCT imaging is restricted to special clinical circumstances. In such cases, the benefits obtained from the imaging should Outweigh any potential risks resulting from radiographic exposure associated with this technology.

The term "artificial intelligence" (AI) was coined in the 1950s and refers to the idea of building machines that are capable of performing tasks that are normally performed by humans. The recent advancements have resulted in enormous development in diagnostic models for medical imaging and diagnosis. (5) Advancements in computer-assisted diagnosis have resulted in the development of AI models designed for application in health sectors. This brief review describes the application, limitations and possible future of AI-based dental diagnostics, treatment planning, and conduct, such as, image analysis, prediction making, record keeping, as well as dental research and discovery in endodontics.

Artificial Intelligence in Dentistry.

AI-based applications in dentistry are used to streamline care, decrease the dental workforce from lengthy routine tasks, increasing dentalcare at lower costs for a larger population, and eventually facilitate personalized, predictive, preventive dentistry.

A subdomain of AI is machine learning (ML), which "learns" intrinsic statistical patterns in data to eventually cast predictions on data which is not seen otherwise. Deep learning is a ML technique using multi-layer mathematical operations for learning and inferring on complex data like imagery. Deep learning (DL) or convolutional neural networks (CNNs) are developed to mimic the functioning of the human brain; they are designed to solve equations by passing through a series of convolutional filters and are trained on a large number of datasets. [(6)] AI models have been widely applied in medical imaging for systemic diseases such as cardiovascular diseases and respiratory diseases and have displayed exceptional performances that are similar to those of experienced specialists.[(7)] Additionally, in dentistry, AI models are designed for diagnosing oral diseases such as dental caries, periodontal diseases, and oral cancer as well as treatment planning for orthognathic surgeries and predicting the treatment outcomes These models have demonstrated excellent performances, with a major advantage of this being improved diagnostic efficiency with a reduced image interpretation time.[(6,8)]

Artificial Intelligence in Diagnosis for Endodontic lesions

Detection of Periapical Lesions

The radiographic detection of periapical lesions has been mostly challenging for even the most expert clinicians. Studies have shown that in order for a periapical radiolucency to be visualized on a two-dimensional radiograph, there has to be on average 7.1% mineral bone loss or at least 12.5% cortical bone loss.[(9)] Further, there is a large degree of subjectivity in the interpretation of radiographs. [(10)]

CBCT has shown to be more accurate in the diagnosis of periapical lesions in comparison to periapical radiographs. Patel S et al have showed that the overall sensitivity for the detection of periapical lesions was 28% for periapical radiographs and up to 100% for CBCT.[(11)] However, the interpretation of CBCT volumes can be tedious and time consuming than periapical radiographs. Additionally, there is the potential for the clinician, particularly if they are not trained oral radiologists, to overlook subtle density changes in CBCT volumes,[(12)] especially in larger fields of view. To overcome these problems, AI is currently being developed to aid the clinician in the localization of periapical pathosis. [(12)] AI segmentation was used to label each voxel as “periapical lesion”, “tooth structure”, “bone”, “restorative material”, or “background”. This deep learning AI system was found to be 93% accurate in detecting lesions with a specificity of 88%.[(13)] In the future, it may be possible for AI to “read” a CBCT scan, which could alert the clinician to areas of possible apical pathosis, as well as other odontogenic or non-odontgenic lesions that may be present on the scan. This is of great value particularly in areas where access to oral radiologists and proper radiology training is limited.

Detection of Fractures

Crown and Root fractures are extremely challenging to detect. A systematic review has revealed that CBCT imaging is only 78% accurate in diagnosing vertical root fractures (VRF).[(14)] Fukuda et al in their study used AI to detect VRF on panoramic radiographs and reported a 75% sensitivity and a 93% positive predictive value in their detection.[(15)] Another study utilizing AI for the same purpose showed a 97% accuracy, 93% sensitivity, and 100% specificity in correctly diagnosing VRF.[(16)] Still research is ongoing to improve the overall diagnostic accuracy of AI and detecting fractures in multirooted teeth.[(17)] AI in diagnosis of VRF can eliminate unnecessary treatment of non-restorable teeth as well as extraction of perfectly healthy teeth that were earlier misdiagnosed.

Artificial Intelligence in Treatment Planning

Determinization of Root Canal Morphology

To determine the root canal morphology of the tooth being treated, periapical radiographs, bitewing radiographs, and CBCT imaging have been used. However, these techniques be subjective and requires training and experience. AI has been used to evaluate the root canal morphology and number of canals. Hiraiwa et al. used AI on panoramic radiographs and reported an 87% accuracy in the ability to diagnose single or multiple distal roots on mandibular first molars.[(18)] AI has also been used to accurately measure root canal curvatures and three-dimensional canal changes following root canal instrumentation.[(19)] Already, there are commercial AI software companies such as Diagnocat (LLC Diagnocat, Moscow, Russia) that helps practitioners analyze their patients’ CBCTs and determine the type of root canal morphology present. It also has the capability to automatically segment the teeth and create 3D Standard Tessellation Language (STL) models that dentists can print out for further analysis. Hence, AI has the potential to assist the clinicians in choosing the appropriate endodontic files to clean the root canal system and automatically adjust the most appropriate speed and torque on their endodontic handpiece/motor that is required to complete the endodontic treatment with minimal errors.

Determination of Working Length

Determination of working length and the apical limit of the root canal system is a critical step during root canal treatment. An accurate working length (WL) determination allows for thorough mechanical and chemical disinfection of the root canal system. As it also helps to protects the periodontal tissues from instrumentation beyond the canal terminus and helps prevent the extrusion of debris and reduces post-operative pain. It has been shown that a mm loss in WL can reduce the success rate by 12–14% when dealing with infected root canal systems.(20) The methods used to determine the canal length include use of a combination of electronic apex locators and periapical radiographs. The interpretation of digital radiographs with accuracy is highly dependent on the image quality and the subjectivity of the clinician.(21) Although apex locators can provide a high degree of accuracy, but still apex locator readings can be associated with errors in wet canals, presence of metallic restoration or defective cables. All these variables thus contribute to inaccurate measurements that can negatively impact the treatment outcome.

AI algorithms are currently being developed to aid the clinician in the location of the apical terminus on radiographs. Saghiri et al used AI to determine working length measurements and found that AI was 100% accurate in determining the root length when compared to the actual measurement following tooth extraction. They also concluded that AI was able to locate the minor apical constriction 96% of the time.(22) This has showed that the advancement of this technology can allow AI to gather information from imaging techniques and translate this information to the endodontic handpiece and drive the endodontic files to the cementodentin junction with minimum operator interference to preserve the apical constriction and prevent over instrumentation.

AI in the prediction of endodontic treatment outcome.

AI has been used to predict certain outcomes with regards to endodontic treatment. Lee et al., created an effective AI based module that allowed accurate clinical decisions on tooth prognosis, in consideration of an ideal treatment plan.(23) This study utilized data from a multidisciplinary study team at Harvard which consisted of leading specialists from prosthodontics, periodontics, endodontics, and experienced clinician educators. Their results showed that an effective AI-based module allows for accurate clinical decisions on tooth prognosis with comparable results to clinicians from multiple disciplines.

For the endodontic retreatment cases, a study by Campo et al. utilized a case-based reasoning paradigm to predict the outcome of nonsurgical root canal retreatment with benefits and risks.(24) The system reported whether retreatment should be performed or not. The system included the data from different areas such as recall and statistical probabilities.

With regards to endodontic microsurgery, Qu et al.(25) examined different machine learning models for prognosis prediction by 8 common predictors: including tooth type, lesion size, type of bone defect, root filling density, root filling length, apical extension of post, age, and sex. The study showed that there is potential in being able to predict the prognosis of endodontic microsurgery with 80% accuracy. Further application of this technology can assist clinician in predicting the long-term prognosis of the various treatment options before and after intervention by factoring elements related to diagnosis, and prognostic risk determination.(12)

Future Trends in AI

Photorealistic 3D Reconstructions

An area which is gaining more interest these days is the use of AI enhanced algorithms is to create photorealistic 3D reconstructions of the root canal space and the tooth anatomy as well as common orofacial lesions. This novel reconstruction method is referred to 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. This can potentially improve the diagnostic accuracy by better displaying the anatomical details. Such technology may have a great potential in clinical training and teaching.

Robotics & Microbots

Another future application is the development of AI-guided robots to aid in rendering actual treatment on the patients. Image-guided robotic surgery has been used frequently in neurosurgery and orthopedics. This involves the use of preoperative or intraoperative images along with a tracked device to create an interactive map of deep anatomy, vasculature, and pathology.

Besides AI guided robots, AI guided microrobots is another field of endodontics that holds a lot of potential. In endodontics there is a push to continually enhance the ultimate therapeutic strategy of defeating the biofilm colonies of bacteria which adhere to the dentin, within the most complex areas of the root canal wall.

Limitations

AI solutions have not by large, entered routine dental practice, mainly due to limited data availability, accessibility, structure, and comprehensiveness, lacking methodological rigor and standards in their development, and practical questions around the value and usefulness of these solutions, but also ethics and responsibility. Any AI application in dentistry should demonstrate tangible value by, for example, improving access to and quality of care, increasing efficiency and safety of services, empowering, and enabling patients, supporting medical research, or increasing sustainability. Individual privacy, rights, and autonomy need to be put front and center; a shift from centralized to distributed/federated learning may address this while improving scalability and robustness. Lastly, trustworthiness into, and generalizability of, dental AI solutions need to be guaranteed; the implementation of continuous human oversight and standards grounded in evidence-based dentistry should be expected. Methods to visualize, interpret, and explain the logic behind AI solutions will contribute ("explainable AI").Dental education will need to accompany the introduction of clinical AI solutions by fostering digital literacy in the future dental workforce.

Conclusion

In the field of endodontics, AI has already been proven to be useful. The evolution of this technology and its continuous application can positively impact the field of endodontics and assist in preserving the natural dentition. Clinical implications: AI is currently being used for specific endodontic applications and possible potential applications in the future horizon.

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