Review

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Artificial intelligence in dental radiology: a narrative review

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Abstract

This article examines how artificial intelligence (AI) is revolutionizing dental radiology, a vital aspect of dental diagnosis and treatment planning. AI improves diagnosis accuracy through sophisticated applications like automated anomaly identification, image segmentation, and treatment planning, whereas traditional imaging techniques like periapical and panoramic radiography have limits. Clinical procedures are streamlined, and accurate dental condition diagnosis is made possible by methods such as recurrent neural networks (RNNs) and convolutional neural networks (CNNs). AI contributes to improved patient outcomes by lowering radiation exposure and improving picture quality. Dental radiography has a bright future despite current obstacles including data collection and algorithm training; nonetheless, further study and cooperation are required to maximize AI's incorporation into clinical practice. AI has the potential to revolutionize dental diagnostics, despite obstacles in data collection and the requirement for strong algorithm training. The creation of innovative imaging modalities, further research on AI applications, and cooperative efforts between scientists, physicians, and industry participants are some of the future directions. The dentistry community may better utilize AI to enhance patient care and diagnostic skills by creating clear criteria for its integration. In the long run, AI has the potential to transform dental radiology, resulting in better treatment outcomes and a more effective practice.

Keywords: artificial intelligence, dental radiology, dentistry

Introduction

Dental radiography is essential for diagnosis and treatment planning in dentistry. It aids in diagnosing dental caries and periodontal diseases, evaluating tooth fractures and trauma, detecting hidden dental anomalies, guiding endodontic and implant treatments, and monitoring treatment outcomes. Digital radiography advancements minimize radiation and enhance image quality. Artificial intelligence (AI) is the ability of a machine to mimic human behavior and intelligence to carry out particular tasks[1]. Artificial intelligence (AI) is increasingly being integrated into various medical fields, offering significant advancements in diagnostics, treatment planning, and patient management. In dental radiology, AI holds the potential to transform traditional practices by enhancing diagnostic accuracy, reducing radiation exposure, and improving workflow efficiency. This review aims to explore the current applications of AI in dental radiology, discuss its limitations, and highlight future directions for research and clinical integration.

HIGHLIGHTS

- Artificial intelligence (AI) in dental radiography has the potential to drastically change treatment planning and diagnostic procedures.
- Artificial intelligence improves diagnosis accuracy through sophisticated applications like image segmentation and treatment planning.
- Dental radiography is essential for diagnosis and treatment planning in dentistry.

Limitations of traditional imaging methods

Traditional dental imaging methods, such as periapical and panoramic radiographs, have been widely used for diagnosis and treatment planning. However, these 2D methods – including periapical scans, bitewings, and panoramic radiographs – are inherently limited by their 2D nature. These limitations lead to the following:

- **Image overlap and distortion,** resulting in obscure anatomical structures.
- **Inability to differentiate buccal and lingual surfaces,** making lesion detection difficult.
- **Magnification and asymmetrical distortion,** particularly in panoramic radiographs.
- Higher radiation exposure increases health risks.

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For example, the buccal bone may obscure infrabony abnormalities, leading to misdiagnosis. Similarly, periapical scans may not capture the full extent of anomalies, and bitewings can fail to provide clear posterior imaging[2]. Artificial intelligence (AI) has emerged as a transformative tool in dental radiology, offering enhanced diagnostic precision through deep learning models such as convolutional neural networks (CNNs). AI applications in dental imaging include automated anomaly detection, image enhancement, segmentation, and treatment planning.

Emergence of AI in dental radiology

The concept of artificial intelligence originated during a summer workshop at Dartmouth in 1956. It has the potential to pave the way for significant advances in several fields of research, including theory of computation, neural networks, machine learning, and natural language processing[3]. Machine learning is the process of teaching robots to mimic intelligent human behavior that was previously exclusive to humans[4]. Machine learning refers to the process of training machines to perform tasks that typically require human intelligence, such as recognizing patterns and making decisions. With the use of sophisticated software, these AI advancements have a substantial impact on dentistry, encompassing many subspecialties like orthodontics, oral surgery, implant dentistry, and oral radiography, in terms of diagnosis and treatment planning[5]. Automatically detecting diseases based on images and utilizing other diagnosis-support technologies is one of the few new advancements in oral radiology diagnosis[5]. AI systems can automatically detect diseases by analyzing dental images, making the diagnosis process faster and more accurate. This technology supports dentists by identifying anomalies that might be missed during manual analysis, thus enhancing overall diagnostic and treatment planning in dental practices.

Objective: review AI applications and potential

Artificial intelligence (AI) is transforming dental radiology through various applications, including automated anomaly detection, dental condition diagnosis and classification, image segmentation and reconstruction, image enhancement and denoising, and patient data analysis. AI-powered algorithms can accurately identify caries, fractures, and other dental anomalies, while also aiding in orthodontic analysis and treatment planning. One of the most promising AI technologies used in dental radiology is based on convolutional neural networks (CNNs). CNNs are a type of deep learning model specifically designed for processing visual data like images. These models can learn to recognize patterns and features in dental radiographs, making them highly effective for detecting dental caries and other anomalies with high precision. CNN-based models have immense potential for precise diagnosis and detection of dental caries[6]. Additionally, AI-driven image segmentation enables precise 3D modeling, facilitating improved diagnosis and treatment.

Many AI models are being developed for automatic illness risk prediction, abnormality/pathology detection, diagnosis, and prognosis evaluation in the field of clinical medicine[7]. When it comes to processing picture data that are difficult or time-consuming for human observers, or when other automatic processing techniques fall short, artificial intelligence (AI) can play a significant role. Segmenting 3D models of teeth and/or bones from CBCT scans for surgical planning is one prominent example[8]. Moreover, a great deal of research has been done on automated cephalometric landmark detection, which is probably going to be the first dental "AI" application that is widely employed in clinical practice[8]. These advancements enhance diagnostic accuracy, streamline clinical workflows, and enhance patient results, opening the door to more individualized and effective dental treatment.

Clinical implications in dental radiography

Together with the rise in the overall number of dental X-ray exams, there has been a comparatively large increase in the combined dose given to patients and dental healthcare professionals, which is somewhat detrimental to human health[9]. It has been suggested that minors under the age of 18 should not participate in ionizing radiation-related work activities due to workplace exposures[10]. The lens equivalent dosage limit for occupationally exposed persons has been lowered from 150 mSv/year to 20 mSv/year, and dose limitations for exposed workers are defined[10].

Improved diagnostic accuracy

High-quality direct digital image processing has little impact on the precision of diagnosis[11]. Traditional film radiographs were converted to digital format using three separate digitizers: a TV camera, a drum scanner, and a laser scanner[12]. The best diagnostic accuracy was achieved in images that were digitized using the drum scanner[12]. While CBCT imaging demonstrated exceptional diagnostic accuracy, peripheral radiographs, both digital and conventional, exhibited good diagnostic accuracy in differentiating false apical periodontitis from no lesions[13].

Enhanced patient care

The introduction of digital 3D imaging represents a technological leap. This provides a thorough understanding of your oral anatomy, which facilitates precise and thorough treatment planning[14]. File administration and comparison have been made easier by the integration of digital imaging equipment with dental software such as Pearl Dental Software. Monitoring the development of your dental health over time is now simpler[14]. By carrying out a variety of tasks, such as problem-solving, learning, perception, reasoning, and decision-making, artificial intelligence (AI) in dentistry can improve patient care. AI systems can handle and analyze a vast amount of data quickly by simulating human-like cognitive processes through the use of sophisticated algorithms, machine learning, and data analysis[15].

AI applications in dental radiology

Image analysis and processing

AI algorithms can process a vast amount of image data, identifying patterns and anomalies that might be missed by human observers. The process of performing operations on an image to improve it or extract valuable information is known as image processing. AI is capable of learning from millions of images and using that knowledge to interpret and comprehend new images. Artificial intelligence plays a major role in automating operations such as photo

processing, leading to faster and more precise outcomes[16]. AI-powered image processing is revolutionizing medical imaging by assisting radiologists in diagnosing diseases, identifying abnormalities, and developing personalized treatment strategies. It also aids in surgical planning, patient outcome monitoring, and pathology analysis[16]. This capability is crucial in enhancing the diagnostic accuracy of dental radiographs.

Automated detection of dental anomalies

The key to enabling personalized dentistry is the capacity to classify images using intraoral photographs. With the use of a saliency map and an intraoral photo upload feature, the dentist would be able to expedite clinical visits and improve their diagnostic skills by using a trained neural network to identify anomalies and provide explanations. Speed, repeatability, and reliability of anomaly classification could all be improved by automating the process with DNNs for dental anomalies[17]. Convolutional neural networks (CNNs) are a cutting-edge approach to image classification that has been effectively used in dentistry in recent years[18].

Diagnosis and classification of dental conditions

AI-powered tools can classify various dental conditions with a level of accuracy comparable to experienced radiologists, streamlining the diagnostic process and reducing the likelihood of human errors. In fields including orthodontics, endodontics, prosthodontics, restorative dentistry, periodontics, and oral and maxillofacial surgery, artificial intelligence in dentistry alone has attracted a great deal of attention recently[19]. When it comes to identifying dental caries, sinusitis, periodontal disease, and TMJ issues, neural networks and machine learning seem to be just as good as or superior to skilled radiologists and clinicians Research on salivary gland cancers, lymph nodes, squamous cell carcinoma, and premalignant lesions demonstrates promising outcomes for the predictive and diagnostic utility of AI[19]. The results were validated by Jeyraj and colleagues (2019). CNNs were utilized to differentiate between malignant tissues and those that were not using hyperspectral pictures. The findings imply that CNNs can be used, under expert supervision, for image-based oral cancer categorization and diagnosis[20]. Oral cancer is a highly severe and difficult malignancy that spreads widely. Early diagnosis and classification are made possible via the use of deep learning algorithms and advanced technology.

Image segmentation and reconstruction

AI enhances dentistry through image segmentation and reconstruction, improving diagnosis accuracy and treatment planning. Techniques like CNNs and 3D modeling enable personalized care and streamlined workflows. Applications include computer-aided diagnosis, patient education, and dental prosthesis design. In deep learning, the segmentation task is a method that separates an image into objective segments to identify it from other objects and the background[21]. The AI method for 3D tooth and alveolar bone segmentation from CBCT pictures proposed in this paper is completely automatic, accurate, reliable, and – most importantly – clinically practical. It has undergone comprehensive validation on a large-scale multicenter dataset of dental CBCT images[22]. The technical positioning quality of periapical radiographs was evaluated using segmentation and classification methods, which suggested that a deep learning system would be useful[23]. Artificial intelligence techniques do exceptionally well in tooth segmentation in CBCT images, according to another systematic review[24]. The research has effectively created an end-to-end segmentation technique that includes the data needed for surgical planning for dental implants[25]. To enhance various facets of image quality, AI has also been crucial in the optimization of image reconstruction parameters, advanced reconstruction algorithms, and image denoising techniques[26].

Radiation dose reduction

Minimizing radiation exposure is crucial for patients and dental professionals. Radiation therapy can harm the salivary glands, teeth, bone, and face and neck muscles in addition to the oral mucosa[27]. The main long-term effects of head and neck radiation therapy are dental decay and osteoradionecrosis (ORN)[26]. According to a study, AI-guided decision assistance improved the pre-radiation therapy dental dose estimate's precision and accuracy[28]. AI has the potential to significantly reduce radiation doses to patients by automating and streamlining data collection procedures[29]. AI transforms dental imaging with enhanced modalities, including CBCT, digital radiography, intraoral scanners, dental MRI, and CT scans. These advancements improve image quality, reduce radiation exposure, and boost diagnostic accuracy, streamlining treatment planning[30].

Deep learning techniques in dental radiology

Deep layers of artificial neural networks make up the subgroup of machine learning known as "deep learning." Many layers make up the model's architecture, which is referred to as "deep." Deep learning requires training models from vast volumes of data rather than manually extracting characteristics, in contrast to typical machine learning[31]. This means that deep learning models can automatically learn from data without the need for humans to tell the model what to look for. Various deep learning networks are used for different data types and scenarios. For instance, convolutional neural networks (CNNs), a type of deep learning model specifically designed for analyzing visual data, are more frequently employed for computer vision and classification applications, whereas recurrent neural networks (RNNs), a type of deep learning model designed to analyze sequences of data, such as time series or speech, are frequently utilized for speech recognition and natural language processing[31]. Dental cone-beam computed tomography (CBCT) and digital 3D radiography have gained popularity in dentistry since the first decade of the twenty-first century. Consequently, the study and advancement of computer-aided detection and diagnosis (CAD), a software tool that assists dental professionals in automatically detecting abnormalities in radiographs, which had not been vigorous in the medical domain, accelerated in domains such as dentistry[21].

Several deep learning techniques in image analysis

1. Convolutional neural networks (CNNs): Specialized in pattern recognition for detecting caries, periapical lesions, and bone loss.

2. Recurrent neural networks (RNNs): Useful for analyzing sequential imaging data for age estimation and growth predictions.
3. Transfer learning: Allows AI models to leverage pre-trained networks for dental anomaly detection with limited datasets.

Convolutional neural networks

CNNs are used in dentistry for both pathology detection (like caries and apical lesions) and structural detection (like teeth and bones)[32]. A convolutional neural network (CNN) is a mathematical framework structured with three primary layers: convolution, pooling, and fully connected layers. The convolution and pooling layers focus on extracting essential features from input data, while the fully connected layer processes these extracted features to generate the final output, such as classification[33].

Recurrent neural networks

Recurrent neural networks (RNNs) consist of interconnected neurons that collaborate to handle complex tasks. These neurons are structured into three layers: input, hidden, and output. The input layer receives data for processing, while the output layer delivers the final result. The hidden layer is responsible for analyzing the data, performing computations, and making predictions[34]. Recurrent neural networks (RNNs) are especially helpful for detecting temporal dependencies, which provide precise age estimates based on developmental changes. Furthermore, it has been shown that generative adversarial networks (GANs) can synthesize high-quality dental images, help with data augmentation, and solve problems with minimal datasets[35].

Transfer learning

The process of transfer learning involves using a neural network that has been pre-trained to identify a "general feature" in an image[36]. Transfer learning enhances AI-driven dental diagnostics in several key areas:

- Image classification: Transfer learning enables automated classification of dental images into categories such as normal, pathological, or requiring further assessment.
- Segmentation of teeth and bone structures: Pre-trained models help automate tooth segmentation in CBCT scans, which is essential for surgical planning and orthodontic analysis.

Data limitation is an issue that traditional deep learning and machine learning approaches were unable to address. A novel solution to this issue is transfer learning[37]. The accuracy is increased with the application of transfer learning[38].

Challenges in dental radiology

Comparing dentistry to medicine, the use of AI is still a few years behind schedule. While artificial intelligence (AI) is revolutionizing many fields of medicine, dental radiology still lags behind, trailing by a few critical years. The primary hurdle lies in the daunting task of acquiring and annotating vast datasets necessary for training robust AI algorithms. Unlike general medicine, where AI integration is rapidly advancing, dentistry faces unique obstacles. AI thrives on big data, where the more information it processes, the sharper its predictions become. However, in dental radiology, the data pool is not just about quantity but also about the quality and specificity of imaging, which can vary significantly from patient to patient. This is mostly because it is expensive to acquire and annotate the enormous amounts of data needed for adequate AI algorithm training, which is necessary to guarantee the architecture's resilience[36]. AI's basic tenet is to learn from the data it gathers; the more data gathered and examined, the more precise the algorithm's predictions will be. Artificial intelligence has advanced due to big data, but human intuition will always be superior[36]. Despite these challenges, the potential for AI in dental radiology is immense. With improved data acquisition techniques and collaborative efforts among dental professionals, AI could soon offer unparalleled diagnostic precision, enhancing early detection of oral diseases and streamlining treatment plans.

Future directions in dental radiology

AI training, integrating AI into clinical tools for real-time support, and developing user-friendly AI systems that even non-experts can use. Systems for direct digital dental radiography have the potential to alter how dentists identify and manage dental diseases. They eliminate the need for developing chemicals and equipment, provide radiographs instantly, and significantly reduce radiation exposure for patients[39]. Future directions include developing more such systems that are not only time-efficient but also enhance diagnostic accuracy, reduce costs, improve patient comfort, and facilitate remote consultations through tele-dentistry. Additionally, integrating AI could enable real-time image analysis, predictive analytics, and personalized treatment recommendations, further transforming dental care. The majority (68%) of dental specialists agreed that AI will be useful in evaluating minute radiographic details missed by practitioners and 64% stated that AI will help budding dentists make the radiological diagnoses[40]. Additionally, using semi-supervised learning could lessen the need for fully annotated data, and continuous learning systems would keep AI updated with the latest information. Educating both professionals and patients about AI's role in dentistry and establishing clear ethical guidelines will also be crucial for its successful adoption.

Conclusion

Artificial intelligence (AI) in dental radiography has the potential to drastically change treatment planning and diagnostic procedures. AI improves diagnosis accuracy by getting around the drawbacks of conventional imaging techniques by using sophisticated approaches like deep learning models, automatic anomaly identification, and image segmentation. Workflows are simplified, radiation exposure is decreased, and patient outcomes are enhanced by these technologies. AI has enormous potential to improve clinical dental practice, considering current obstacles like data collection and algorithm training. Future advancements have to concentrate on further study, participant co-operation, and the creation of precise rules for the application of AI. AI promises to enhance diagnostic abilities as well as provide individualized patient care and effective practice management as it develops further. AI integration into dental radiography has the potential to revolutionize the field of imaging. Further research is necessary to explore AI's full potential, address challenges, and optimize clinical adoption.

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