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Current State of Artificial Intelligence in Caries Detection: A Literature Review

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Abstract: This review article investigates the application of artificial intelligence (AI) in dentistry, explicitly focusing on caries detection. After appropriate filtering, ten relevant studies were carefully examined from PubMed and IEEE Xplore. Bitewing radiographs emerged as the most frequently utilized imaging modality, followed by near infrared transillumination, periapical, intraoral, and radiovisiography images. Different neural networks were employed in these studies to detect the desired variables, and the quality and type of input data substantially impacted the outcomes. The article emphasizes the need for further research, particularly in exploring larger datasets and different image types to enhance the implementation of neural networks in caries detection. While the potential of AI in dentistry for caries detection is promising, continuous research and refinement of methods are vital to harness its capabilities thoroughly. Therefore, ongoing investigations are crucial to advancing dental practice through the effective utilization of AI. The article highlights the necessity for continued exploration and improvement in this evolving field.

Keywords: Artificial intelligence, Caries detection, Neural networks.

I. Introduction

Artificial intelligence (AI) in healthcare has gained significant attention in recent years due to its potential to improve patient outcomes, optimize clinical workflows, and reduce healthcare costs [1]. Medical imaging technologies like X-ray, MRI, and CT scans have been instrumental in detecting, diagnosing, and treating various diseases, including cancer and cardiovascular disease. In dentistry, the emerging field of dental informatics shows great promise in improving treatment and diagnosis, saving time, and reducing stress and fatigue during daily practice [2, 3]. Dental professionals generate vast amounts of data from high-resolution medical imaging, biosensors, and electronic medical records. Computer programs can assist dental professionals in making prevention, diagnosis, and treatment planning decisions [1, 4].

Convolutional neural networks (CNNs) have been used in dentistry to detect periodontal bone loss, caries on bitewing radiographs, apical lesions, and medical image classification. These neural networks can detect, classify, and segment structures such as teeth and caries. However, they require training and optimization using an image database [5].

Dental radiography is a fundamental tool in modern dentistry for the detection, diagnosis, and treatment planning of various dental diseases. There are three main types of dental radiographs commonly used in dentistry: panoramic, periapical, and bitewing radiographs [6].

Panoramic radiographs provide a comprehensive view of the entire oral and maxillofacial region. They are suitable for screening purposes and can aid in detecting various dental conditions, including impacted teeth, tumors, and jaw fractures. Additionally, panoramic radiographs help evaluate the position of the mandibular nerve and the temporomandibular joint (TMJ) [7]. However, they have limited diagnostic accuracy and cannot provide detailed information on individual teeth or the surrounding bone. See Fig. 1.

Periapical radiographs provide detailed information on a single tooth and the surrounding bone. They diagnose various dental conditions, including caries, periodontal bone loss, and apical lesions. Additionally, periapical radiographs are used for endodontic treatment planning and can aid in assessing root canal morphology and detecting root fractures. However, periapical radiographs have a limited field of view and require multiple exposures to capture the entire dentition [8]. See Fig. 2.

Bitewing radiographs detect caries on the occlusal and proximal surfaces of posterior teeth. They provide a more detailed view of the tooth than panoramic radiographs and are more sensitive than clinical examination alone. Additionally, bitewing radiographs help monitor caries's progression and evaluate the quality of dental restorations. However, bitewing radiographs have a limited field of view and do not provide information on the surrounding bone or soft tissue. See Fig. 3.

The choice of radiographic technique depends on the specific dental condition being evaluated and the information required for diagnosis and treatment planning. Dental professionals should carefully consider the benefits and limitations of each radiographic technique to ensure accurate diagnosis and optimal patient care.

This literature review provides an overview of the current state of artificial intelligence applications in dentistry, focusing on caries detection.

II. Materials and Methods

A search was conducted on April 10, 2023, using electronic databases such as MEDLINE/PubMed and the Institute of Electrical and Electronics Engineers (IEEE) Xplore. MEDLINE/PubMed was the primary database for medical journal manuscripts. IEEE Xplore publishes computer science, electrical engineering, and electronics articles. Among others, Table I shows the strategy that was used. The eligible studies for this review were full manuscripts and conference proceedings that reported using neural networks to detect teeth and caries. No limitations were set on the language or the date of publication. The exclusion criteria were reviews, studies without dental applications, and studies that did not employ neural networks.

III. Results

A. Relevant Data of Included Studies

The selected manuscripts included in this review were published from 2013 to 2023. Table II provides an overview of the critical characteristics of these caries studies. As shown in Table I, the number of published studies increased yearly. The selected studies were conducted in seven countries, with the highest studies conducted in the United States (n = 2), England (n = 2), and Switzerland (n = 2).

B. Caries Detection

In Sarah [9] this study utilized a fully convolutional neural network to detect proximal caries, which was then compared to the traditional method of using dentists. A cluster-randomized cross-over controlled trial was conducted using AI and traditional methods, involving 22 dentists who were asked to detect caries in a pool of 140 bitewings. The results indicated that dentists using AI had a significantly higher mean area under the Receiver-Operating Characteristics curve (0.89; 95% CI: 0.87-0.90) than traditional methods.

Lee [10] used 3000 periapical radiographs to detect dental caries. The dataset comprised 25.9% maxillary premolars, 25.6% maxillary molars, 24.1% mandibular premolars, and 24.4% mandibular molars. The authors used a deep CNN algorithm with weight factors and preprocessed the datasets using a pre-trained Google Net Inception v3 CNN network with transfer learning. The study obtained an accuracy of 89%, 88%, and 82% in premolar, molar, and premolar-molar, respectively, and AUC values of 0.917, 0.89, and 0.845 for premolar, molar, and premolar-molar, respectively.

Table I: Search Strategy

Database	Search Strategy	Search Data
MEDLINE/ PubMed	(Deep learning OR artificial intelligence OR neural network *) AND (dentistry OR dental)	April 10, 2023
IEEE Xplore	(“Full Text Only”: artificial intelligence) OR (“Full Text Only”: neural network)	April 10, 2023

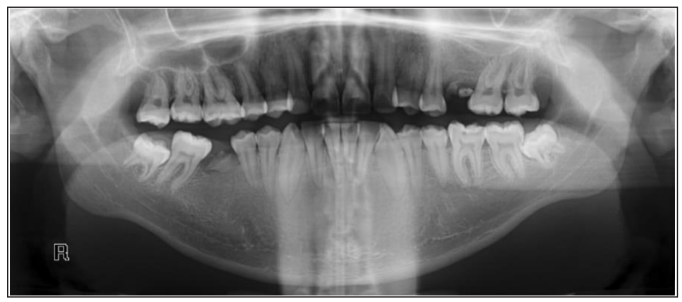

Fig. 1: Panorama X-Ray

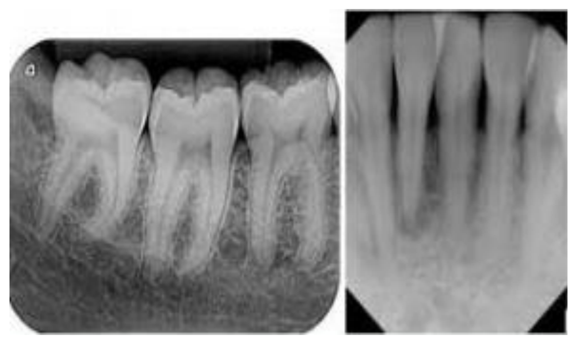

Fig. 2: Periapical X-Ray

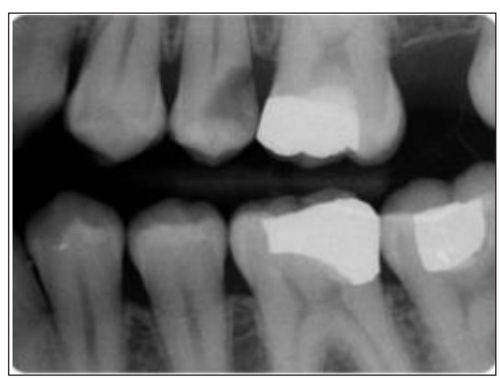

Fig. 3: Bitewing X-Ray

This paper presents a novel approach that integrates image processing techniques with convolutional neural networks to detect proximal dental caries in bitewing radiographic images and classify them based on lesion severity. The algorithm was evaluated using 112 images, and after conducting 2000 iterations, the model's accuracy was found to be 73.3% [11].

Zanella-Calzada [12] analyzed caries concerning socioeconomic and dietary factors using an ANN to determine oral health. The study employed an ANN with seven layers, four dense layers, and three dropout layers. Nine thousand eight hundred twelve subjects were used, with 70% used for training and 30% for testing. The study achieved an accuracy of approximately 0.69 and an AUC of 0.75.

Prajapati [13] employed a convolutional neural network to detect caries in 251 radiovisiography images, achieving an accuracy of 0.875.

In this study [14] convolutional neural networks were utilized to detect proximal caries at various levels of severity on periapical radiographs. The study included approximately 800 periapical radiographs that were randomly distributed. Additionally, different training strategies were employed, such as image recognition (IR), edge extraction (EE), and image segmentation (IS). The achieved area under the curve (AUC) values were 0.805, 0.860, and 0.549 for IR, EE, and IS, respectively.

Geetha study [15] used a back-propagation neural network with a database of 105 intra-oral images to detect caries, achieving an accuracy of 0.971 and a precision-recall curve (PRC) area of 0.987.

The Casalengo study [16] used a deep-learning model to detect and locate dental lesions in near-infrared transillumination images of molars and premolars. The study used 217 images, with 185 for training and 32 for validation. The results showed an area under the curve (AUC) of 85.6% for proximal lesions and 83.6% for occlusal lesions.

Srivasta [17] used a deep, fully convolutional neural network to detect dental caries in 3000 bitewings images. The study obtained a recall of 0.805, a precision of 0.615, and an F1-score of 0.7.

Table II: Caries Detection Main Characteristics

Authors	Journal	Country, Year	Image	Total Image	Neural Network	Outcome
Sarah	Journal of Dentistry	Germany, 2021	Bitewings	140	CNN	AUC
Lee	Journal of Dentistry	England, 2018	Periapical	3000	CNN	Accuracy/ AUC
Maira	MDPI stays neutral	Brazil, 2022	Bitewing	112	CNN	Accuracy
Zanella-Calzada	Bioengineering	Switzerland, 2018		9812	ANN	Accuracy/ AUC
Prajapati	5th International Symposium on Computational and Business Intelligence	United Arab Emirates, 2017	Radiovisiography image	251	CNN	Accuracy
Xiujiao	MDPI stays neutral	China, 2022	Periapical	800	CNN	AUC
Geetha	Health Information Science and Systems	Switzerland, 2020	Intraoral radiographs	105	Back-propagation neural network	Accuracy/ Precision recall
Casalengo	Journal of Dental Research	USA, 2019	Near-infrared transillumination	217	CNNs for semantic segmentation	AUC
Srivastava	NIPS 2017 workshop on Machine Learning for Health (NIPS 2017 ML4H)	USA, 2017	Bitewing	3000	deep fully convolutional neural network	Recall/Precision/F1-Score
Schwendicke	Journal of Dentistry	England, 2019	Near-infrared light transillumination	226	Resnet18 Resnext50	AUC/Sensitivity/Specificity

IV. Discussion

The purpose of this review was to present an overview of the current state of artificial intelligence in detecting various dental conditions including caries. Neural networks can consist of one or multiple layers, with interconnected nodes or neurons facilitating signal transmission within the network. These networks generally have three layers of neurons: input (receives information), hidden (extracts patterns and performs internal processing), and output (presents final network output). The training process entails the optimization of parameters, and this framework is being utilized not only for teeth detection but also across diverse industries to facilitate progressively intricate decisions. Numerous alternatives exist in this regard. Nonetheless, our outcomes might require rephrasing to ensure clarity. For example, despite our findings, a dearth of guidance persists regarding the choice of suitable methods customized for the healthcare sector [7]. Neural networks have been proven beneficial in medicine and dentistry due to their capacity to handle vast amounts of data for analysis, diagnosis, and disease monitoring. Deep learning has become an increasingly valuable tool in the medical field and is starting to impact dentistry. Based on the publication year of the studies examined in this review, 2019 saw the highest number of articles published in this area [4].

The studies mentioned above highlight the effectiveness of deep learning models and image processing techniques in detecting dental caries from various radiographic images. In Sarah's study [9] a controlled trial was conducted involving 22 dentists who examined 140 bitewing radiographs. The AI-assisted dentists achieved a significantly higher mean AUC (0.89) than traditional methods. Lee [10] used a dataset of 3000 periapical radiographs and employed a deep CNN algorithm with transfer learning. Their approach achieved accuracies ranging from 82% to 89% for different tooth types and AUC values of 0.845 to 0.917. This study [11] proposed an algorithm combining image processing techniques with convolutional neural networks for proximal caries detection on bitewing radiographs. The model achieved an accuracy of 73.3% after evaluating 112 images.

Using an ANN, Zanella-Calzada [12] investigated the relationship between caries and socioeconomic and dietary factors. Their study achieved an accuracy of approximately 0.69 and an AUC of 0.75 with a dataset of 9812 subjects. Prajapati [13] used a convolutional neural network to detect caries in 251 radiovisiography images, obtaining an accuracy of 0.875. The study [14] employed convolutional neural networks for proximal caries detection on periapical radiographs. Their model achieved AUC values ranging from 0.549 to 0.860 using training strategies on approximately 800 radiographs.

In Geetha's study [15] a back-propagation neural network was utilized and a dataset of 105 intra-oral images. The model achieved an accuracy of 0.971 and a PRC area of 0.987. Casalengo [16] focused on near-infrared transillumination images of molars and premolars. Their deep learning model achieved AUC values of 85.6% for proximal lesions and 83.6% for occlusal lesions using a dataset of 217 images. Srivasta [17] utilized a deep, fully convolutional neural network for caries detection in 3000 bitewing images, achieving recall, precision, and F1-score values of 0.805, 0.615, and 0.7, respectively.

In conclusion, the studies demonstrate that deep learning models can enhance the accuracy of caries detection in radiographic images and could be complementary to traditional methods in dental diagnosis. Further research and validation studies are needed to optimize these models' performance and clinical application.

V. Conclusions

In conclusion, dental radiography is an essential diagnostic tool in dentistry, and the application of artificial intelligence in this field is promising. The studies discussed in this review demonstrated the potential of deep learning algorithms in accurately and efficiently detecting dental caries, with some achieving results comparable or even superior to those of human dentists. These AI models can potentially improve the accuracy and speed of diagnoses, leading to earlier detection and treatment of dental caries, ultimately resulting in better patient outcomes. However, more studies are needed to assess the reliability and generalizability of these algorithms before they can be implemented in routine clinical practice. Overall, the future of dental radiography looks promising with the integration of AI, and we can expect continued advancements in this field.

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