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Artificial Intelligence - New Horizon for Restorative Dentistry

Rupam Kaur Virk*, **Kanwalpreet Bhullar, Harkiran Sahiwal, Smiley Goyal**

Department of Conservative Dentistry and Endodontics, Sri Guru Ram Das Institute of Dental Sciences and Research Sri Amritsar, India

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***Corresponding author:** Rupam Kaur Virk, Department of Conservative Dentistry and Endodontics, Sri Guru Ram Das Institute Of Dental Sciences And Research Sri Amritsar, India

ABSTRACT

Artificial intelligence (AI) has been defined as the capacity of an integrated platform to obtain, process and implement the skills and knowledge acquired through education or experience that are usually linked to human intelligence. Artificial intelligence leverages computers and machines to mimic the problem-solving and decision-making capabilities of the human mind. AI is a broad field of research that studies "Intelligent agents" or agents that are capable of flexible autonomous action. The AI technologies have primarily been used in dentistry to diagnose dental diseases, plan treatment, make clinical decisions, and predict the prognosis. This review focuses on applications of AI in diagnosis of dental caries various algorithms currently available and the steps followed for dental caries diagnosis using AI technology.

Keywords: Dental caries diagnosis; Artificial intelligence; Machine learning; AI technologies; Convolutional neural networks

Dental caries is a prevalent ailment that impacts an estimated 3.5 billion individuals worldwide, making it one of the most widespread health issues among humans. It affects between 60% and 90% of children and a majority of adults globally, resulting in substantial financial burdens and compromising overall well-being [1,2]. The early detection of dental caries can prevent the necessity for invasive treatments and lead to significant reductions in healthcare costs [3]. However, identifying initial proximal caries solely through clinical assessments is a challenging task, which underscores the value of bitewing radiography as the gold standard for diagnosing demineralized proximal caries. Other methods for detecting caries include fiberoptic transillumination, techniques based on fluorescence, and cone-beam computed tomography (CBCT) [4]. Nonetheless, each of these methods has its limitations, such as difficulties in detecting posterior initial proximal caries and additional expenses associated with the required equipment.

Amid these challenges, a promising development has arisen in the form of artificial intelligence (AI), which has the potential to revolutionize various aspects of healthcare, including the diagnosis of dental caries. Artificial intelligence is described as an engineered system, a set of methods, or automated entities that collaboratively construct, optimize, and apply a model. This enables the system to compute predictions, provide recommendations, or make decisions for predefined tasks. AI constitutes a broad field of study that focuses on "intelligent agents" capable of autonomous and flexible actions. AI systems take various forms, ranging from expert systems to those that learn intricate computational models from data to make predictions on novel information [1]. The second category comprises machine learning systems, equipped with an array of tools, techniques, and algorithms. Machine learning is a subset of AI encompassing algorithms and models trained to identify statistical patterns within a given dataset (known as the training data) with the goal of recognizing similar patterns in new data (test data). This pattern recognition proves valuable in diverse tasks, including classification (predicting the category of a data point from predefined categories), regression (predicting function values for a given input), and clustering (grouping dataset elements based on similarity or other criteria) [5].

Machine learning algorithms offer the advantage of interpreting dental images, including radiographs, photographs, and three-dimensional scans, with greater accuracy and consistency compared to human observation. This reduces the subjective variability associated with conventional diagnostic methods [6]. The potential of artificial intelligence (AI) in dental caries diagnosis extends beyond mere disease identification; it can also contribute to forecasting disease progression and treatment outcomes, offering a more comprehensive approach to dental care [7].

Artificial intelligence algorithms, specifically machine learning and deep learning models, have demonstrated promising results in the detection and diagnosis of dental caries. These algorithms leverage extensive datasets of dental images to learn the patterns and characteristics associated with caries. This enables them to accurately identify the condition in new, unseen images [8]. Predictive modeling, which combines data with statistical algorithms, is used to forecast outcomes with exceptional precision.

Convolutional Neural Networks (CNNs) in Image Analysis and Caries Detection

Convolutional neural networks (CNNs) belong to a category of AI designed to autonomously learn spatial features from images. This makes them highly suitable for tasks like image classification, object detection, and semantic segmentation. Once trained on annotated dental images, CNN models can accurately detect and classify dental caries in new images [9]. They excel at identifying intricate patterns that might escape human observation, enhancing diagnostic accuracy. In particular, CNNs trained with the Edge Extraction strategy have shown excellent performance in detecting proximal caries on periapical radiographs [10].

Caries Net

Caries Net is a deep learning model built upon a CNN architecture. It utilizes AI and machine learning to analyze dental radiographs and precisely identify the presence of dental caries. Caries Net performs pixel-level classification, distinguishing carious lesions from healthy tissue. This capability allows dentists to pinpoint the exact location and extent of decay[24].

Support Vector Machines (SVMs) for Enhanced Dental Caries Diagnosis

SVMs are powerful machine learning algorithms primarily employed for classification and regression tasks. In the context of caries diagnosis, SVMs prove highly effective because they can handle various data types, including dental images, patient histories, and potentially genomic data. SVMs excel at recognizing complex patterns within data, which may not be readily apparent to human observers [12]. Moreover, SVMs are robust against over fitting, a common issue in machine learning where models perform poorly on new data. SVMs are particularly valuable for handling high-dimensional data and complex, nonlinear classification problems in diagnosing dental caries [13].

Random Forest Algorithm for Improved Dental Caries Detection

Random forests are advantageous in caries analyses due to their ability to manage high-dimensional data and handle missing or unbalanced data effectively. Unlike some machine learning models that operate as "black boxes," random forests provide insights into which features are crucial in predicting dental caries. This interpretability aids dentists in understanding risk factors and tailoring preventive measures for patients [14,15].

Deep Learning for Dental Caries Based on the ICDAS™ Radiographic Scoring System

Deep learning techniques applied in alignment with the International Caries Detection and Assessment System (ICDAS™) scoring system hold great promise [16]. ICDAS™ provides a standardized approach to caries detection, offering a scoring system that ranges from 0 to 6, indicating the extent of decay. Deep learning models built on this foundation can significantly improve the precision and speed of dental caries diagnosis. This approach aligns with the universally recognized ICDAS™ system, facilitating communication and comparison of findings among dental professionals [17].

In summary, AI algorithms, including CNNs, SVMs, random forests, and deep learning, hold significant potential in revolutionizing dental caries diagnosis by providing more accurate and consistent results, offering insights into disease progression, and aiding in treatment planning.

The process of identifying caries lesions in dental radiographs involves several essential steps, from initial image acquisition to advanced image processing and analysis [18]. Summarizing the steps: [19]

1. **Image Acquisition**: Dental images are captured using techniques such as bitewing radiography or orthopantomogram. High-quality images are crucial to enhance subsequent analysis accuracy.

2. **Pre-processing**: This step aims to improve image quality for better analysis. Techniques include noise reduction using filters like Gaussian smoothing or median filters. Contrast enhancement methods like histogram equalization make caries lesions more visible.

3**. Segmentation:** Dividing the image into regions or segments. Thresholding is commonly used, classifying pixels as "tooth" or "not tooth" based on intensity.

4. **Feature Extraction:** Extracting features from pre-processed images to help identify caries. Intensity-based features utilize pixel values, typically lower in caries regions. Texture-based features analyze patterns and variations in pixel intensities. Shape-based features involve the shape and size of suspected caries lesions.

5. **Classification:** A classifier is used to identify whether the extracted features represent caries. Various machine learning and AI algorithms like SVMs, random forests, or CNNs are employed. The classifier is trained on labeled data with confirmed presence or absence of caries.

6. **Post-processing:** Refining classification results to improve accuracy. Removing small isolated regions identified as caries that may be noise or artifacts.

7. **Validation:** The entire image processing and analysis pipeline's performance is validated using an independent test set. Performance measures like sensitivity, specificity, precision, recall, and F1 score are calculated to evaluate the effectiveness of the techniques.

Several AI technologies are currently being employed or developed for dental caries diagnosis:

1. Pearl®:

An AI-powered dental radiograph interpretation tool. Enhances diagnostic accuracy and standardization across dental practices. Trained on dental radiographs to identify and annotate dental pathologies, including caries [20]. Serves as a second opinion for dentists but does not replace clinical judgment [21].

2. Overjet:

Uses advanced AI technology for dental imaging interpretation. Offers greater accuracy, consistency, and efficiency in analysis. Reduces variability and enhances diagnostic accuracy across dental practices. Identifies and annotates dental conditions, including caries [22].

3. Denti. AI®:

Designed to transform dental caries diagnosis using AI algorithms and machine learning. Provides a more objective, standardized analysis of dental radiographs. Aims to make caries detection and treatment planning more accurate and efficient [8].

Future Perspectives on AI-Based Caries Detection and Diagnosis

AI's ability to process data quickly and accurately will continue to transform caries diagnosis. AI systems are expected to become more sophisticated, learning from new cases and improving diagnostic capabilities. Wider adoption of AI-based diagnosis in dental clinics, hospitals, and schools is likely.

Ongoing research, innovation, and collaboration among AI experts, dental professionals, ethicists, and legal experts will be crucial for addressing challenges and ethical considerations in AI implementation [23]. The integration of AI into dentistry holds significant promise for enhancing the accuracy and efficiency of caries diagnosis and treatment planning in the future.

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