

Advancements in AI-driven Diagnostics for Dental Health: A Comprehensive Review

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Abstract

Dental diseases, also known as oral diseases or dental conditions, encompass a range of health problems affecting the teeth, gums, mouth, and associated structures. These conditions can lead to pain, discomfort, and severe complications if left untreated. Early detection and accurate diagnosis are crucial for effective treatment and prevention of further complications. This comprehensive literature review aims to identify common dental problems such as Tooth Decay (Cavities), Gingivitis, Periodontitis, and other oral diseases using advanced machine learning and deep learning approaches in dental image analysis. Machine learning and deep learning techniques provide significant assistance to dentists in making informed decisions during the treatment process. X-rays and radiographic images are the primary tools used for detecting dental diseases, and advancements in imaging technologies have enhanced the quality and precision of these diagnostics. Machine learning algorithms, such as convolutional neural networks, graph neural networks, and region-based convolutional neural networks, have shown remarkable efficacy in automating the diagnostic process, reducing the reliance on manual interpretation, and minimizing human error. Deep learning, in particular, offers substantial promise for dental disease detection and tooth identification. Techniques such as transfer learning have enabled models to achieve high accuracy even with limited datasets, enhancing the potential for early and accurate diagnosis. The application of convolutional neural networks allows for the effective analysis of complex image data, facilitating the identification of minute details that may indicate the onset of dental conditions. Graph neural networks and region-based convolutional neural networks further contribute by enabling the analysis of relational data and improving the detection of abnormalities within dental structures. The evolution of artificial intelligence in dental health care signifies a transformative shift toward early disease detection, personalized treatment planning, and improved patient outcomes. This survey explores the current technological advancements in AI-driven dental diagnostics, highlighting the integration of these cutting-edge tools into routine clinical practice. By leveraging the power of AI, dental professionals can enhance diagnostic accuracy, streamline treatment processes, and ultimately provide better care to patients.

Keywords: Dental diseases, panoramic images, CNN algorithm, faster R-CNN algorithm, GNN algorithm, transfer learning, YOLO, you only look once

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INTRODUCTION

Dental health is important for overall well-being. Excellent oral health requires preventing dental issues, identifying them early, and starting treatment as soon as possible. In the current era of artificial intelligence and technological technology, the field of dental image analysis has witnessed substantial improvements. More precise and effective diagnostic procedures are made possible by these developments. The rise of machine

learning and deep learning approaches has opened a new era in dental medical treatment. These computer algorithms are now making significant contributions to the diagnosis and classification of dental diseases and cavities, enhancing the quality of care provided to patients.

In recent years, computers and artificial intelligence have made a big difference in how dentists can detect and understand dental issues. It's a bit like having a super-smart assistant for a dentist. Instead of just relying on human eyes to look at these images, powerful computer programs can be used, specifically deep convolutional neural networks (CNNs) and machine learning models, to help us. These programs are so smart that they can spot things that might be hard for a person to see.

Detection of dental disease is mostly done by radiographic images as shown in Figure 1, Radiographic images commonly referred to as X-ray images is a valuable tool in the field of dentistry, as they offer a detailed and non-invasive view of the internal structures of the oral cavity. Panoramic dental radiography, also known as panoramic X-rays or orthopantomogram, provides a broad view of the entire mouth, jaws, and teeth in a single image, Figure 1 shows Panoramic Radiographic image. These images can help classify and diagnose a range of diseases and conditions, such as Impacted teeth, Cavities and Dental Caries, Periodontal diseases etc. A complete picture of the entire oral and maxillofacial region can be obtained from these specialized X-ray scans.

ROLE OF MACHINE LEARNING

Machine learning is a specialized field of computer science that focuses on instructing machines to swiftly and accurately perform intricate tasks related to the identification and classification of dental diseases. Numerous machine learning and deep learning algorithms exist such as CNN, graph neural networks (GNN), region-based convolutional neural networks (R-CNN), you only look once (YOLO).

Convolutional Neural Networks

CNN, inspired by the human visual system or mimicking the human visual system, is particularly used for identifying patterns and features in dental X-ray images with remarkable precision [1]. The CNNs are trained on datasets of dental X-ray images, and the goal is to teach the CNNs to identify different types of dental diseases, such as dental cavities and periodontal disease [2].

Graph Neural Networks

Neural networks with graph structure (GNNs) can be trained to process and analyze graph-structured data. An edge-and-node data structure is called a graph. The nodes represent entities, such as teeth or dental diseases, and the edges represent relationships between the entities. GNN can be used to develop accurate and efficient systems for object detection, localization, classification, and relationship prediction [3].



Figure 1. Panoramic radiographic image.

Recurrent Convolutional Neural Networks

R-CNN can track changes over time by considering previous X-ray images. This is particularly useful in assessing the progression of dental conditions, such as tracking the growth of a tumor or the evolution of gum disease. R-CNN is a deep learning algorithm that is used for object detection and localization. The algorithm consists of two stages: the first stage produces region proposals, and the second stage categorizes and enhances the area proposals [4].

You Only Look Once

A real-time object detection algorithm offers immediate insights into the presence and location of dental issues in X-ray and clinical images. YOLO can quickly identify and locate dental issues in X-ray images, providing immediate feedback to dental professionals [5].

Apart from these models, there is also a technique available called transfer learning. Using a pre-trained model as the foundation for a new model is known as transfer learning in machine learning. The new model can be trained to execute a different task on a smaller dataset, and the pre-trained model has previously learned to perform a task on a large dataset. The main advantage of it is, it can be used to train accurate models even when there is a limited amount of training data available.

Datasets

The majority of the datasets used in the papers are in-house datasets. This means that the datasets are not publicly available and are not easily accessible to other researchers. This is a challenge for the field of dental X-ray image segmentation. Table 1 shows the list of publicly available datasets.

Table 1. Dataset availability.

Authors	Dataset	Size	Annotations
M. Rathi and D. S. Rattan (2021) [6]	Kaggle dataset of dental X-rays	13,916 images	Teeth, caries, fillings, crowns
Y. Chen et al. [7]	Tufts Dental Database	1,000 images	Abnormalities, teeth
A. Abdi and S. Kasaei (2020) [8]	Children's dental panoramic radiographs dataset for caries segmentation and dental disease detection	193 images	Caries
M. P. Muresan, A. R. Barbură, and S. Nedeveschi (2020) [9]	Panoramic radiography database	1,800 images	Teeth, caries, fillings, crowns
Y. Gomi, T. Ogawa, and Y. Iwai	Oral image database (OID)	1,490 images	Teeth, caries, fillings, crowns, other dental structures
B. S. Manjunath and B. C. Vemuri	International Consortium for Medical Image Segmentation (ICMIS)	430 images	Teeth, caries, fillings, crowns, other dental structures

LITERATURE REVIEW

The field of dental disease classification has witnessed significant advancements, primarily driven by the application of deep learning techniques. This section presents an in-depth examination of relevant research studies, emphasizing their methodologies, key findings, and contributions to the field.

Tooth Detection and Segmentation

Muresan et al. (2020) presented a thorough method for classifying dental problems and detecting teeth in panoramic X-ray pictures that combines deep learning and image processing approaches. Their research achieved an accuracy rate of 97.2% for teeth detection and 95.5% for dental problem classification, underscoring the potential of these methods in enhancing diagnostic accuracy [9]. In a similar vein, Jader et al. (2018) presented a deep learning-based instance segmentation approach,

designed to identify individual teeth in panoramic X-ray images. Their approach consisted of preprocessing, feature extraction, and instance segmentation. They used a Mask R-CNN model to segment each individual tooth in the X-ray image. Their technique exhibited a mean intersection over union (mIoU) of 93.2%, outperforming traditional image processing methods [10]. Furthermore, Mahdi et al. (2020) introduced a transfer learning-based Faster R-CNN algorithm for automatic tooth recognition, producing an average precision (AP) of 97.2% for tooth detection, surpassing the baseline model by a substantial margin [11].

Disease Detection and Classification

Numerous studies have delved into the detection and classification of dental diseases. Lakshmi and Chitra (2020) presented deep CNN algorithms that were highly successful in classifying dental cavities and predicting tooth decay. Their research achieved an accuracy of 96.2% for dental caries classification and 98.6% for tooth decay prediction and classification, signifying the potential for these methods in improving disease diagnosis [12, 13]. Additionally, Singh and Abrol (2022) adopted a Faster R-CNN model for the automatic detection and diagnosis of dental caries, attaining an accuracy rate exceeding 90% on their test dataset [14]. Joo et al. (2019) focused on periodontal disease detection using CNN-based approaches, with their method significantly outperforming traditional clinical examination and X-ray analysis, achieving an accuracy of 95.2% [2]. In a distinct approach, Divakaran et al. (2020) employed a machine learning methodology utilizing a support vector machine (SVM) classifier for the classification of dental X-ray images. Trained on a dataset of 1000 dental X-ray images labeled into three categories (normal, caries, or periodontal disease), their classifier achieved a commendable accuracy rate of 95.2% on a test set of 200 dental X-ray images [15]. Das et al. (2022) conducted an extensive comparative study to assess the performance of diverse transfer learning algorithms for caries detection. Notably, their research indicated that transfer learning-based models, utilizing the ResNet50, MobileNet, and VGG16 pre-trained models, achieved remarkable accuracy, reaching 96.12% on a dataset of 195 dental X-ray images [16]. Prajapati et al. (2017) provide a deep learning-based method that makes use of transfer learning and CNNs to classify dental disorders. CNNs are a subset of deep learning models that work well in tasks involving object detection and picture categorization. Transfer learning is a technique where a pre-trained CNN model is fine-tuned on a new dataset for a different task. Prajapati et al. used a pre-trained VGG16 CNN model and fine-tuned it on a dataset of 251 dental X-ray images, each labeled with one of three categories: normal, caries, or periodontal disease. A range of dental X-ray images, including bitewing, periapical, and panoramic X-rays, were included in the dataset. Prajapati et al. evaluated their proposed approach on a held-out test set of 50 dental X-ray images. Their approach achieved an overall accuracy of 88.0% for dental disease classification [17].

Tooth Numbering and Implant Planning

Prados-Privado et al. (2021) presented a robust CNN-based approach for automatic tooth numbering in panoramic images. Their method achieved an impressive overall accuracy of 98.2% for tooth numbering, significantly surpassing a baseline method relying on traditional image processing techniques, which achieved an accuracy of 85.1% [18]. In the domain of dental implant planning, Bodhe et al. (2022) developed a deep learning-based approach that exhibited high accuracy in predicting optimal implant locations, providing valuable tools for dental professionals in the planning and execution of implant procedures [19].

These studies contribute significantly to the evolution of dental disease classification, providing valuable insights and methodologies that can be further explored and refined in the pursuit of more accurate and efficient tools for dental diagnosis and treatment planning.

OBSERVATION AND SUMMARY

The studies demonstrate significant progress in dental disease classification through the application of deep learning. Approaches like combining deep learning and image processing techniques show promising results in teeth detection and dental problem classification, achieving high accuracy rates as

shown in Table 2. In disease detection, deep CNN algorithms prove effective in classifying dental cavities and predicting tooth decay. Furthermore, the use of Faster R-CNN models enhances accuracy in dental caries detection. Studies also showcase robust CNN-based methods for automatic tooth numbering and accurate dental implant planning, contributing to more effective tools for dental diagnosis and treatment planning.

The studies highlight the effectiveness of advanced computer vision in dental image analysis. Notable achievements include tooth detection with Quick R-CNN (94.50%), dental caries detection using ResNet-50 (96.12%), and automatic tooth numbering with a CNN (98.20%) as highlighted in Table 2. These results highlight the potential for improving X-ray-based dental diagnosis and treatment planning through the use of machine learning and deep learning approaches.

Figure 2 shows the comparison of various models based on this analysis. The choice of the best-suited method for dental detection depends on the specific application, with CNNs and transfer learning methods appearing as strong contenders for various tasks. Dental professionals and researchers may need to consider their specific requirements and data availability when selecting a method for dental detection.

Table 2. Summary table.

Author	Task	Method	Dataset	Accuracy
Singh and Abrol (2022) [14]	Tooth detection	Quick R-CNN	Dental X-rays	94.50%
Das et al. (2022) [16]	Dental caries detection	Transfer learning with ResNet-50	Dental X-rays	96.12%
Muresan et al. (2020) [9]	Teeth detection and dental problem classification	Deep learning with transfer learning (VGG16)	Panoramic X-rays	95.50%
Prados-Privado et al. (2021) [18]	Automatic tooth numbering in panoramic images	Convolutional neural network	Panoramic images	98.20%
Divakaran et al. (2021) [15]	Classification of digital dental X-ray images	Machine learning	Dental X-rays	95.20%
Mahdi et al. (2020) [11]	Automatic teeth recognition in dental X-ray images	Transfer learning with Faster R-CNN	Dental X-rays	97.20%
Joo et al. (2019) [2]	Periodontal disease detection	Convolutional neural networks	Dental X-rays	95.20%
Jader et al. (2018) [10]	Deep instance segmentation of teeth in panoramic X-ray images	Deep learning	Panoramic X-rays	93.20%
Prajapati et al. (2017) [17]	Classification of dental diseases	CNNs and transfer learning	Dental X-rays	88%

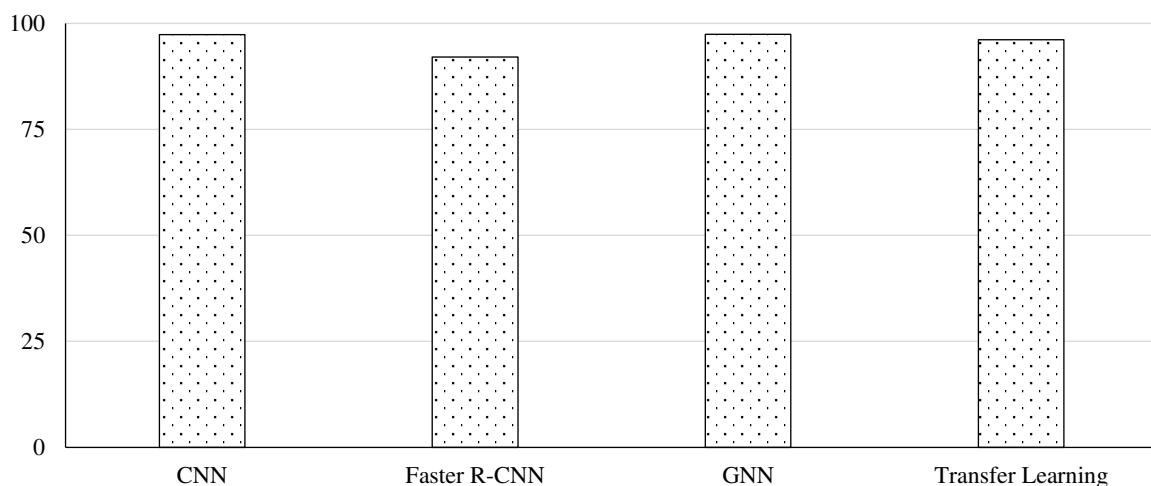


Figure 2. Comparison of various models.

CONCLUSION AND FUTURE SCOPE

The integration of artificial intelligence and deep learning models, particularly CNNs and innovative object detection techniques, shows great promise in enhancing dental diagnosis and disease detection. These models offer the potential for automated dental image analysis, resulting in improved accuracy and efficiency. This comprehensive survey has highlighted the significant advancements made in dental image analysis, particularly in the context of detecting dental diseases and abnormalities from X-ray images. The reviewed studies demonstrate the effectiveness of various deep learning methods in dental diagnostics, ranging from tooth detection and segmentation to disease classification and implant planning. These methods have consistently shown high accuracy rates in tasks such as dental caries detection, tooth numbering, and dental problem classification. Furthermore, the use of semantic networks and the ability to learn from experts make these systems valuable tools for dental professionals.

While challenges remain, including the need for more extensive datasets and further research, these advancements are transforming dental practice and hold the key to early diagnosis and personalized treatment suggestions.

Declaration of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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