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Artificial Intelligence in Dental Imaging for Disease Detection and Treatment

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Research Article

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Abstract

This study explores the growing role of artificial intelligence (AI) in oral and dental health, specifically in the analysis of advanced imaging techniques. Traditional methods, such as Computed Tomography (CT), Cone Beam Computed Tomography (CBCT), and X-rays, require intensive, experience-based analysis by a physician, which is both time-consuming and susceptible to human error. The text reviews current AI studies that utilize panoramic and intraoral X-ray images to automate disease detection and facilitate orthodontics. It addresses the challenges of accessing patient data and highlights the diversity of approaches in this field, including various algorithms, models, and data labeling methods, such as marking quadrants or identifying specific dental conditions like decay, missing teeth, or implants. The primary goal of this review is to consolidate existing research, providing a comprehensive overview that can inspire and guide future studies in the application of AI for dental diagnostics and treatment.

Keywords: *Artificial intelligence, X-ray, orthodonthics, dental imaging.*

Introduction

Dental treatments require advanced imaging techniques, utilizing various technologies, to ensure accurate pre-treatment. These include Computed Tomography (CT), Cone Beam Computed Tomography (CBCT), Magnetic Resonance Imaging (MRI), ultrasound, and traditional intraoral

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periapical X-rays (Scarfe and Farman, 2008). These techniques are only used to visualize dental diseases in the mouth, but a physician is needed to detect the diseases. This not only consumes the physician's time but also requires experience and a high degree of attention (Bruno et al., 2015). Artificial intelligence (AI), one of today's current technologies, is expected to be integrated into this field. Studies on the use of artificial intelligence technology for the detection of diseases in oral and dental health, which is an important part of human health, have been carried out for some time (Yüksel et al., 2021; Revilla-Leon et al., 2022). There are many studies that use different algorithms and models. It has also taken its place in the field of orthodontics as a very useful tool that facilitates the procedure time and helps the technicians (Abdalla-Aslan et al., 2020; Nassiri and Akhloufi, 2025). For the use of artificial intelligence, Panoramic X-ray images, more commonly known and widely used as intraoral periapical X-rays, are generally used. However, since these images are personal health information, they should be publicly available and authorized for use. Although access to this information is difficult, the potential success of artificial intelligence in analyzing these images and the benefits it will bring to this field pave the way for studies and cause demand (Zhang et al., 2023).

There are various current artificial intelligence models and algorithms for artificial intelligence studies in this field. At the same time, various ways are used in the labelling phase of the data. Some studies divided the oral structure into 4 quadrants and then numbered the teeth, while some studies directly numbered the teeth. In some studies, markings were made only to detect decayed teeth, while in some studies, missing teeth, broken teeth, decayed teeth and teeth with implant treatment were also marked. In addition to various methods in markings, studies also have different approaches when training artificial intelligence. There are many studies that use different algorithms and models that are run using different classification methods. While these various studies were carried out, various progress and methods were also used (Pauwels, 2021; Ma et al., 2024).

The health information of the patient before treatment is very important for the course of treatment and patient health (Brahmi and Jdey, 2024; Chowdhury et al., 2024). The correct determination of the patient's disease, how the treatment will be applied, and most importantly the correct application of the treatment is determined by the data obtained from this health information (Medica et al., 2009). This information is also important in dentistry and is obtained by computerized Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and finally X-rays (Hcini et al., 2024). The information obtained with these techniques determines which tooth will be treated and how it will be treated in oral and dental health. The evaluation of these images is a time-consuming workload for physicians (Kumar et al., 2021). Since new general practitioners are inexperienced in radiology, the possibility of misdiagnosis is high (Bruno et al., 2015).

The ability to create algorithms with new models in AI technology has paved the way for automatic diagnosis from X-ray images (Yüksel et al., 2021; Abusalim et al., 2022). However, it is very difficult to access this information since permissions are required for the public use of panoramic radiological images, which are included in the personal health information of the person (El Joudi et al., 2022). At the same time, the potential benefits of incorporating AI into the analysis of radiological images are too high to ignore, as it enables on-site and rapid intervention for accurate treatment (Pauwels, 2021).

This study aims to consolidate research on the accurate, rapid, and reliable analysis of dental X-ray images to illuminate existing knowledge and guide future projects that support precise diagnostics in dentistry.

Material and Methods

X-ray

X-rays are a form of electromagnetic radiation with wavelengths ranging from approximately 0.01 to 10 nanometers. This short wavelength allows them to penetrate the tissues of the human body. In the field of diagnostic radiology, X-rays have long been widely used for imaging body tissues. Since different densities of tissue absorb them at varying rates as they pass through the body, they create a shadow image of the internal structures on a detector placed behind them (a film or digital sensor). This imaging technique plays a key role in aiding the diagnosis of various diseases and conditions, particularly in the detection of bone fractures, lung infections, and foreign objects (Berger et al., 2018). X-rays are very important for dentists because they show things inside the teeth, bones, and tissues that cannot be seen with just a visual exam as shown in Figure 1.

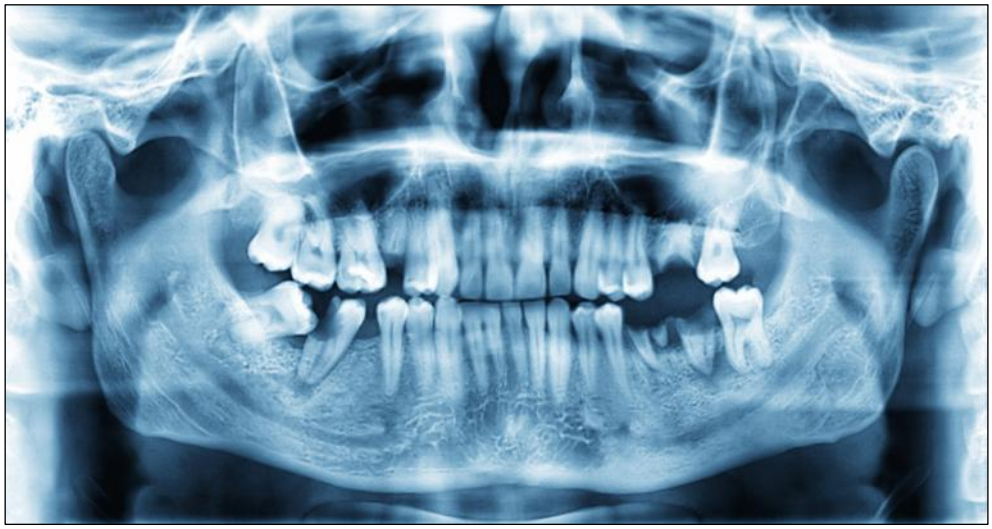

Figure 1. Panoramic dental X-Ray image (njsmile.com, 2025).

Deep learning

Deep learning is a subset of Artificial Intelligence (AI) and Machine Learning (ML) that uses artificial neural networks (inspired by how the human brain works) to learn patterns from large amounts of data. Deep learning is powerful because it can automatically learn features from raw data without needing humans to manually program rules. Actually, Deep learning–based image recognition and computer vision applications are widely used in many fields today. Face recognition technology plays a key role in unlocking smartphones and enhancing security systems by identifying individuals. Deep learning models analyze facial features such as the distance between the eyes, nose shape, and jawline, creating unique mathematical representations for reliable identity verification. In medical imaging, deep learning assists healthcare professionals in detecting tumors, cavities, or bone loss with high accuracy. These systems work on X-rays, MRIs, CT scans, and dental radiographs to identify

abnormalities, enabling early diagnosis and supporting doctors in decision-making. In the case of autonomous vehicles, computer vision is crucial for interpreting traffic signs, detecting pedestrians, and recognizing other vehicles. Images captured by cameras and sensors are processed through deep learning algorithms, allowing the system to read road signs, track lanes, and avoid collisions. This technology paves the way for safer, smarter, and driverless transportation (Sarker, 2021).

Result and Discussion

Accurately collecting and evaluating patient health data before treatment is critical to the effectiveness of diagnosis and treatment processes (Medica et al., 2009; Brahmi and Jdey, 2024; Chowdhury et al., 2024). In dentistry, this data is mostly obtained through imaging methods such as Computed Tomography (CT), Cone Beam Computed Tomography (CBCT), Magnetic Resonance Imaging (MRI), and X-rays and plays a fundamental role in planning oral and dental health interventions (Hcini et al., 2024). However, interpreting these images is time-consuming, especially for dentists with inexperience, and increases the risk of errors (Kumar et al., 2021; Bruno et al., 2015).

In recent years, advances in artificial intelligence (AI) technologies have enabled the automation of this process and the strengthening of clinical decision support systems (Yüksel et al., 2021; Abusalim et al., 2022). Indeed, although access to panoramic radiological images is subject to certain permissions within the scope of personal health data (El Joudi et al., 2022), AI-based approaches provide significant contributions in terms of speed and accuracy in diagnostic processes (Pauwels, 2021).

Table 1. Comparison of the study and used datasets.

Model Used	Dataset	Results
Encapsulation classifier (Haghanifar et al., 2023)	470 panoramic images	86% success
Single Shot Detector classifier (Ali et al., 2023)	3818 panoramic images	AP: 0.9842, AR: 0.9871, AF1: 0.9857
R-CNN, YOLOv5 (Ünsal and Adem, 2023)	553 patients' panoramic images	Accuracy: R-CNN 86.7%, YOLOv5 92.7%
Mask R-CNN (Suryani et al., 2021)	116 patients from Noor Medical Imaging Centre	Success rate: 91%-96%
U-Net, R2 U-Net, PSPNet, DeepLabV3 (Zhang et al., 2023)	116 patients from Noor Medical Imaging Centre	U-Net: 0.9719, R2 U-Net: 0.9724, PSPNet: 0.9681, DeepLabV3: 0.9665
Support Vector Machine (SVM), Faster R-CNN (Zdravkovic et al., 2021)	116 patients from Noor Medical Imaging Centre	Average precision: 0.95-0.97
Two-Stream Coordinate Attention (TSCA), Residual Omni-Dimensional Convolution (ROCM) (Ma et al., 2024)	Archive dataset (116 sources), Dataset & Code dataset (1500)	Accuracy: Archive dataset 97.79%, Dataset & Code dataset 97.32%
Attention U-Net (Padalia et al., 2022)	116 panoramic X-ray images from Mendeley Data platform	F1 score: 93.71%
Combined UNet and Convolutional Variational Auto Encoder (CVAE) architecture (Kim et al., 2024)	Tufts Dental Database (TDD: 1000 images), HUSHDD (256 images), NMICDD (116 images)	UNet-CVAE (Proposed) with DBSCAN clustering (HUSHDD) Dataset Accuracy (94.9%) Precision (92.1%) Specificity (97.6%)

A comparative analysis of studies (Table 1) reveals the contributions of different AI models to dental diagnosis. The Encapsulation classifier used by Haghanifar et al. (2023) demonstrated the applicability of automated diagnosis systems by achieving 86% accuracy on panoramic images. However, generalizability was limited due to the limited dataset. Furthermore, Ali et al. (2023) demonstrated that dental anomalies can be detected with high precision by achieving AP, AR, and F1 scores above 0.98 with the YOLOv7 and Single Shot Detector algorithms. This performance offers significant potential for real-time clinical applications. Ünsal and Adem (2023) achieved an accuracy rate of 92.7% by integrating physician knowledge with models such as YOLOv5 and R-CNN, thus highlighting the role of hybrid approaches in supporting human expertise. This demonstrates that using human interpretation in conjunction with AI increases the reliability of clinical decisions, especially in complex cases. Similarly, segmentation models such as Mask R-CNN and U-Net demonstrated high performance in distinguishing dental structures and identifying pathological regions, contributing to the standardization of diagnostic processes and the reduction of inter-observer variability (Suryani et al., 2021; Zhang et al., 2023). In a more recent study, Ma et al. (2024) achieved accuracy rates of 97.79% and 97.32% on two different datasets using the Two-Stream Coordinate Attention (TSCA) and Residual Omni-Dimensional Convolution (ROCM) architectures, respectively. These results demonstrate the strong potential of modular AI architectures in dental imaging for scalability and adaptability.

Overall, these findings demonstrate that AI-based approaches offer significant advantages in terms of both accuracy and speed in dental diagnostic processes. Hybrid models developed through physician-AI collaboration, in particular, stand out in increasing the reliability of clinical decisions. Deep learning is a prominent method in this context. Its ability to learn complex patterns in tasks such as image recognition, natural language processing, and speech analysis without the need for manual feature extraction makes it effective in areas requiring high precision, such as dental radiology. Its ability to work directly with unstructured data (e.g., panoramic images) and achieve accuracy levels that can sometimes exceed human performance, provides speed and reliability in clinical applications. However, there are also limitations, such as the need for large amounts of labeled data and high processing power, difficulties in explainable decision mechanisms, and the risk of data bias being introduced into the model. Therefore, while deep learning-based approaches offer strong potential, they also present issues that must be carefully considered in terms of cost, transparency, and ethics.

In conclusion, the integration of artificial intelligence into dental diagnostic processes promises a significant transformation in terms of both improving clinical accuracy and reducing workload. Advanced architectures such as YOLOv7, Mask R-CNN, and TSCA have demonstrated high success in panoramic x-ray analysis, demonstrating the potential in this field. However, the limitations of anonymized datasets and ethical concerns remain key obstacles in model development. To overcome these challenges, collaborative approaches that protect data privacy, such as federative learning, are proposed. Furthermore, integration with different imaging techniques such as CT and MRI, and hybrid model designs, can offer more comprehensive solutions for the diagnosis of rare and complex cases. Given that AI systems can also contribute to education and interdisciplinary collaboration, the strategic and ethical adoption of these technologies will advance patient care and clinical efficiency in dentistry.

Conflict of Interest

The authors declare that for this article they have no actual, potential or perceived conflict of interest.

Author Contributions

Ö.M.D. and Y.K. performed all the experiments and drafted the main manuscript text. All authors reviewed and approved the final version of the manuscript.

Ethical Approval Statements

No ethics committee permissions are required for this study.

Data Availability

The data used in the present study are available upon request from the corresponding author.

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