Inclusion of AI in Conservative Dentistry and Endodontics: A New Era of Precision and Efficiency

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Abstract— Recent advancements in science and technology have led to the growing integration of artificial intelligence (AI) within dentistry. AI-driven algorithms hold significant promise for enhancing diagnostic accuracy, treatment planning, execution of endodontic procedures, and predicting treatment outcomes. A literature review was conducted to explore the applications of AI in conservative dentistry and endodontics. AI models have been utilized to analyze root canal system anatomy, determine root canal length, detect periapical pathologies and root fractures, predict the success of retreatment procedures, and assess the viability of dental pulp stem cells. AI has already demonstrated its value in conservative dentistry and endodontics. As this technology continues to evolve and expand in application, it is expected to further enhance clinical outcomes and support the preservation of natural teeth.

***Index Terms* —** Artificial Intelligence, Artificial neural networks, Convolutional neural networks, Super AI, Vertical root fractures

I. INTRODUCTION

Artificial Intelligence (AI) was first introduced by John McCarthy in 1956, its potential applications have garnered significant interest across various fields. AI, a branch of computer science, focuses on developing intelligent systems capable of perceiving inputs, analyzing data, and responding appropriately. Often referred to as the "fourth industrial revolution," AI simulates human-like behavior, critical thinking, and decision-making using advanced computer technologies. [1,2]

The integration of artificial intelligence (AI) into healthcare has heralded a transformative era, and dentistry is no exception. Within the specialized fields of conservative dentistry and endodontics, AI is rapidly emerging as a powerful tool for enhancing diagnostic accuracy, treatment planning, and clinical outcomes. These disciplines, which focus on preserving the natural dentition and managing complex root canal systems, demand high levels of precision and clinical decision-making—an area where AI excels. AI algorithms, particularly those driven by machine learning and deep learning, are now being trained to analyze radiographs, detect carious lesions, predict treatment success, and even assist in real-time procedural guidance. This paradigm shift not only reduces human error but also enables personalized and minimally invasive interventions tailored to the specific needs of each patient. [3]

Over the past decade, the number of scientific publications on artificial intelligence (AI) in healthcare has increased significantly, reflecting its growing impact on medical practice. As the dental profession enters this new era, understanding the scope, benefits, limitations, and ethical considerations of AI integration becomes imperative. The objective of this review is to explore how AI is reshaping conservative dentistry and endodontics, highlighting its role in diagnosis, treatment planning and execution, and outcome prediction. Additionally, the article aims to highlight potential future developments that may contribute to improved patient care and treatment outcomes.

II. TYPES OF ARTIFICIAL INTELLIGENCE (AI)

Based on Capabilities:

Narrow AI - Narrow AI performs specific tasks within set limits and cannot make independent decisions, hence called "weak AI." It's widely used in spam filtering, recommendations, image recognition, and disease mapping but may fail outside its defined scope.[4]

General AI - General AI refers to systems capable of understanding, learning, and applying knowledge in a manner similar to human beings. These systems are not limited to predefined tasks and instead aim to simulate human cognitive abilities using complex reasoning models, such as the "theory of mind." Fujitsu's supercomputer *K* represents one of the ambitious efforts toward achieving this level of AI. [5]

Super AI - Super AI is a theoretical concept where machines surpass human intelligence and capabilities. It is envisioned as possessing superior perception, reasoning, emotional intelligence, and decision-making skills. Though currently hypothetical, super AI represents the future frontier of AI development. [6]

Based on Functionalities

Reactive Machines - These AI systems operate based solely on current inputs without storing or using past experiences. They do not possess memory or the ability to learn from previous data. A well-known example is IBM's chess-playing computer, which analyzes the present game state to make moves. [6]

Limited Memory - Limited memory AI can make decisions using data from past experiences. This type of AI is commonly used in self-driving cars, which rely on past data—such as the movement of nearby vehicles and road conditions—to make real-time driving decisions. [6]

Theory of Mind - Still under development, this form of AI is expected to understand human emotions, beliefs, intentions, and thoughts. It aims to interact more naturally with humans by simulating emotional intelligence. Although not yet fully realized, early examples like *Sophia*—the humanoid robot—hint at the potential of such systems. While Sophia can engage in conversations, she lacks true emotional understanding. [7]

Self-Awareness AI - This is the most advanced and hypothetical form of AI, characterized by consciousness, self-awareness, and an understanding of both its own emotional states and those of others. Once achieved, such AI would possess human-like intelligence, self-recognition, and emotional needs. Basic example is chat generative pretrained transformer. [6]

III. ARTIFICIAL INTELLIGENCE IN DENTISTRY

AI has seen rapid growth in dentistry, with applications spanning diagnosis, decision-making, treatment planning, and outcome prediction. Among these, diagnostic assistance is currently the most prominent. AI enhances diagnostic accuracy and efficiency, easing the workload on dental professionals.
While the use of AI in dentistry is expanding, comparing research studies remains challenging due to variations in study design, data splitting (training, testing, validation), and performance metrics (e.g., accuracy, sensitivity, specificity, F1 score, AUC, recall). To address this, the **MI-CLAIM checklist** has been proposed to standardize reporting and ensure transparency in clinical AI research. [8]

Key Applications of AI in Dentistry

1. **Diagnostic Assistance:** AI excels in analyzing dental images (e.g., X-rays, CBCT) to detect caries, tumors, and pathologies with high accuracy. Tools like *Dentim* and *VivaScope* enhance diagnostic precision and reduce human error.

2. **Personalized Treatment Planning:** AI can generate individualized treatment plans by integrating patient data, including medical history, imaging, and genetic factors. It aids in areas such as orthodontics and prosthodontics for optimal care delivery.

3. **Robotic Surgery and Prosthetics:** AI-driven robotic systems are used in procedures like implant placement and soft tissue surgeries. These systems offer superior precision, better outcomes, and reduced recovery times.

4. **Predictive Analytics:** AI can forecast future dental conditions by analyzing patient history and risk factors. It helps anticipate issues like tooth decay or periodontal disease and recommends preventive strategies, including hygiene improvements or dietary modifications.

5. **Virtual Dental Assistants:** AI-powered chatbots and virtual assistants handle tasks such as appointment scheduling, answering FAQs, and patient education. These tools provide 24/7 support, enhancing patient engagement and service efficiency.

6. **Clinical Decision Support:** AI systems analyze large datasets to identify patterns that inform clinical decision-making. This aids in early diagnosis and optimized treatment planning by offering data-driven insights.

7. **Administrative Automation:** AI streamlines administrative processes like billing, insurance verification, and scheduling. This reduces the clerical burden on dental staff and improves workflow efficiency, allowing more focus on patient care.

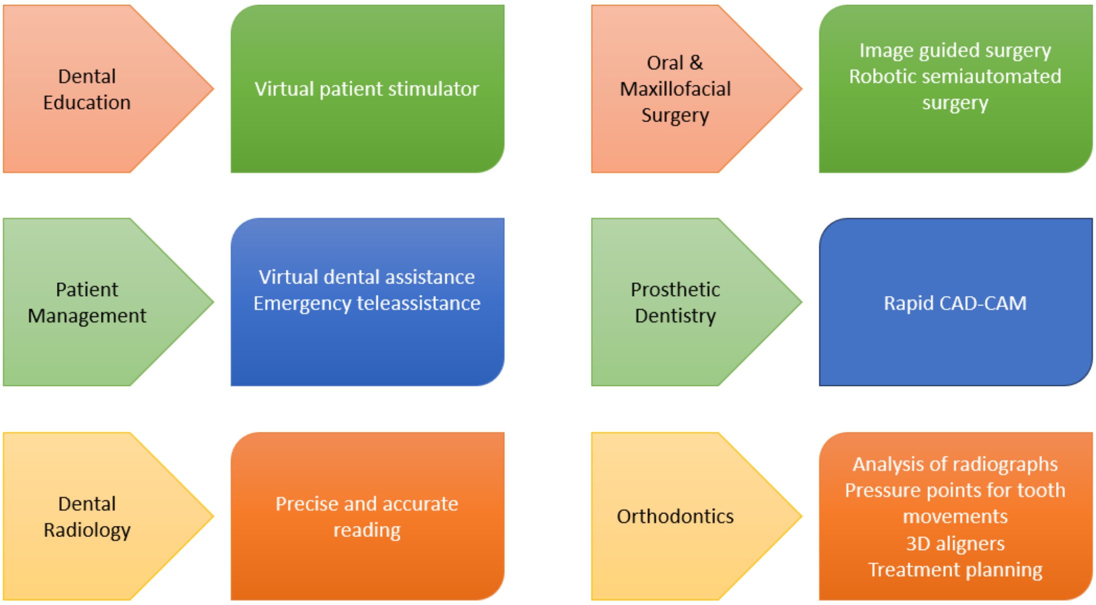

Figure 1: Applications of AI in dentistry

IV. ARTIFICIAL INTELLIGENCE IN CONSERVATIVE DENTISTRY

AI is increasingly being utilized in conservative dentistry, particularly for enhancing diagnostic accuracy and treatment planning. Key applications include:

- **Caries Detection**
- **Vertical Tooth Fracture Identification**
- **Detection of Tooth Preparation Margins**
- **Prediction of Restoration Failure**
- **Enables faster, more accurate fabrication of inlays, onlays, crowns and bridges**
- **Supports treatment planning by allowing previsualization of smile designs before procedures.**

Caries Detection

Artificial intelligence, especially machine learning and deep learning techniques, has demonstrated significant potential in the detection and diagnosis of dental caries. By analyzing large datasets of dental images, these algorithms learn to recognize patterns and features linked to caries, allowing for accurate identification in previously unseen images [6]. The integration of AI—particularly machine learning—has substantially improved the effectiveness and accuracy of predictive models.

Convolutional Neural Networks in Image Analysis and Caries Detection

Convolutional Neural Networks (CNNs) are a class of artificial intelligence models specifically designed to automatically and adaptively learn spatial feature hierarchies from image data. This makes them particularly effective for tasks such as image classification, object detection, and semantic segmentation. When trained using edge extraction strategies, CNNs have demonstrated excellent performance in detecting proximal caries on periapical radiographs. Their application in dental caries detection holds considerable promise, offering improvements in diagnostic accuracy, operational efficiency, and predictive capabilities. [9]
One such model, **CariesNet**, is a proposed deep learning architecture developed to enhance the diagnostic process of dental caries. Based on a CNN framework, CariesNet leverages artificial intelligence and machine learning to analyze dental radiographs and accurately detect the presence of carious lesions. This AI-driven methodology has shown substantial potential to outperform traditional manual inspection methods in both accuracy and efficiency. [9,10]

Image Processing and Analysis for Caries Detection
Identifying caries in dental radiographs involves several key steps, from image capture to classification and validation. [9,11]
Image Acquisition:
High-quality images are captured using bitewing radiographs, orthopantomograms, or other dental imaging methods to ensure accurate analysis.
Pre-processing:
Enhances image quality using techniques such as:

- Noise reduction (e.g., Gaussian smoothing, median filters)
- Contrast enhancement (e.g., histogram equalization) to make caries lesions more distinguishable.

Segmentation:
The image is divided into segments, often by thresholding pixel intensities to separate tooth structures from the background.

Feature Extraction:
Key features indicative of caries are extracted:

- **Intensity-based:** Darker pixel values in carious areas
- **Texture-based:** Distinct patterns differing from healthy tissue
- **Shape-based:** Size and morphology of lesions

Classification:
Machine learning algorithms (e.g., SVMs, random forests) or deep learning models like CNNs classify regions as carious or healthy. Training uses labeled datasets.

Post-processing:
Refines results by removing noise or false positives, improving accuracy.

Validation:
The entire pipeline's performance is assessed on independent test data using metrics such as sensitivity, specificity, precision, recall, and F1 score.
The process of analyzing dental radiographs and identifying dental caries is illustrated in Figure 2.

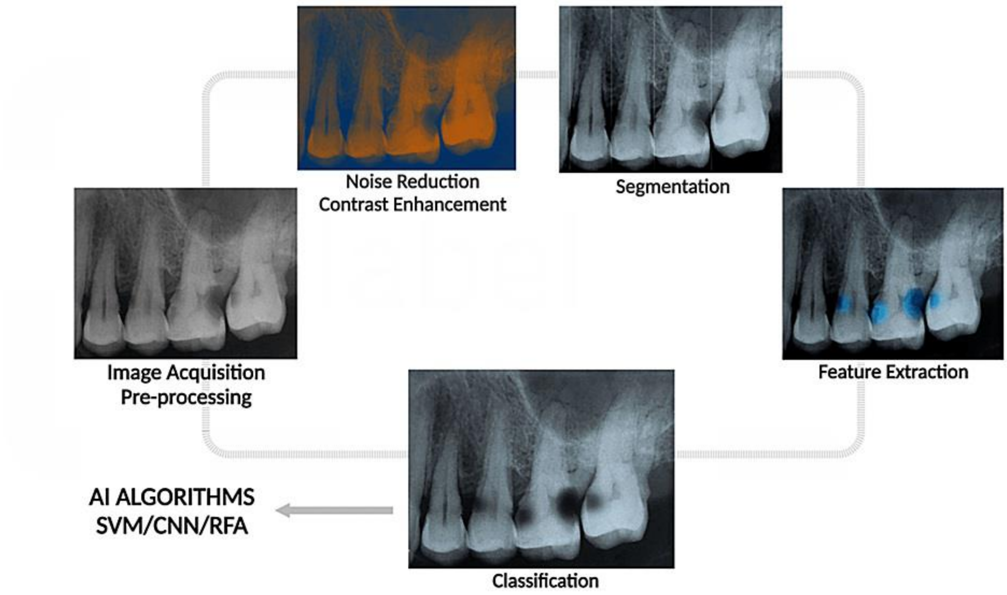

Figure 2: The process of analyzing dental radiographs and identifying dental caries through artificial intelligence. SVM = Support Vector Machine; CNN = Convolutional Neural Network; RFA = Random Forest Algorithm

Existing AI Technologies for Dental Caries Diagnosis

Several AI-powered tools are currently enhancing dental caries detection and diagnosis:

Pearl®
Pearl uses deep learning models trained on extensive dental radiograph datasets to identify and annotate dental pathologies such as caries, periodontal bone loss, and periapical lesions. It improves diagnostic precision and consistency across practices, serving as a reliable second opinion for dentists. However, it complements rather than replaces clinical judgment. [12,13,14]

Overjet
Overjet employs advanced AI algorithms to analyze dental images with high accuracy and standardization. Trained on a large set of radiographs, it detects caries, periodontal disease, and other dental conditions, helping reduce diagnostic variability and supporting dentists with consistent, efficient assessments. [15]

Denti.AI®
Focused specifically on dental caries, Denti.AI leverages machine learning to enhance detection and treatment planning. It offers objective, standardized analysis of radiographs, addressing limitations of traditional diagnosis which often relies on subjective interpretation and image quality. [16,17]

V. ARTIFICIAL INTELLIGENCE IN ENDODONTICS

- Detection of periapical lesions and root fractures
- Analysis of root and root canal anatomy
- Determination of working length
- Prediction of retreatment outcomes
- Assessment of dental pulp stem cell viability

Detection of Periapical Lesions

Diagnosing and treatment planning for periapical lesions can be challenging. Apical periodontitis, accounting for about 75% of radiolucent jaw lesions, requires early detection to improve treatment outcomes and prevent complications. Commonly, intraoral periapical and panoramic radiographs are used, but these 2D images can be inaccurate due to the loss of 3D anatomical details. Cone-beam computed tomography (CBCT) offers 3D imaging, improving detection accuracy (0.96 for CBCT vs. 0.73 and 0.72 for conventional and digital periapical radiographs, respectively). [1,19]

Deep learning models, particularly convolutional neural networks (CNNs), have shown promise in matching or exceeding expert radiologists' ability to detect periapical lesions on panoramic and intraoral radiographs. For instance, CNNs demonstrated higher sensitivity, specificity, and diagnostic accuracy than oral and maxillofacial radiologists, although studies had limited sample sizes and often used panoramic images less common in endodontics. AI systems reduce examiner variability and bias and show high reliability (around 92.8%) in detecting periapical lesions on CBCT scans, with volume measurements comparable to human assessments. Despite promising results, AI sensitivity needs improvement, and further research is necessary before widespread clinical use. [15,20]

Poswar Fde et al. [21] used a multilayer perceptron neural network to distinguish periapical cysts from granulomas based on gene expression. Although the model had limitations—such as missing data and inability to differentiate between physiological and inflammatory cytokines—it showed potential for broader biological applications, like cancer biomarker detection. Zheng et al. [22] demonstrated that a novel Dense U-Net deep learning model improved CBCT lesion segmentation accuracy and sensitivity, despite a small sample size.

Detection of Fractures

Radiographic detection of crown and root fractures is challenging. CBCT shows about 78% accuracy for diagnosing vertical root fractures (VRF). AI applications have improved detection: one study reported 75% sensitivity and 93% positive predictive value using panoramic radiographs, while another achieved 97% accuracy, 93% sensitivity, and 100% specificity on periapical radiographs and CBCT for single-rooted premolars. Ongoing research aims to enhance AI accuracy, especially for multi-rooted teeth. Improved AI diagnosis can prevent unnecessary treatments and extractions of healthy teeth. [23,24]

Determination of Root Canal Morphology

Successful root canal treatment requires accurate knowledge of root canal anatomy, traditionally assessed via periapical, bitewing, and CBCT images, which can be subjective and experience-dependent. AI has improved this process by evaluating root canal morphology and canal number with high accuracy. Hiraiwa et al. [25] reported 87% accuracy detecting single or multiple distal roots on mandibular first molars using AI on panoramic radiographs. AI also efficiently measures root canal curvatures and 3D canal changes post-instrumentation. Commercial AI tools like Diagnocat analyze CBCT scans, segment teeth, and create 3D printable models for detailed evaluation. Future advancements aim to expand AI datasets to cover more anatomical variations and assist clinicians in selecting appropriate instruments and motor settings to minimize procedural errors during treatment. [24,26]

Determination of Working Length

Accurate determination of the working length (WL) is crucial for effective root canal treatment, ensuring thorough cleaning while protecting periodontal tissues and preventing debris extrusion. Even a 1 mm error in WL can reduce treatment success by 12–14%. Currently, WL is measured using electronic apex locators combined with periapical radiographs, but these methods can be affected by image quality, anatomical variations, and technical issues such as wet canals or metallic restorations. [27,28]

AI is being developed to improve WL accuracy. For instance, Saghiri et al. demonstrated that AI accurately determined root length with 100% accuracy and located the minor apical constriction 96% of the time in a cadaver model. Future AI integration may allow automatic control of endodontic instruments to maintain precise WL, minimizing operator error and protecting the apical constriction. [29,30]

Retreatment Prediction

AI has been applied to predict outcomes in endodontic treatment and retreatment. Lee et al. developed an AI module, based on multidisciplinary expert data from Harvard, that accurately predicts tooth prognosis, matching clinical decisions across prosthodontics, periodontics, and endodontics. [31]

Campo et al. used a case-based reasoning AI system to forecast nonsurgical root canal retreatment outcomes by analyzing past similar cases, balancing benefits and risks. While promising, its accuracy depends on the quality and amount of data available. [32]

For endodontic microsurgery, Qu et al. [33] evaluated machine learning models using factors like tooth type, lesion size, bone defect, and patient demographics, achieving about 80% accuracy in prognosis prediction. Such AI tools could aid clinicians in forecasting treatment success and guiding decision-making both pre- and post-intervention.

Predicting the Viability of Stem Cells

Bindal et al. used a neuro-fuzzy inference system to evaluate dental pulp stem cell viability in regenerative therapies under microbial stress. By simulating bacterial lipopolysaccharide-induced inflammation, the system accurately predicted stem cell survival after treatment, demonstrating its potential to assess regenerative outcomes in infected environments. [3,34]

VI. LIMITATIONS

Further testing is needed to identify optimal AI algorithms for diverse clinical scenarios, as current systems struggle to adapt quickly to new imaging platforms or hardware. Training and continuous validation require access to patient data, raising concerns about privacy and data security. Misclassified data can lead to inaccurate outcomes. Although AI holds great promise in healthcare, its adoption faces challenges, including hesitancy around secure data sharing and the need for stronger protections of patient confidentiality. [6]

VII. FUTURE DIRECTIONS IN AI

To ensure AI's effectiveness in dental diagnostics, key challenges must be addressed. These include improving the quality and diversity of datasets, conducting collaborative clinical validation, and fostering trust through real-world testing. Educating dental professionals on AI use and expanding research to include a wider range of dental conditions will enhance adaptability. Interdisciplinary collaboration is essential to develop responsible, ethical AI frameworks that protect patient data. Additionally, designing user-friendly AI tools that integrate smoothly into existing dental systems will support broader adoption. These steps are vital for advancing reliable, efficient, and widely accepted AI applications in dentistry. [8]

Photorealistic 3D Reconstructions

A promising emerging application is the use of AI-enhanced algorithms to create photorealistic 3D reconstructions of root canal spaces, tooth anatomy, and orofacial lesions. This technique, known as **cinematic rendering (CR)**, utilizes CBCT datasets combined with high dynamic range lightmaps to produce images with natural lighting and enhanced anatomical detail, potentially improving diagnostic accuracy. In medicine, cinematic rendering has been paired with augmented reality (AR) headsets to allow users to visualize and manipulate images in physical space—a technology that holds significant promise for clinical training and education in dentistry as well. [3]

VIII. CONCLUSION

Artificial intelligence in dentistry is rapidly evolving, significantly enhancing diagnostic accuracy, streamlining treatment planning, improving patient care, and minimizing human error. Its applications span a broad spectrum, from advanced diagnostic imaging to virtual assistants, demonstrating immense potential to transform and advance oral healthcare.

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