

The Role of Artificial Intelligence (AI) In Dentistry: Enhancing Diagnosis Accuracy and Treatment

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Abstract

Artificial intelligence (AI) is reshaping dentistry, enhancing diagnostic accuracy, treatment planning, and patient care. Using techniques such as machine learning and deep learning, AI applications have demonstrated superior performance in tasks such as detecting dental lesions, analyzing radiographs, and predicting treatment outcomes. Tools such as convolutional neural networks are particularly effective in diagnosing conditions such as tooth decay and root fractures, while AI-powered solutions in orthodontics are improving alignment designs and automating cranial analysis. Despite these advances, challenges hinder the integration of AI into clinical practice. Limited access to diverse and annotated datasets, regulatory hurdles, ethical concerns about algorithmic transparency and bias, and high implementation costs pose significant barriers. However, strategies such as tailored regulations, global collaboration on datasets, and scalable AI solutions can address these issues. This review explores the impact of AI across dental specialties, emphasizing its potential to transform oral healthcare.

Keywords: Dentistry, Artificial intelligence (AI), Oral Health, Patient care.

Introduction

Modern technology and artificial intelligence (AI) tools are transforming the healthcare landscape and improving the quality of diagnosis, the accuracy of treatment planning, and the management of patient care [1].

In dentistry, AI has enabled innovative applications based on machine learning (ML) and deep learning (DL) techniques such as deep neural networks, to provide effective solutions in diagnosing oral and dental diseases, planning treatments, and predicting treatment progress [2,3]. In some cases, these techniques have outperformed human capabilities, especially in analyzing X-ray and computed tomography (CBCT) images. AI tools in dentistry enhance diagnostic accuracy, identify root fractures, and detect infectious lesions in the areas surrounding the teeth [4].

AI techniques used in dentistry rely on several approaches, including supervised learning, unsupervised learning, and reinforcement learning, each of which has a specific role in analyzing data, extracting patterns, and formulating predictions [5]. Convolutional neural networks (CNNs) have proven effective in analyzing radiographic images, while tools such as reinforcement learning have shown future potential in improving treatment plans [5,6].

However, the integration of AI tools in dentistry faces many challenges such as limited data, ethical issues, regulatory hurdles, and high costs [7]. Therefore, these technological transformations require a multidisciplinary approach that brings together experts in the fields

of dentistry, software engineering, and ethics, to establish clear standards that ensure the safety and security of AI applications in this field [7,8]. Accordingly, this review aims to examine the impact of AI on different dental specialties, and shed light on its achievements, challenges, and future trends that may contribute to the development of dentistry.

Applications of Artificial Intelligence (AI) in Dentistry

Artificial Intelligence (AI) has rapidly advanced in its application across various dental disciplines, significantly improving diagnostic accuracy, treatment planning, and improving patient care. AI enables more accurate, efficient, and personalized approaches in dentistry.

Endodontics: Revolutionizing Root Canal Diagnosis

Endodontics has benefited greatly from AI-driven advances, particularly in complex diagnostic scenarios:

- **Periapical lesion detection:** AI models such as convolutional neural networks (CNNs) have demonstrated exceptional accuracy in analyzing cone-beam CT images, often identifying periapical infections more accurately than experienced radiologists. These systems accelerate early intervention, reducing the risk of complications [9].
- **Root morphology analysis:** AI tools excel at analyzing complex root morphology and diagnosing vertical root fractures. These models address common imaging challenges, such as noise and resolution limitations, enabling detailed assessments that aid in treatment planning. This capability is particularly valuable in cases of unusual root canal anatomy or multiple root systems [10].
- **Advanced imaging technologies:** AI-integrated imaging systems enhance clarity and reduce artifacts in cone-beam CT scans, providing clinicians with the high-quality images necessary for accurate diagnosis [11]. These innovations significantly reduce the time to interpretation and improve patient outcomes.

Oral Radiology: Improving Diagnostic Imaging

AI has brought accuracy and efficiency to oral radiology, reshaping how clinicians interpret radiographic data:

- **Pest detection and classification:** Advanced models such as GoogLeNet Inception and DetectNet excel at identifying a wide range of dental pathologies, including tooth decay, cysts, and tumors. These tools enhance diagnostic confidence, reduce false negatives, and enable early interventions [12].
- **Tooth segmentation and localization:** AI systems automate the segmentation of individual teeth in panoramic and cone beam CT images, helping to identify anomalies such as impacted or supernumerary teeth. This simplifies the diagnostic process and reduces the workload on radiologists [13].
- **Metal artifact reduction:** AI frameworks mitigate the interference caused by metallic restorations, such as implants and crowns, in cone beam CT scans [14]. This advance ensures more accurate imaging results and enhances diagnostic reliability.

Oral Surgery: Precision in Pre- and Post-Surgical Planning

In oral surgery, AI applications range from detailed pre-surgical planning to post-surgical monitoring:

- **Surgical planning:** Deep learning models predict outcomes such as facial swelling, bone remodeling, and soft tissue changes after surgical procedures such as orthognathic procedures. These insights enable surgeons to customize treatments for optimal outcomes [15].
- **Dental implants:** AI systems help in implant planning by assessing bone density and anatomical constraints from CT scans. They recommend the best implant size, position, and angle, reducing complications and improving long-term success rates [16].

- **Improved diagnostic accuracy:** AI-powered systems analyze X-rays to detect complex conditions such as proximity to the maxillary nerve or the risk of sinus perforation [17]. This accuracy reduces surgical errors and improves patient safety.

Orthodontics: Redefining Treatment Planning and Analysis

AI has advanced the science and practice of orthodontics, particularly in automating repetitive and time-consuming tasks:

- **Automated Cephalometric Analysis:** AI tools identify anatomical landmarks on cephalometric x-rays with remarkable accuracy, helping with skeletal classification and orthodontic treatment planning [18]. This automation reduces the time spent on manual analysis and improves accuracy.
- **Progressive Prediction and Simulation:** Neural networks assess growth stages and predict skeletal growth patterns, enabling orthodontists to make informed decisions about treatment timing. AI-driven simulations visualize potential outcomes, enhancing patient communication and satisfaction [19].
- **Alignment Optimization:** AI optimizes the design and fit of clear aligners by analyzing patient-specific data. This ensures effective and comfortable orthodontic treatment [20].

Pediatric Dentistry: Prioritizing Prevention and Early Intervention

AI plays a vital role in pediatric dentistry by addressing the unique challenges of diagnosing and managing conditions in children:

- **Dental Caries Risk Assessment:** Machine learning models analyze clinical and behavioral data, such as dietary habits and oral hygiene practices, to predict a child's risk of developing tooth decay [21]. This allows for early preventive measures to be taken.
- **Non-invasive Diagnosis:** AI systems use imaging techniques to diagnose conditions such as enlarged lymph nodes or adenoids, reducing the need for surgical procedures. These tools ensure a stress-free experiences for young patients [21].
- **Behavioral Prediction:** AI models predict a child's behavior during dental visits, enabling dentists to tailor their approach and ensure a positive experience [21].

Periodontics: Revolutionizing Periodontal Care

AI in periodontics focuses on early detection and management of gum and bone diseases:

- **Measuring Alveolar Bone Loss:** AI systems measure bone loss from X-rays, providing detailed assessments that help diagnose periodontitis and plan interventions [17].
- **Gingivitis and periodontitis detection:** Deep learning algorithms analyze intraoral images to detect signs of gingivitis and disease severity. This facilitates timely treatment and prevents disease progression [22].
- **Implant stability monitoring:** AI assesses the stability of dental implants over time by analyzing changes in bone density around the implant, ensuring long-term success [23].

Aesthetic dentistry: Connecting technology and aesthetic dentistry

In prosthetic dentistry, AI enhances the accuracy and efficiency of prosthetic and aesthetic procedures:

- **Implant planning and placement:** AI integrates with CT scans to determine optimal implant locations, considering bone density, proximity to anatomical structures, and patient-specific requirements [24].
- **Improved dental prosthetic design:** AI-powered CAD and CAD systems simplify the design of crowns, bridges, and dentures, ensuring precise fit and aesthetic appeal [25]. This reduces chair-side adjustments and improves patient satisfaction.
- **Predicting the longevity of materials:** AI models predict the durability and performance of restorative materials, guiding clinicians in selecting the most appropriate options for each patient [25].

Restorative Dentistry: Precision and Personalization

AI is enhancing restorative dentistry practices through its ability to analyze complex data and improve treatment outcomes:

- **Detection and Classification of Caries:** AI models analyze radiographs and dim light to detect and classify caries with greater sensitivity and specificity than traditional methods [12].
- **Robotic Cavity Preparation:** Emerging AI-powered robotic systems ensure precision in cavity preparation, minimizing loss of healthy tooth structure and enhancing restoration success [26].
- **Restoration Evaluation:** AI systems evaluate the condition of dental restorations, identifying defects or areas requiring re-treatment. This improves restoration life and patient satisfaction [26].

Challenges in Integrating AI into Dentistry

- **Data Limitations:** AI models require diverse, high-quality, and annotated datasets, which are often difficult to obtain due to privacy regulations. The lack of diversity in datasets also limits the generalizability of AI models across different demographics [27].
- **Regulatory Barriers:** Approval processes by regulatory bodies such as the FDA and the European Medicines Agency are resource-intensive, slowing the adoption of AI [28]. Additionally, the adaptive nature of AI systems requires constant monitoring and revalidation.
- **Ethical Considerations:** AI systems often lack transparency, making their decision-making processes difficult to interpret. This undermines trust and complicates accountability for errors. Biases in training data can also lead to inequities in care, raising ethical concerns [7,8].
- **Cost and Accessibility:** The high costs of implementing AI technologies, including infrastructure and training, are a barrier for smaller practices. Resource-constrained settings also face challenges in accessing the necessary technology, widening the digital divide [7].

Future Trends for AI in Dentistry

To overcome these challenges and maximize the benefits of AI, several strategies can be implemented [29,30].

- **Standardization and Dataset Diversity:** Standardized protocols for data collection and AI evaluation can improve reliability and streamline regulatory processes. Enhancing dataset diversity through global collaboration ensures that AI models perform consistently across different populations.
- **Tailored Regulatory Frameworks:** Developing AI-specific regulatory guidelines will help accommodate the adaptive nature of AI systems while ensuring safety and effectiveness. This will accelerate approval processes and enable broader adoption.
- **Developing Ethical and Transparent AI:** Addressing biases and designing transparent AI systems will enhance trust and equity in care. Clear accountability frameworks will also establish accountability for AI-driven outcomes, ensuring ethical use.
- **Collaboration across disciplines and pilot studies:** Collaboration between dentists and AI tool developers as well as pilot studies will ensure that AI tools are clinically effective, ethically sound, and ready for real-world application.

Conclusions

Artificial intelligence is transforming the dental landscape, enhancing diagnostic accuracy, treatment precision, and patient care. From endodontics to restorative dentistry, AI tools are complementing the work of doctors, reducing workload and human error. However, AI remains an adjunct, not a replacement for human expertise. Addressing legal, ethical, and

methodological challenges is critical to the widespread adoption of AI. As research and technology continue to advance, AI has tremendous potential to redefine dental practice, ensure better patient outcomes, and advance the field of dentistry.

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