

Advancements and Challenges of Artificial Intelligence in Modern Dentistry: A Narrative Review

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Abstract: Artificial intelligence (AI) is rapidly transforming modern dentistry, offering new opportunities to enhance diagnostic accuracy, treatment outcomes, and clinical efficiency. This narrative review delves into current AI applications across dental specialties such as diagnostic imaging, orthodontics, prosthodontics, and pediatric dentistry—highlighting successes and existing limitations. Emphasis is placed on machine learning, radiographic interpretation, computer - aided restorations, and ethical challenges related to privacy, access, and transparency. The article advocates for further research to standardize methodologies and address data - related concerns, ensuring responsible and effective integration of AI in dental practice.

Keywords: artificial intelligence, pediatric dentistry, diagnostic imaging, early childhood caries, dental education

1. Introduction

Definition of Artificial Intelligence

Artificial intelligence (AI) has seen increasing application in dentistry and medicine in recent years (1). The process of teaching a machine to think like a human is known as artificial intelligence (2). Artificial intelligence is a computing system capable of simulating the cognitive abilities of the human mind, allowing it to acquire knowledge, engage in reasoning, and perform tasks or behaviors informed by acquired experience (3, 4). Essentially, AI encompasses algorithms trained by computers to replicate human intelligence. John McCarthy first used the term “artificial intelligence” at a conference in 1956 in Dartmouth.

AI tools are playing a growing role in various dental specialties today. Human intelligence refers to the innate cognitive capacity of humans, which is biologically endowed and encompasses a range of abilities such as perception, knowledge acquisition, problem - solving, choice - making, language comprehension, and social interaction (5). AI primarily works through learning—collecting data and establishing principles for transforming it into actionable knowledge (6). These principles, called algorithms, instruct the computer/machine to perform a specific task consistently.

Classification of AI

Artificial Intelligence encompasses all forms of non - human intelligence. There are two main categories of AI: weak AI and strong AI (7).

Weak AI refers to systems designed for specific tasks and is further divided into subsets such as expert systems and machine learning. A prominent area within machine learning is deep learning, which is currently one of the most active research fields. A particular type of deep learning model used for image creation and recognition is known as Convolutional Neural Networks (8).

Strong AI, on the other hand, is defined as having capabilities and intelligence comparable to that of humans. The aim of strong AI is to develop a multi - tasking decision - making

algorithm. One specific deep learning algorithm is Generative Adversarial Networks. This unsupervised learning technique is designed to automatically identify patterns in input data and generate new data with similar characteristics (8).

The purpose of this review is to explore how artificial intelligence is currently applied in dentistry, especially in pediatric settings, and to discuss the associated ethical, practical, and technological considerations. This review is based on recent peer - reviewed articles published between 2020 and 2025, selected for relevance and quality from major scientific databases. Understanding AI’s capabilities and limitations in dentistry is essential for improving patient care, guiding future research, and framing ethical guidelines for its use.

AI tools are becoming increasingly significant in various dental specialties. The creation of AI programs aimed at aiding clinicians in diagnosing patients, selecting treatments, and predicting outcomes pertains to the application of AI in healthcare. AI is increasingly being integrated into pediatric dentistry, offering promising advancements in diagnostic accuracy, treatment planning, and patient management. AI applications in pediatric dentistry primarily focus on early childhood caries detection and prediction, tooth identification, and the identification of dental anomalies such as supernumerary teeth and mesiodens. Key areas of AI implementation in dentistry include:

- **Diagnostic Imaging:** AI has transformed how dental radiographs, CBCT, and other imaging tools are analyzed, significantly enhancing diagnostic accuracy for various conditions, including dental caries, vertical root fractures, and maxillofacial pathologies (9). Studies show that AI algorithms increase the accuracy, sensitivity, and specificity of caries detection on dental radiographs (10, 11). These systems also improve the detection and segmentation of apical pathoses and jaw lesions, resulting in shorter diagnostic times and greater accuracy (10). Moreover, AI enhances the identification of cephalometric landmarks, which is especially beneficial in orthodontic treatment planning (12). Additionally, AI algorithms assist in detecting and quantifying bone loss around teeth

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and implants, providing valuable support in the diagnosis and management of periodontal and peri-implant diseases (12). AI plays a critical role in detecting and classifying various maxillofacial pathologies, including cysts, tumors, and fractures, thereby improving diagnostic capabilities in complex cases (13). Within CBCT, AI helps localize anatomical landmarks, segment teeth and jaws, and identify pathologies such as periodontitis and periapical lesions, all of which contribute to improved diagnostic accuracy and clinical decision-making (14). In summary, the implementation of AI in diagnostic imaging within dentistry enhances the precision and reliability of radiographic interpretations, offering particular advantages to less experienced clinicians and fostering improved inter-observer agreement. However, further validation using larger and more diverse datasets is essential to ensure that these AI systems are generalizable and reliable in clinical practice.

- **Treatment Planning:** AI assists in designing personalized treatment plans by analyzing patient data and predicting treatment outcomes, which is particularly useful in orthodontics, prosthodontics, and implantology (15, 16). Artificial intelligence has significantly enhanced treatment planning in dentistry by optimizing clinical decision-making and personalizing patient care. AI algorithms, particularly those based on machine learning and deep learning, can analyze large datasets, including dental images and patient records, to identify patterns and make predictions that assist in treatment planning. This capability allows for early detection and intervention, which is crucial for effective treatment planning. AI also plays a role in orthodontics, where it can analyze cephalometric radiographs to identify anatomical landmarks and predict treatment outcomes. This aids in creating precise orthodontic treatment plans tailored to individual patients (17). Additionally, AI can simulate orthodontic treatment outcomes, providing visual guidance for both clinicians and patients.

In restorative dentistry, AI enhances computer-aided design/computer-aided manufacturing (CAD/CAM) processes by automating the design of dental restorations. AI algorithms can incorporate esthetic factors, occlusal schemes, and historical data to optimize the design and predict the longevity of restorations (18). Furthermore, AI can assist in treatment planning by predicting the prognosis of various dental treatments. By analyzing historical treatment data and patient-specific factors, AI can provide recommendations on the most effective treatment options and anticipate potential complications (19).

AI provides recommendations for treatment based on data-driven insights, aiding in decision-making processes across various dental specialties, including endodontics and periodontics (17). The dentists can use AI to ensure quality treatment, better oral health care outcome, and achieve precision. AI can help to predict failures in clinical scenarios and depict reliable solutions (19).

- **Patient Management:** AI technologies streamline administrative tasks, enhance patient communication, and improve practice management efficiency (20). AI streamlines administrative tasks, such as record-keeping and appointment scheduling, thereby increasing efficiency

and reducing the administrative burden on dental practitioners (21). This allows dentists to focus more on patient care and less on routine administrative tasks. Overall, AI in dentistry increases operational efficiency, ultimately leading to better patient outcomes and more efficient dental practice management.

- **Dental Education:** AI is utilized in educational settings to simulate clinical scenarios and enhance learning through virtual training environments (22). AI-driven virtual patients and chatbots provide dental students with interactive, simulated clinical scenarios. These tools help students practice diagnostic skills and clinical decision-making in a controlled, risk-free environment. For instance, a study involving dental students interacting with an AI chatbot that simulated a virtual patient showed high satisfaction and improved diagnostic skills among participants (23).
- AI can track students' progress and provide personalized feedback based on their performance. This individualized approach helps identify areas where students need improvement and tailors educational content to their specific needs, enhancing the overall learning experience (24).
- **Research and Development:** AI contributes to dental research by analyzing large datasets to identify trends and improve understanding of disease pathogenesis (25). AI significantly contributes to dental research and development by enhancing data analysis, improving diagnostic tools, and facilitating innovative treatment methodologies. AI algorithms, particularly machine learning and deep learning, can analyze large datasets to identify patterns and correlations that may not be apparent through traditional analysis. This capability is crucial in epidemiological studies and in understanding the etiology of dental diseases. For instance, AI can process vast amounts of patient data to identify risk factors for conditions like periodontal disease and caries, leading to more targeted preventive strategies (17, 21).

AI expedites drug discovery by predicting compound efficacy and safety. In dental research, this can lead to the development of novel therapeutics for conditions such as oral cancers and periodontal disease. AI models can screen vast chemical libraries to identify potential drug candidates, significantly reducing the time and cost associated with traditional drug discovery methods (26).

AI enhances the efficiency of clinical trials by optimizing patient recruitment, monitoring, and data analysis. AI algorithms can identify suitable candidates for trials based on electronic health records and predict patient adherence and response to treatments. This leads to more efficient and effective clinical trials, ultimately accelerating the development of new dental treatments (27).

A systematic review and meta-analysis by Rokhshad et al. highlighted that AI tools have been developed for various tasks, including the detection of caries on radiographs, primary tooth identification, and supernumerary tooth identification (28). The accuracy of these AI applications ranges from 60% to 99%, with sensitivity and specificity varying widely depending on the specific task and dataset used (28). Another systematic review by Hartman et al.

examined the use of deep learning algorithms for dental anomaly detection in pediatric dentistry. The review found that AI systems demonstrated an average accuracy of 85.38% and sensitivity of 86.61%, although human performance still outperformed AI with 95% accuracy and 99% sensitivity (29).

Early Childhood Caries (ECC) and AI

AI's role in ECC detection and prediction has also been extensively studied. Artificial intelligence demonstrates comparable diagnostic accuracy to traditional methods in detecting early childhood caries, with reported accuracy, sensitivity, and specificity metrics that match or exceed those of experienced dentists.

Dental caries is the most common dental disease in children and is a significant chronic condition with considerable economic and qualitative consequences (30). Recent studies indicate that its prevalence has increased among children aged 2 to 5 years worldwide, making this age group a priority for global health initiatives (31). If left untreated, dental caries can lead to pain, discomfort, growth retardation, reduced quality of life, and tooth loss (32). Therefore, early detection of dental caries in high - risk children, along with preventive measures to promote optimal oral health, is crucial.

Sadegh - Zadeh et al. focused their study on identifying and referring children at high risk for caries through dental examinations and the use of computer - based methods early in life. These measures aim to implement strict preventive strategies for high - risk groups (33). Machine learning techniques, developed using computer algorithms that analyze multiple correlated parameters, have shown promise in identifying and predicting childhood caries (33).

The most effective machine learning models included the Multilayer Perceptron, Random Forest, and Support Vector Machine, all of which achieved an accuracy rate of over 97% in classifying the presence of caries risk.

Another important application in pediatric dentistry is the diagnosis of deep caries and pulpitis in periapical radiographs. In a study conducted by Zheng et al., the automated diagnosis of deep caries and pulpitis using artificial intelligence involved comparisons of three different convolutional neural networks (CNNs) (34). The ResNet18 model, when combined with clinical data, demonstrated high accuracy, precision, sensitivity, and specificity. The multimodal CNN utilizing ResNet18 with clinical parameters provided significant accuracy in diagnosing deep caries and pulpitis (34). Thus, early diagnosis of dental caries in students through artificial intelligence can serve as a vital tool for implementing preventive measures and maintaining good oral health (34).

According to a systematic review, AI tools for ECC detection have accuracies ranging from 78% to 86%, sensitivities between 67% and 96%, and specificities from 81% to 99% (35). This performance is similar to traditional visual - tactile examinations, which have a sensitivity of 0.86 and specificity of 0.77 for enamel caries detection (35, 36).

AI models, such as those validated for ECC detection in dental photographs, have achieved an accuracy of 97.2%, with sensitivities ranging from 68.8% to 98.5% and specificities from 86.1% to 99.4% (37). These metrics suggest that AI can effectively automate visual examinations, potentially offering more consistent and objective assessments compared to traditional methods. Furthermore, AI - based applications, like the YOLOv5s model, have demonstrated higher precision and sensitivity than junior dentists in detecting dental decay on intraoral photographs, achieving a precision of 90.7% and sensitivity of 85.6% (38).

This shows AI's strength in boosting diagnostic accuracy, especially where practitioner experience is limited. Overall, AI's ability to match or exceed traditional diagnostic methods in accuracy, sensitivity, and specificity highlights its potential as a valuable tool in pediatric dentistry for ECC detection and management.

Primary Tooth Identification and AI

AI applications for primary tooth identification have also demonstrated promising results. According to a systematic review, AI tools for primary tooth identification and numbering showed accuracies between 60% and 99%, with varying sensitivity and specificity (28). These tools help in accurately identifying and numbering primary teeth, which is crucial for effective treatment planning.

Artificial intelligence (AI) can be used to identify primary teeth in dental imaging and diagnostics through advanced deep learning algorithms that analyze radiographic images. These AI systems are trained to detect and number primary teeth with high accuracy, improving diagnostic efficiency and precision. One notable example is the study by Kilic et al., which developed a deep - learning approach using Faster R - CNN Inception v2 models to automatically detect and number deciduous teeth in pediatric panoramic radiographs (39). The AI system demonstrated high sensitivity (0.9804), precision (0.9571), and F1 score (0.9686), indicating its effectiveness in identifying primary teeth (39). Another significant contribution is the work by Xu et al., which utilized a U - Net - based region of interest extraction model and a Hybrid Task Cascade - based teeth segmentation and numbering model. This AI algorithm achieved precision and recall rates exceeding 97% for teeth segmentation and numbering, and an Intersection - over - Union (IoU) of 92%, showcasing its robustness across primary, mixed, and permanent dentitions (40). These AI systems not only enhance the accuracy of primary tooth identification but also streamline the diagnostic process, providing valuable support to clinicians in pediatric dentistry.

Identification of Dental Anomalies (Supernumerary Teeth and Mesiodens) and AI

AI systems have been effective in identifying dental anomalies such as supernumerary teeth and mesiodens. A systematic review on deep learning algorithms for dental anomaly detection reported an average accuracy of 85.38% and sensitivity of 86.61% for AI systems, although human performance still outperformed AI (29). Another review highlighted that AI tools for identifying supernumerary teeth and mesiodens on radiographs had accuracies ranging from 60% to 99% (28).

Assessment of child's behavior and AI

Artificial intelligence can be utilized to identify a child's behavior before dental treatment by analyzing various data points to predict potential behavior management issues. Machine learning algorithms, particularly those using deep learning techniques, can process large datasets that include information on dental health, previous dental treatments, parental dental fear, general anxiety, and socioeconomic variables. A study by Klingberg et al. demonstrated the application of machine learning methods to analyze multifactorial and complex relationships in large datasets, specifically focusing on dental fear and behavior management problems in children. The study used inductive analysis programs to create knowledge trees that highlight the importance of different attributes in predicting dental fear and behavior management issues (41). AI systems can integrate data from electronic health records, questionnaires, and behavioral assessments to predict a child's likelihood of experiencing dental fear or exhibiting behavior management problems. These predictions can help dental professionals tailor their approach to each child, potentially improving the overall experience and outcomes of dental treatment.

Furthermore, AI can assist in creating personalized behavior management plans by identifying specific triggers and suggesting interventions based on historical data. This reflects the concept of augmented intelligence, where AI supports clinical decision - making (17).

Artificial intelligence (AI) can be used for managing a child's behavior before dental treatment by predicting potential behavior management issues and tailoring interventions accordingly. AI systems can analyze large datasets that include information on dental health, previous dental treatments, parental dental fear, general anxiety, and socioeconomic variables to predict a child's likelihood of experiencing dental fear or exhibiting behavior management problems. AI can also assist in creating personalized behavior management plans by identifying specific triggers and suggesting interventions based on historical data. For example, AI can recommend the use of distraction techniques, such as music or robotic assistance, which have been shown to reduce anxiety and improve behavior during dental treatment (42, 43).

Ethical considerations when using artificial intelligence in pediatric dentistry, particularly for improving diagnostic accuracy for early childhood caries and dental anomalies, include several key principles:

- **Privacy and Data Protection:** Ensuring the confidentiality and security of patient data is paramount. AI systems require large datasets, often including sensitive patient information. Robust measures must be in place to protect this data from unauthorized access and breached (44).
- **Transparency and Explainability:** AI algorithms should be transparent and their decision - making processes explainable. This is crucial for building trust among clinicians and patients. The ability to understand how AI arrives at its conclusions can help in validating its accuracy and reliability (45).
- **Equity and Access:** AI should be designed to be equitable, ensuring that all patients, regardless of socioeconomic

status, have access to its benefits. This includes addressing potential biases in the datasets used to train AI models, which can lead to disparities in diagnostic accuracy across different populations (46).

- **Accountability and Responsibility:** Clear guidelines must be established regarding who is accountable for AI - driven decisions. Clinicians must retain ultimate responsibility for patient care, ensuring that AI serves as a supportive tool rather than a replacement for professional judgment (44, 45).
- **Autonomy and Consent:** Patients and their guardians should be informed about the use of AI in their care and provide consent. This respects their autonomy and ensures they are aware of how AI may influence their diagnosis and treatment (44).
- **Ethical Development and Implementation:** AI systems should be developed and implemented following ethical guidelines that prioritize patient welfare, fairness, and the minimization of harm. Continuous oversight and adherence to ethical standards are essential (44, 46). These considerations are critical to ensure that AI enhances pediatric dental care while safeguarding patient rights and maintaining trust in the technology.

2. Conclusion

Artificial intelligence has already begun reshaping dentistry, especially in diagnostics and treatment planning. While its benefits in pediatric dentistry and other specialties are clear, challenges related to data privacy, standardization, and ethical responsibility must be addressed. As we move toward integrating AI into routine dental care, ongoing research and policy - making must focus on making these technologies safe, reliable, and accessible.

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