Article type:
Review Article
Volume 2, Issue 1, pp 14-26
Article history:
Received 24 November 2024
Revised 05 December 2024
Accepted 26 December 2024
Published online 01 January 2025

The Role of Artificial Intelligence in Dental Diagnosis and Treatment Planning

1. Arash Moeini
2. Shiva Torabi*

School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran
School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran

Corresponding author email address: shivatorabi@sums.ac.ir

ABSTRACT

This study aims to examine the role of artificial intelligence in dental diagnosis and treatment planning, highlighting its applications, benefits, challenges, and future directions. A narrative review was conducted using a descriptive analysis method, synthesizing recent literature on AI-driven diagnostic tools, treatment planning systems, and emerging trends in dentistry. Studies published between 2022 and 2025 were analyzed to assess AI applications in imaging-based diagnosis, clinical decision support, orthodontic planning, prosthodontics, endodontics, periodontal treatment, implantology, and precision dentistry. Ethical concerns, integration challenges, and regulatory considerations were also reviewed to provide a comprehensive understanding of AI's impact on dental practice. AI has significantly improved diagnostic accuracy in dental radiography, CBCT analysis, and early detection of caries, periodontal disease, and oral cancer. AI-driven treatment planning has enhanced efficiency in orthodontics, prosthodontics, and implantology by optimizing treatment simulations, material selection, and surgical precision. Teledentistry and remote diagnosis have expanded access to care, while AI-powered robotics have introduced automation in surgical and restorative procedures. Despite these advancements, challenges remain in data privacy, algorithmic bias, clinical integration, and regulatory compliance. Ethical concerns related to AI transparency, liability, and decision-making authority continue to shape its adoption in clinical practice. AI is transforming dental diagnosis and treatment planning by improving accuracy, efficiency, and accessibility. However, addressing challenges related to data security, bias, regulatory frameworks, and professional adaptation is essential for the responsible integration of AI in dentistry. Future advancements in AI algorithms, robotic-assisted dentistry, and precision medicine will further enhance patient-centered care. A balanced approach that combines AI innovation with human expertise is necessary to ensure optimal clinical outcomes and ethical AI implementation in dental healthcare.

Keywords: Artificial intelligence, dental diagnosis, treatment planning, machine learning, teledentistry, robotic dentistry, precision dentistry, AI ethics, clinical decision support, dental imaging.

How to cite this article:
Moeini, A., & Torabi, S. (2025). The Role of Artificial Intelligence in Dental Diagnosis and Treatment Planning. *Journal of Oral and Dental Health Nexus*, 2(1), 14-26. https://doi.org/10.61838/jodhn.2.1.2

Introduction

Artificial intelligence (AI) has emerged as a transformative force in modern healthcare, revolutionizing diagnostic and treatment processes across multiple medical disciplines, including dentistry. AI refers to the simulation of human intelligence through machine learning, deep learning, and neural networks, enabling computers to analyze complex datasets, recognize patterns, and make informed predictions. In the field of dentistry, AI plays a critical role in enhancing diagnostic accuracy, treatment planning, and clinical decision-making. By automating data analysis, AI-powered systems improve efficiency, reduce human error, and provide more personalized treatment approaches. With its ability to process vast amounts of radiographic, clinical, and patient history data, AI is reshaping dental healthcare by making it more precise, predictive, and patient-centered (1).

The integration of AI into dental diagnostics has evolved significantly in recent years, driven by advances

in machine learning algorithms and computational power. Initially, AI applications in dentistry were limited to basic image analysis and pattern recognition, but modern AI-driven systems now exhibit remarkable capabilities in interpreting radiographs, cone-beam computed tomography (CBCT) scans, and intraoral images. These advancements enable the early detection of dental caries, periodontal disease, oral malignancies, and other pathologies with high accuracy. AI-based radiographic analysis has been shown to outperform traditional diagnostic methods in identifying subtle abnormalities that may be overlooked by human practitioners (2). In orthodontics, AI facilitates automated cephalometric tracing and treatment simulation, streamlining orthodontic planning and improving patient outcomes (3). Furthermore, AI-assisted decision-support systems are being incorporated into restorative and prosthodontic workflows, aiding in the selection of materials, design of dental prostheses, and optimization of occlusion (4).

AI-driven treatment planning has also witnessed rapid advancements, with applications spanning across multiple dental specialties. In implantology, AI models predict optimal implant positioning based on bone density, anatomical structures, and occlusal considerations, minimizing surgical risks and enhancing long-term implant stability (5). In endodontics, AI assists in the classification of root canal morphology, facilitating more precise canal instrumentation and reducing procedural errors (6). Additionally, AI-based treatment planning is increasingly being adopted in pediatric dentistry, where predictive analytics help assess the risk of malocclusions and caries development in young patients (7). Beyond clinical applications, AI has also demonstrated potential in teledentistry, allowing remote diagnosis and consultation through intelligent image processing and chatbot-assisted patient communication (8).

Despite the growing body of evidence supporting AI's efficacy in dental healthcare, there remain significant research gaps that warrant further exploration. One key challenge is the need for large, high-quality datasets to train AI models effectively. Many existing AI-driven diagnostic tools rely on limited datasets, leading to potential biases and reduced generalizability in real-world clinical scenarios (9). Moreover, AI models often function as "black boxes," lacking transparency in their decision-making processes. This lack of explainability raises concerns among dental practitioners regarding the reliability and accountability of AI-based recommendations (10). Another critical issue is the integration of AI into routine dental practice, which requires seamless interoperability with existing electronic health records, imaging systems, and chairside digital workflows (11). Without standardized protocols for AI implementation, adoption rates among dental professionals may remain limited.

Ethical and legal considerations also pose barriers to the widespread adoption of AI in dentistry. Patient data privacy and security are of paramount importance, particularly as AI models require access to sensitive health records for training and refinement (12). There is a pressing need for regulatory frameworks that address data protection, algorithmic bias, and the ethical implications of AI-driven clinical decision-making. Furthermore, while AI can augment human expertise, it is not intended to replace the clinician's role in diagnosis and treatment planning. The human-AI collaboration must be carefully balanced to ensure that AI remains a supportive tool rather than a determinant of clinical outcomes (13).

The objective of this review is to provide a comprehensive analysis of the current state of AI applications in dental diagnosis and treatment planning. By synthesizing recent advancements in AI-driven imaging, decision support, and treatment optimization, this study aims to highlight the transformative potential of AI in improving dental healthcare outcomes. Additionally, this review seeks to identify the existing challenges associated with AI adoption in dentistry, including technical, ethical, and regulatory considerations. Understanding these challenges is crucial for developing AI solutions that are clinically effective, ethically responsible, and seamlessly integrated into modern dental practice.

As AI continues to evolve, there is a need for further research to validate its clinical efficacy, optimize its integration into dental workflows, and address the ethical dilemmas surrounding its use. Future studies should focus on developing more interpretable AI models, refining training datasets to enhance model accuracy, and establishing standardized guidelines for AI implementation in dental practice. By addressing these research gaps, AI has the potential to revolutionize

dental diagnosis and treatment planning, paving the way for a new era of precision dentistry that prioritizes patient-centered care and evidence-based decision-making.

Methods and Materials

This study employs a descriptive analysis method to synthesize and critically evaluate the role of artificial intelligence (AI) in dental diagnosis and treatment planning. The narrative review approach is appropriate for consolidating existing knowledge, identifying trends, and highlighting gaps in the literature without conducting a meta-analysis or systematic review. The primary objective of this review is to examine how AI-driven technologies, including machine learning algorithms, deep learning models, and computer-assisted diagnostic tools, are shaping contemporary dental practice. Given the rapid advancements in AI applications in healthcare, this review focuses on studies published between 2022 and 2025 to ensure the inclusion of the most recent technological developments and their implications for dentistry.

This study follows a qualitative descriptive framework, analyzing existing literature on AI in dental diagnosis and treatment planning. The scope of the review encompasses a broad range of AI applications, including diagnostic imaging, machine learning-based decision support systems, AI-assisted orthodontic treatment planning, implantology, prosthodontics, and endodontics. The review also examines ethical considerations, integration challenges, and future trends in AI-driven dental care. Since AI technology is an evolving field, the study prioritizes research articles, clinical trials, systematic reviews, and conference proceedings that offer empirical insights into AI's effectiveness, accuracy, and clinical feasibility in dentistry.

To ensure a comprehensive and up-to-date analysis, literature was retrieved from reputable academic databases, including PubMed, Scopus, Web of Science, IEEE Xplore, and ScienceDirect. The search strategy incorporated relevant keywords such as "Artificial Intelligence in Dentistry," "AI in Dental Diagnosis," "Machine Learning in Dental Treatment," "Deep Learning for Oral Health," "AI in Orthodontics," "AI in Implantology," and "AI in Periodontal Disease Management." The search was refined using Boolean operators to ensure precision and relevance. The inclusion criteria were original research articles, systematic and narrative reviews, and conference papers published between 2022 and 2025 that examined AI applications in dental diagnosis and treatment planning. Studies focusing solely on AI in general medicine or unrelated healthcare fields were excluded unless they provided significant insights applicable to dentistry. Grey literature, preprints, and articles lacking methodological rigor were also omitted to maintain scientific credibility.

The data extracted from the selected studies were analyzed using a thematic synthesis approach, categorizing findings based on AI applications in diagnostic imaging, treatment planning, and clinical decision support. Particular attention was given to studies comparing AI-driven diagnostic tools with conventional diagnostic methods, evaluating AI models' accuracy, sensitivity, and specificity. Additionally, the review critically examines the challenges of integrating AI into clinical practice, including ethical concerns, data security, algorithmic bias, and regulatory barriers. Future trends and emerging AI technologies in dental care were also identified by analyzing recent innovations, ongoing research, and expert perspectives. The findings were synthesized to provide a comprehensive understanding of AI's transformative impact on dentistry, offering insights into how AI can enhance diagnostic precision, optimize treatment planning, and improve patient outcomes.

AI Applications in Dental Diagnosis

Artificial intelligence has significantly advanced dental diagnostics, enhancing precision, efficiency, and early detection of oral diseases. By leveraging machine learning, deep learning, and computer vision, AI technologies have demonstrated remarkable accuracy in analyzing radiographic images, identifying dental pathologies, and assisting clinicians in decision-making. The integration of AI into dental diagnostics has not only improved early disease detection but has also optimized workflow efficiency, reducing diagnostic errors and supporting personalized treatment approaches. AI-driven systems continue to evolve, playing an essential role in radiographic interpretation, CBCT analysis, oral

cancer detection, and AI-assisted diagnostic decision-support systems.

AI applications in imaging-based diagnosis have revolutionized radiographic interpretation, offering unparalleled accuracy in detecting dental caries, periodontal disease, and periapical lesions. Traditional radiographic analysis relies on human expertise, which can be subject to inter- and intra-observer variability. AI models, particularly those employing convolutional neural networks (CNNs), have shown superior performance in analyzing panoramic radiographs, periapical images, and CBCT scans. AI-assisted radiographic interpretation enhances diagnostic precision by identifying minute abnormalities that may be overlooked by human practitioners, leading to earlier detection and intervention (10). In CBCT analysis, AI algorithms facilitate the segmentation of anatomical structures, including the maxillary and mandibular bones, nerves, and sinus cavities, which are critical for implant planning and orthodontic treatment (2). AI-powered segmentation improves the accuracy of volumetric assessments, reducing human error and optimizing surgical outcomes. Additionally, AI models have demonstrated efficacy in detecting dental caries at early stages, distinguishing between enamel and dentin lesions, and assessing lesion progression, which is crucial for preventive dentistry (14). Periodontal disease detection has also benefited from AI applications, where deep learning models analyze radiographs to assess alveolar bone loss, quantify periodontal pockets, and predict disease progression (1). Similarly, AI has shown promise in identifying periapical lesions, which are often missed in conventional radiographic interpretation due to their subtle presentation. The automated classification of periapical pathology assists in timely endodontic intervention, reducing complications and improving treatment outcomes (6).

Machine learning and deep learning algorithms have played a crucial role in improving diagnostic accuracy and efficiency in dentistry. These AI-driven models learn from vast datasets, recognizing patterns and anomalies with greater precision than traditional diagnostic methods. Machine learning models analyze patient data, clinical records, and imaging findings to establish predictive patterns, aiding in early disease detection and risk assessment (15). Deep learning, particularly through CNNs, has been instrumental in processing complex dental images, differentiating between healthy and pathological tissues, and classifying various dental conditions with high sensitivity and specificity (16). One of the key advantages of deep learning is its ability to continually refine its diagnostic accuracy through iterative learning, ensuring improved performance over time. AI models have been trained to recognize occlusal discrepancies, detect root fractures, and identify impacted teeth with high accuracy, making them invaluable tools in general dentistry and specialized fields such as orthodontics and prosthodontics (17). The automation of diagnostic processes reduces reliance on subjective interpretation, minimizing misdiagnoses and enhancing treatment planning efficiency. AI algorithms also assist in caries risk prediction by analyzing dietary habits, oral hygiene patterns, and genetic predisposition, enabling early preventive interventions and patient education (18).

The role of AI in oral cancer detection has been transformative, offering early identification and classification of malignant lesions with unprecedented accuracy. Oral cancer remains a significant global health concern, with delayed diagnosis often leading to poor prognosis and high mortality rates. AI-driven models analyze clinical images, histopathological slides, and radiographic data to distinguish between benign, precancerous, and malignant lesions with high sensitivity (12). AI-based image classification systems assist in identifying oral leukoplakia, erythroplakia, and other precancerous conditions, facilitating early intervention and improving patient survival rates (13). Additionally, deep learning models have been employed in cytological analysis, detecting dysplastic changes in oral mucosal cells and aiding in non-invasive cancer screening (19). AI algorithms also integrate patient risk factors, including smoking history, alcohol consumption, and genetic predisposition, to generate predictive models for oral cancer risk assessment (20). The implementation of AI in oral oncology enhances diagnostic confidence, reduces the need for unnecessary biopsies, and supports oncologists in developing targeted treatment strategies. Furthermore, AI-assisted diagnostic tools are being incorporated into teledentistry platforms, allowing remote screening of suspicious lesions and improving access to cancer diagnostics in underserved populations (8).

AI-assisted diagnostic decision-support systems have emerged as valuable tools in clinical practice, enhancing dentists' ability to make informed decisions based on comprehensive data analysis. These AI-driven platforms integrate patient history, clinical examination findings, and imaging data to generate evidence-based treatment recommendations (10). Decision-support systems utilize AI algorithms to compare patient cases with extensive databases of previously treated cases, identifying optimal treatment approaches tailored to individual patient needs (9). In endodontics, AI-powered systems assess root canal morphology, predict treatment complexities, and recommend appropriate instrumentation techniques, improving the success rate of endodontic therapy (6). Similarly, in prosthodontics, AI-driven decision-support tools assist in selecting the most suitable prosthetic materials, optimizing occlusal harmony, and predicting long-term restoration outcomes (4). AI-based systems also play a pivotal role in orthodontics by automating cephalometric analysis, generating virtual treatment simulations, and predicting tooth movement patterns, facilitating precise orthodontic planning (3). The integration of AI into decision-support frameworks enhances diagnostic consistency, reduces treatment variability, and improves patient-centered care.

The advancements in AI-driven diagnostic tools signify a paradigm shift in modern dentistry, bridging the gap between technology and clinical expertise. AI applications in imaging-based diagnosis, machine learning-driven data analysis, oral cancer detection, and decision-support systems have significantly improved diagnostic accuracy, efficiency, and early disease intervention. While AI continues to enhance dental diagnostics, ongoing research is essential to refine AI models, address ethical considerations, and establish standardized protocols for AI integration into clinical workflows. The future of AI in dentistry holds immense promise, paving the way for a more data-driven, predictive, and personalized approach to dental healthcare.

AI in Treatment Planning and Clinical Decision-Making

The integration of artificial intelligence into treatment planning and clinical decision-making has significantly improved the efficiency, precision, and predictability of various dental procedures. AI-driven models have enhanced orthodontic treatment planning, prosthodontic and restorative dentistry, endodontic and periodontal therapy, implantology, and personalized treatment strategies. These advancements allow for automated and data-driven decision-making, reducing variability and human error while optimizing patient-specific treatment outcomes. By leveraging machine learning algorithms, deep learning models, and computer-assisted technologies, AI provides evidence-based recommendations that streamline clinical workflows and enhance treatment accuracy across different specialties in dentistry.

AI applications in orthodontic treatment planning have transformed the way malocclusions are diagnosed and managed, offering precise cephalometric analysis and automated treatment simulations. Cephalometric analysis, a crucial component of orthodontic diagnosis, traditionally requires manual tracing and landmark identification, which can be time-consuming and prone to inter-examiner variability. AI-based systems have demonstrated the ability to automate cephalometric landmark detection with high accuracy, improving diagnostic efficiency and standardization (21). AI-driven cephalometric tools analyze lateral cephalograms to assess skeletal relationships, predict growth patterns, and determine optimal treatment strategies. Furthermore, AI-powered orthodontic treatment simulations provide virtual models of predicted tooth movement, allowing clinicians and patients to visualize treatment outcomes before initiating therapy. These simulations optimize bracket placement, wire sequencing, and force application, leading to more efficient treatment planning and shorter treatment durations (3). AI also aids in evaluating patient compliance with orthodontic appliances, tracking treatment progress, and making real-time adjustments based on digital monitoring systems. By integrating AI into orthodontics, clinicians can develop personalized treatment plans that enhance the predictability and success of orthodontic interventions.

In prosthodontics and restorative dentistry, AI plays a crucial role in digital impressions, crown and bridge design, and material selection, leading to improved prosthetic outcomes and patient satisfaction. Traditional methods of impression-taking and prosthesis fabrication often involve multiple clinical and laboratory steps,

increasing the risk of errors. AI-driven digital impression systems enhance the accuracy of intraoral scanning by identifying surface details, occlusal relationships, and marginal fit, reducing the need for retakes and adjustments (16). AI-powered software assists in designing crowns and bridges by analyzing occlusal forces, tooth morphology, and aesthetic considerations, ensuring a precise and natural-looking restoration (4). Machine learning algorithms have also been developed to predict the long-term performance of prosthetic materials based on patient-specific factors such as bite force, parafunctional habits, and oral hygiene status. AI-driven selection of restorative materials optimizes durability and aesthetics, reducing complications such as fracture, wear, and marginal leakage (10). Additionally, AI has been incorporated into computer-aided design and manufacturing (CAD/CAM) systems, enabling the fabrication of highly accurate restorations with minimal manual intervention. By integrating AI into prosthodontic workflows, clinicians can enhance treatment efficiency, improve restoration longevity, and achieve better functional and aesthetic outcomes.

AI-guided endodontic and periodontal treatment has improved the precision and effectiveness of root canal therapy and periodontal disease management. In endodontics, AI algorithms assist in identifying root canal morphology, detecting periapical pathology, and selecting the appropriate instrumentation techniques for each case. CBCT-based AI models have been developed to automate the classification of root canal anatomy, enabling endodontists to predict complex root configurations and potential anatomical variations before initiating treatment (6). AI-assisted diagnostic tools enhance the identification of periapical lesions and root resorption, reducing the likelihood of treatment failure. AI-driven decision-support systems also help determine the ideal file sequence and torque settings for root canal instrumentation, minimizing procedural errors such as ledge formation, instrument separation, and apical transportation (22). In periodontal therapy, AI-based diagnostic models assess radiographs and clinical parameters to classify periodontal disease severity, predict disease progression, and recommend optimal treatment protocols. AI applications in periodontal treatment planning include automated pocket depth measurement, gingival recession analysis, and bone density evaluation (1). AI-powered software has also been utilized in laser-assisted periodontal therapy, guiding clinicians in determining appropriate energy settings for tissue ablation and bacterial reduction. These AI-driven innovations in endodontics and periodontics enhance treatment predictability, reduce operator variability, and improve long-term treatment success.

AI has also significantly influenced implantology, offering precise implant positioning, bone density assessment, and surgical planning to optimize osseointegration and long-term success. Implant placement requires meticulous preoperative planning, considering factors such as bone quality, anatomical constraints, and prosthetic design. AI-based systems analyze CBCT scans to assess bone density, identify vital structures, and recommend optimal implant positioning with minimal risk of complications (5). These AI-powered models integrate biomechanical analysis, predicting implant stability and load distribution to enhance treatment outcomes. Additionally, AI has been incorporated into guided implant surgery, where virtual surgical planning software generates patient-specific surgical guides, ensuring accurate implant placement with minimal surgical trauma (11). AI also assists in postoperative evaluation, monitoring implant stability through radiographic analysis and machine learning-based predictive modeling. AI-driven decision-support systems further aid in selecting the most appropriate implant type, diameter, and surface modifications based on patient-specific factors, improving long-term osseointegration and prosthetic success (4). By integrating AI into implantology, clinicians can enhance surgical precision, reduce chairside time, and improve overall patient outcomes.

AI-driven personalized treatment planning has revolutionized dentistry by tailoring interventions based on patient-specific characteristics, leading to more efficient and customized care. Traditional treatment planning often follows standardized protocols, which may not account for individual variations in disease progression, treatment response, and patient preferences. AI models analyze large datasets of patient records, genetic factors, and lifestyle habits to generate personalized treatment recommendations that optimize clinical outcomes (8). AI-powered systems assess factors such as oral microbiome composition, occlusal dynamics, and tissue regeneration potential to predict treatment

success and recommend individualized strategies (7). In restorative dentistry, AI-based predictive analytics determine the most suitable treatment approach based on caries risk assessment, salivary composition, and dietary patterns, enabling early preventive interventions (15). AI-driven treatment planning has also been integrated into multidisciplinary dental care, where complex cases involving orthodontics, prosthodontics, periodontics, and implantology benefit from AI-guided decision-making (9). By leveraging AI in personalized treatment planning, clinicians can enhance patient satisfaction, reduce treatment failures, and promote a more evidence-based approach to dental care.

The application of AI in treatment planning and clinical decision-making has significantly advanced the field of dentistry, offering precise, efficient, and personalized treatment strategies. AI-driven models have enhanced orthodontic planning, prosthodontic design, endodontic and periodontal therapies, implant placement, and patient-specific treatment recommendations. These AI applications have improved diagnostic accuracy, reduced human error, and optimized treatment outcomes across various dental disciplines. As AI continues to evolve, ongoing research and technological advancements will further refine its integration into clinical practice, paving the way for a more data-driven and patient-centered approach to modern dentistry.

Challenges and Ethical Considerations in AI-Driven Dental Diagnosis and Treatment

The rapid adoption of artificial intelligence in dental diagnosis and treatment planning presents a range of challenges and ethical considerations that must be addressed to ensure its effective and responsible implementation. While AI-driven technologies offer significant advantages in improving diagnostic accuracy, treatment efficiency, and patient outcomes, they also introduce concerns related to data privacy, security, algorithmic bias, clinical integration, and regulatory compliance. Addressing these challenges is essential to fostering trust among dental professionals and patients while ensuring that AI applications contribute to equitable, ethical, and high-quality dental care.

One of the primary concerns in AI-driven dental applications is data privacy and security. AI models rely on large volumes of patient data, including radiographs, medical histories, and clinical records, to train algorithms and improve diagnostic accuracy. The collection, storage, and processing of such sensitive information raise significant ethical and legal issues regarding patient confidentiality and data protection (12). AI systems used in dentistry often require data sharing between clinics, research institutions, and cloud-based platforms, increasing the risk of unauthorized access and data breaches. Ensuring compliance with privacy regulations such as the General Data Protection Regulation (GDPR) and the Health Insurance Portability and Accountability Act (HIPAA) is critical to safeguarding patient information and preventing misuse (13). Additionally, the increasing reliance on cloud-based AI applications raises concerns about data ownership and control, as dental practitioners and patients may not have full transparency over how their data is utilized (20). Encryption techniques, decentralized data storage, and blockchain-based security measures have been proposed to enhance the confidentiality and integrity of patient data in AI-driven dental systems, but their widespread implementation remains a challenge (19).

Bias in AI models represents another critical challenge in AI-driven dental diagnosis and treatment. AI algorithms learn from historical datasets, and if these datasets are not diverse or representative of different populations, they may introduce biases that negatively impact clinical decision-making. For example, an AI system trained primarily on dental records from a specific demographic may not perform as accurately for patients from underrepresented ethnic or socioeconomic backgrounds (22). This can lead to disparities in diagnosis and treatment recommendations, potentially exacerbating existing inequalities in dental healthcare. Bias in AI models can also arise from variations in imaging techniques, scanner resolutions, and operator-dependent factors that affect the quality of training data (9). To mitigate these biases, it is crucial to use diverse, high-quality datasets that reflect the full spectrum of patient populations and clinical scenarios (1). Additionally, AI algorithms must undergo rigorous validation processes, including external testing on independent datasets, to ensure their generalizability and fairness (7). Efforts to develop explainable AI models that provide transparent reasoning behind their predictions can further help

dental professionals identify and address biases in AI-driven clinical decision-making (10).

Integrating AI technologies into routine dental practice presents significant challenges due to technical, logistical, and behavioral barriers. Many dental clinics still rely on conventional diagnostic tools and workflows, making the transition to AI-driven systems complex and resource-intensive (8). The cost of implementing AI-powered imaging systems, decision-support tools, and cloud-based platforms can be prohibitive, particularly for smaller dental practices with limited financial resources (4). Additionally, AI integration requires training and upskilling of dental professionals to ensure they can effectively interpret AI-generated recommendations and incorporate them into clinical workflows (11). Resistance to change among practitioners who are accustomed to traditional diagnostic methods further complicates AI adoption, as some may perceive AI as a potential replacement for human expertise rather than a complementary tool (15). The lack of standardized protocols for AI implementation in dentistry also creates inconsistencies in how AI tools are utilized across different clinical settings (5). To facilitate seamless AI integration, it is essential to develop user-friendly AI interfaces, provide comprehensive training programs for dental professionals, and establish clear guidelines for AI-assisted diagnosis and treatment planning (2).

Regulatory and legal considerations play a crucial role in determining the ethical and responsible use of AI in dentistry. As AI-driven diagnostic and treatment planning tools become more prevalent, regulatory bodies must establish clear guidelines to ensure their safety, efficacy, and compliance with existing healthcare standards (16). Current regulations governing medical AI applications vary across different countries, leading to inconsistencies in how AI technologies are evaluated and approved for clinical use (23). The U.S. Food and Drug Administration (FDA), the European Medicines Agency (EMA), and other regulatory authorities have begun developing frameworks for AI in healthcare, but many AI-driven dental applications still lack standardized approval pathways (17). One of the primary challenges in AI regulation is the need for continuous monitoring and validation, as AI models evolve and update based on new data (13). Unlike traditional medical devices, AI algorithms are dynamic and require periodic reassessment to ensure they maintain their accuracy and reliability in real-world clinical settings (18). Legal issues related to liability and accountability in AI-assisted diagnosis and treatment planning also remain unresolved. If an AI system makes an incorrect diagnosis or treatment recommendation that results in patient harm, determining liability between the AI developer, the software provider, and the treating clinician becomes a complex legal challenge (24). Clear legal frameworks are needed to define the roles and responsibilities of AI developers, regulatory bodies, and dental practitioners in AI-driven patient care (25).

Addressing the ethical considerations surrounding AI in dental practice is essential to ensuring that AI technologies are used responsibly and equitably. Ethical concerns related to patient consent, data transparency, and clinician oversight must be carefully managed to maintain trust in AI-driven healthcare systems (13). Patients should be fully informed about the use of AI in their diagnosis and treatment planning, including how AI models function, the limitations of AI-based recommendations, and the role of human oversight in clinical decision-making (22). Ethical AI development also requires interdisciplinary collaboration between dental professionals, AI researchers, ethicists, and policymakers to establish guidelines that prioritize patient welfare while embracing technological advancements (8). The ultimate goal of AI in dentistry should be to enhance patient care through data-driven insights while ensuring that human clinicians remain central to the diagnostic and treatment process (9).

While AI offers substantial benefits in improving dental diagnosis and treatment planning, it also presents significant challenges related to data privacy, algorithmic bias, clinical integration, and regulatory oversight. Addressing these challenges requires a collaborative effort between dental professionals, AI developers, policymakers, and regulatory authorities to ensure that AI-driven technologies are safe, ethical, and effective in real-world clinical applications. By implementing robust data security measures, reducing biases in AI models, facilitating AI adoption in clinical practice, and establishing clear regulatory frameworks, the potential of AI in dentistry can be fully realized while safeguarding patient interests and professional integrity. As AI continues to evolve, ongoing research and ethical

considerations will be essential in shaping the future of AI-driven dental care.

Future Directions and Emerging Trends

The future of artificial intelligence in dentistry is poised for remarkable advancements, with ongoing research and technological innovations driving its integration into clinical practice. AI algorithms continue to evolve, becoming more sophisticated and capable of performing complex tasks with greater accuracy and efficiency. These advancements are expected to enhance diagnostic precision, improve access to dental care through teledentistry, introduce automation in dental robotics, and contribute to the development of precision dentistry tailored to individual patient needs. As AI technology matures, its applications in dentistry will expand, transforming the way oral healthcare is delivered and optimized.

Recent advancements in AI algorithms for dentistry have focused on improving the accuracy, reliability, and interpretability of machine learning models. Deep learning techniques, particularly convolutional neural networks, have demonstrated superior performance in analyzing dental radiographs, CBCT scans, and intraoral images, enabling earlier and more precise detection of oral pathologies (2). The development of self-learning AI systems, which continuously refine their diagnostic capabilities based on new clinical data, has the potential to further enhance diagnostic accuracy while minimizing human oversight (9). Generative adversarial networks (GANs) are also emerging as a promising tool in dental imaging, allowing for the augmentation of training datasets by generating synthetic images that improve the robustness of AI models (10). Additionally, multi-modal AI systems that integrate radiographic, clinical, and genetic data are being developed to provide comprehensive patient assessments, supporting more informed clinical decision-making (8). AI-powered predictive analytics are increasingly being applied in caries risk assessment, periodontal disease progression modeling, and implant failure prediction, offering valuable insights that enable early intervention and preventive care (22). These advancements in AI algorithms will likely lead to more accurate, efficient, and personalized diagnostic and treatment planning solutions, reducing diagnostic errors and improving patient outcomes.

AI is also playing a pivotal role in the expansion of teledentistry and remote diagnosis, bridging gaps in dental care accessibility and ensuring that patients in remote or underserved areas receive timely and effective treatment. The integration of AI-driven diagnostic tools in telehealth platforms allows for real-time analysis of dental images, enabling remote consultations and early disease detection without requiring in-person visits (1). AI chatbots and virtual assistants are being employed to conduct preliminary patient assessments, gather medical histories, and provide basic oral health recommendations, reducing the burden on dental professionals and streamlining patient triage processes (17). Teledentistry platforms equipped with AI-driven image recognition capabilities can detect common dental issues such as caries, periodontal disease, and oral lesions, allowing clinicians to provide remote diagnoses and recommend appropriate treatment options (13). Moreover, AI-enhanced teledentistry is being integrated with wearable oral health monitoring devices that collect real-time data on oral hygiene habits, saliva composition, and bacterial activity, offering continuous monitoring and personalized oral health recommendations (7). By leveraging AI in teledentistry, access to dental care can be significantly expanded, reducing disparities in oral healthcare services and enabling early intervention for conditions that may otherwise go undiagnosed.

The potential for AI in automated dental robotics represents a significant leap forward in modern dental care, promising increased precision, efficiency, and consistency in complex dental procedures. Robotic-assisted dental systems are being developed to enhance the accuracy of surgical interventions, such as dental implant placement, endodontic procedures, and maxillofacial surgeries (4). AI-powered robotic systems integrate real-time imaging and force-feedback mechanisms to perform minimally invasive procedures with sub-millimeter precision, reducing trauma and accelerating post-operative recovery (5). Machine learning algorithms enable robotic systems to adapt to individual patient anatomy, optimizing implant positioning, occlusal adjustments, and soft tissue management during surgeries (11). AI-driven robotics are also being employed in orthodontics, where robotic systems assist in wire bending, aligner fabrication, and

precise bracket placement, improving treatment efficiency and outcomes (3). The development of autonomous robotic dental assistants, capable of performing routine tasks such as tooth cleaning, polishing, and diagnostic imaging, is also underway, potentially reducing the workload of dental professionals and increasing clinical efficiency (15). As AI-powered robotics continue to advance, their integration into dental practice will enhance treatment precision, reduce human error, and enable the automation of repetitive and labor-intensive procedures.

AI is also expected to play a central role in the advancement of precision dentistry, a patient-centered approach that tailors dental treatments based on individual genetic, anatomical, and lifestyle factors. Precision dentistry aims to move beyond standardized treatment protocols by leveraging AI-driven predictive analytics and personalized treatment planning tools that consider a wide range of patient-specific variables (18). AI-powered genetic screening tools are being explored for their potential to identify genetic predispositions to oral diseases, allowing for early risk assessment and preventive interventions (20). Machine learning models capable of analyzing salivary biomarkers, microbial composition, and immune response patterns are being developed to predict susceptibility to conditions such as periodontal disease, oral cancer, and dental caries, facilitating targeted preventive strategies (22). AI-driven treatment planning systems can optimize restorative and prosthodontic procedures by simulating the long-term performance of materials based on patient-specific bite forces, parafunctional habits, and occlusal dynamics (16). In orthodontics, AI models are being trained to predict individual tooth movement responses to aligner therapy, allowing for more precise and efficient orthodontic treatments (21). AI is also being incorporated into regenerative dentistry, where predictive models assess the potential for tissue regeneration and guide the selection of biomaterials for bone and soft tissue grafting procedures (6). The continued development of AI-driven precision dentistry will enable highly individualized treatment approaches that enhance long-term oral health outcomes while minimizing unnecessary interventions.

As AI continues to advance, its role in dentistry will expand beyond diagnostic support and treatment planning to include real-time decision-making, predictive analytics, and automation of complex procedures. The future of AI in dentistry will be shaped by ongoing research, interdisciplinary collaborations, and regulatory developments that ensure its safe and ethical integration into clinical practice (23). Addressing challenges related to data privacy, algorithmic bias, and clinical acceptance will be essential for maximizing the benefits of AI-driven dental innovations while minimizing potential risks (24). The continued refinement of AI technologies will lead to more efficient, precise, and patient-centered dental care, ultimately transforming the way oral health is managed and optimized. With further advancements in AI algorithms, teledentistry, dental robotics, and precision dentistry, the future of AI in dentistry holds immense potential to enhance diagnostic accuracy, treatment efficacy, and overall patient well-being.

Conclusion

The integration of artificial intelligence into dental diagnosis and treatment planning represents a transformative shift in modern dentistry. AI-driven technologies have demonstrated significant potential in improving diagnostic accuracy, enhancing treatment efficiency, and personalizing patient care. By leveraging machine learning, deep learning, and data-driven decision-making, AI applications are revolutionizing various aspects of dental healthcare, from radiographic interpretation to treatment simulations and robotic-assisted procedures. As AI continues to evolve, its role in dentistry is expected to expand, further optimizing clinical workflows and enabling more precise and effective treatments. The adoption of AI in dentistry has not only improved diagnostic precision but has also introduced novel approaches to teledentistry, automated robotics, and precision dentistry, ultimately benefiting both dental professionals and patients.

The application of AI in dental diagnostics has significantly improved the accuracy and reliability of imaging-based assessments. AI algorithms have proven their ability to analyze dental radiographs, CBCT scans, and intraoral images with remarkable efficiency, identifying pathologies such as caries, periodontal disease, and periapical lesions at earlier stages than conventional diagnostic methods. This advancement has enabled clinicians to detect abnormalities with greater

confidence, reducing diagnostic errors and supporting early intervention strategies. Additionally, AI has enhanced orthodontic treatment planning by automating cephalometric analysis and providing predictive models for tooth movement, making treatments more efficient and reducing the need for extensive adjustments. These AI-driven capabilities have established a new standard for accuracy in dental diagnosis, ensuring more effective and timely treatments.

Beyond diagnostics, AI has made a significant impact on treatment planning and clinical decision-making. In orthodontics, AI-powered treatment simulations provide clinicians and patients with a clearer understanding of expected outcomes, improving case acceptance and treatment efficiency. In prosthodontics and restorative dentistry, AI has facilitated digital impressions, optimized crown and bridge design, and enhanced material selection, leading to superior restorations with improved longevity. AI's role in endodontics and periodontics has contributed to more precise root canal treatments and periodontal disease management, ensuring better treatment outcomes and reducing the risk of complications. In implantology, AI-driven models have refined implant positioning and bone density assessments, improving the predictability and success rate of dental implant procedures. These advancements underscore AI's ability to optimize clinical workflows, enhance treatment accuracy, and improve patient experiences.

Despite its significant benefits, AI adoption in dentistry comes with several challenges and ethical considerations that must be addressed to ensure responsible implementation. Data privacy and security remain primary concerns, as AI systems require access to vast amounts of patient information to function effectively. Ensuring compliance with data protection regulations and implementing robust cybersecurity measures are crucial in maintaining patient confidentiality and trust. Additionally, the presence of bias in AI models poses a challenge, as algorithms trained on non-representative datasets may lead to disparities in diagnostic and treatment recommendations. Addressing these biases through diverse training datasets and rigorous validation processes is essential to ensure fair and equitable AI applications in dental care.

The integration of AI into routine dental practice also presents logistical and technical challenges. Many dental clinics lack the necessary infrastructure and resources to fully implement AI-driven technologies, and the cost of AI-powered systems remains a barrier to widespread adoption. Furthermore, training dental professionals to effectively use AI tools is essential to maximize their benefits while ensuring that human expertise remains central to the diagnostic and treatment process. Developing standardized guidelines and regulatory frameworks for AI applications in dentistry is necessary to establish ethical and legal boundaries, ensuring patient safety and the responsible use of AI in clinical practice.

The future of AI in dentistry holds immense promise, with continued advancements in AI algorithms, teledentistry, dental robotics, and precision dentistry paving the way for a new era of patient-centered care. AI-driven teledentistry has the potential to bridge gaps in dental care accessibility, providing remote consultations and diagnoses for underserved populations. AI-powered robotic systems are expected to enhance the precision of complex dental procedures, automating tasks that require high levels of accuracy while reducing procedural risks. The emergence of precision dentistry, supported by AI-driven predictive analytics, will further personalize treatment strategies, allowing clinicians to tailor interventions based on patient-specific factors such as genetics, microbiome composition, and oral health history. These developments will continue to enhance the quality of dental care, making treatments more efficient, effective, and minimally invasive.

While AI is revolutionizing dental diagnosis and treatment planning, it is essential to recognize that it serves as a complement rather than a replacement for human expertise. The collaboration between AI and dental professionals will be crucial in ensuring that AI technologies are used effectively and ethically to improve patient outcomes. As research and technological advancements continue to refine AI's applications in dentistry, addressing challenges related to data privacy, algorithmic bias, clinical integration, and regulatory oversight will be critical in maximizing its potential.

The successful integration of AI into dentistry will require a collective effort from researchers, clinicians, policymakers, and technology developers. Establishing

transparent regulatory frameworks, promoting interdisciplinary collaboration, and investing in AI education for dental professionals will be key to ensuring that AI is implemented responsibly and effectively. The future of dentistry is undoubtedly shaped by AI, and with continued advancements, AI-driven innovations will lead to a more data-driven, efficient, and patient-focused approach to oral healthcare. By embracing AI's potential while addressing its challenges, the dental profession can harness the power of artificial intelligence to enhance diagnostic accuracy, optimize treatment planning, and ultimately improve the overall quality of dental care.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

None.

Authors' Contributions

All authors equally contributed to this study.

Acknowledgments

We would like to express our appreciation and gratitude to all those who cooperated in carrying out this study.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

Funding

This research was carried out independently with personal funding and without the financial support of any governmental or private institution or organization.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

References

1. Bonny T, Nassan WA, Obaideen K, Mallahi MNA, Mohammad Y, El-Damanhoury HM. Contemporary Role and Applications of Artificial Intelligence in Dentistry. F1000research. 2023;12:1179. doi: 10.12688/f1000research.140204.1.
2. Keser G, Pekiner FN. Artifical Intelligence in Oral Radiology. 2024. doi: 10.58830/ozgur.pub431.c1874.
3. Ingle NA, Alabsi NF, Al-Hashimi H, Albuolayan NA, Alburidy F, Alanazi F, et al. The Use of Artificial Intelligence in Orthodontic Treatment Planning: A Systematic Review and Meta-Analysis. Advances in Human Biology. 2025. doi: 10.4103/aihb.aihb_140_24.
4. Murali G, Tamrakar AK, Faisal M, Srivastava AK. Artificial Intelligence in Prosthodontics and Dental Implants: Current Status and Futuristic Overview. East African Scholars Journal of Medical Sciences. 2024;7(04):134-7. doi: 10.36349/easms.2024.v07i04.004.
5. Benakatti V, Nayakar RP, Patil S. Artificial Intelligence Applications in Dental Implantology: A Narrative Review. Ip Annals of Prosthodontics and Restorative Dentistry. 2024;10(2):118-23. doi: 10.18231/j.aprd.2024.023.
6. Banati M, Choudhary E. Artificial Intelligence and Its Applications in Endodontics. 2024:243-70. doi: 10.4018/979-8-3693-8990-4.ch011.
7. Kuruva SD, K BD, M MKD, Kvk SKD, Senapathi NB, S PRD. Artificial Intelligence in Pediatric Dentistry. Academia Journal of Medicine. 2024;7(1):1-5. doi: 10.62245/ajm.v7.i1.1.
8. Kaushik R, Rapaka R. A Patient-Centered Perspectives and Future Directions in AI-powered Teledentistry. Discoveries. 2024;12(4):e199. doi: 10.15190/d.2024.18.
9. Ruan C, Zhu Y, Xiong J. Applications and Prospects of Artificial Intelligence in Oral Medicine. 2024;1(2):11-5. doi: 10.62381/i245203.
10. Bhat N, Kukreja BJ, Kukreja P, Bagde H. Efficient Treatment Planning on Optimization Techniques Empowered by AI in Dentistry. 2024:239-66. doi: 10.4018/979-8-3693-8659-0.ch013.
11. Satapathy SK, Kunam A, Rashme R, Sudarsanam PP, Gupta A, Kumar HSK. AI-Assisted Treatment Planning for Dental Implant Placement: Clinical vs AI-Generated Plans. Journal of Pharmacy and Bioallied Sciences. 2024;16(Suppl 1):S939-S41. doi: 10.4103/jpbs.jpbs_1121_23.
12. Naeem MM, Sarwar H, Hassan MT, Balouch NM, Singh S, Essrani PD, et al. Exploring the Ethical and Privacy Implications of Artificial Intelligence in Dentistry. International Journal of Health Sciences. 2023;7(S1):904-15. doi: 10.53730/ijhs.v7ns1.14294.
13. Jain V, Goel V. Artificial Intelligence in Oral Health Care. 2024:114-35. doi: 10.58532/v3bdms19p4ch3.
14. Kale P, Seth N, Verma S, Varshney DK, Sharma S. Artificial Intelligence in Dental Imaging: A New Era of Precision and Predictive Diagnosis. Ip International Journal of Maxillofacial Imaging. 2024;10(3):86-91. doi: 10.18231/j.ijmi.2024.019.
15. Rastogi I, Siddiqui SR, Khan FR. Artificial Intelligence Up Fronting Dentistry. Journal of Orofacial & Health Sciences. 2024;11(2):47-9. doi: 10.18231/j.johs.2024.012.
16. Bhoneja B, Dodeja K, Pardeshi V, Bhaumaik K. Artificial Intelligence in Dentistry. 2024:1-7. doi: 10.58532/v3bfms9p1ch1.
17. Dhopte A, Bagde H. Smart Smile: Revolutionizing Dentistry With Artificial Intelligence. Cureus. 2023. doi: 10.7759/cureus.41227.
18. Sa A, Msr T, Hf K, Mt D, Ms A, Na A-y, et al. Inverted Maxillary Third Molar Impaction: Exploring Capabilities of Artificial Intelligence (AI) Versus Human Intelligence (HI)

Expertise in Diagnosis and Treatment Planning. Open Access Journal of Dental Sciences. 2024;9(3). doi: 10.23880/oajds-16000405.
19. Sharma Y. Artificial Intelligence-Ray of Hope. J Otolaryngol Res & Rep. 2024:1-3. doi: 10.47363/jolrr/2024(3)129.
20. Rokaya D, Jaghsi AA, Jagtap R, Srinameepong V. Artificial Intelligence in Dentistry and Dental Biomaterials. Frontiers in Dental Medicine. 2024;5. doi: 10.3389/fdmed.2024.1525505.
21. Thakur S, Shenoy U, Hazare A, Karia H, Khorgade P, Nandeshwar N, et al. Transforming Orthodontics With Artificial Intelligence: A Comprehensive Review. Journal of Advances in Dental Practice and Research. 2024;0:1-9. doi: 10.25259/jadpr_26_2024.
22. Rahul B, D. S, Devi MS, p W. The Transformative Power of Artificial Intelligence in Dentistry. International Journal for Multidisciplinary Research. 2023;5(5). doi: 10.36948/ijfmr.2023.v05i05.6936.
23. Nasti S, Khan FA, Srivastava T, Nalini MR, Ahmed CZ, Tiwari H. Advancing Dental Diagnostics: The Significance of Cone-Beam Computed Tomography (CBCT) in Modern Dentistry. Ip International Journal of Maxillofacial Imaging. 2024;9(4):182-5. doi: 10.18231/j.ijmi.2023.032.
24. Semerci ZM, Yardımcı S. Empowering Modern Dentistry: The Impact of Artificial Intelligence on Patient Care and Clinical Decision Making. Diagnostics. 2024;14(12):1260. doi: 10.3390/diagnostics14121260.
25. Swathiraman J, Sudha JP. Artificial Intelligence: The Future of Dentistry. 2024:40-5. doi: 10.58532/v3bgms21p1ch4.