

Integrating Artificial Intelligence into Dental Education: Applications, Impacts, and Challenges. A Literature Review

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Abstract

Background: Artificial Intelligence (AI) stands at the forefront of technological advancement, enabling the development of intelligent systems that replicate human cognitive processes. It has become a cornerstone of modern society, seamlessly integrated into daily life and revolutionizing fields such as healthcare, finance, research, and technology. In dental education, AI revolutionizes learning and clinical training through tools such as machine learning and virtual simulations. However, its transformative potential is tempered by challenges that must be addressed for effective

implementation.

Objective: This review discusses the current applications of AI in dental education, its potential impact on student learning and clinical practice, and the challenges of integrating these technologies.

Conclusion: Artificial Intelligence (AI) is revolutionizing dental education through tools such as personalized learning platforms, intelligent tutoring systems, and machine learning-based diagnostics. These technologies accelerate learning, enhance diagnostic accuracy, and foster clinical decision-making skills, significantly improving educational outcomes. However, challenges

like equitable access, curriculum adaptation, ethical concerns, and resource allocation must be addressed to integrate AI into dental education fully.

Keywords: Artificial Intelligence, applications, impact, challenges, dental education

Introduction

Artificial Intelligence (AI) is broadly defined as the ability of computer systems to perform tasks that typically require human intelligence, such as problem-solving, decision-making, visual perception, and natural language processing. [1] Emerging as a formal field of study in the mid-20th century, AI has undergone remarkable evolution. Early AI systems relied on rule-based programming to mimic human reasoning, but their limitations became evident as tasks grew more complex. The advent of machine learning (ML) marked a pivotal shift, enabling systems to learn from data and improve performance without explicit instructions. More recently, deep learning (DL), a subset of ML, has revolutionized AI by employing neural networks to process vast datasets and uncover intricate patterns, making AI a cornerstone of modern technological advancement. [2]

As AI continues to evolve, it is becoming an integral part of daily life, revolutionizing industries such as healthcare, finance, research, and technology. In dentistry, AI holds immense potential to enhance diagnostic accuracy, streamline treatment planning, educate patients, and manage administrative tasks. Its integration into dental education represents a transformative shift, introducing innovative approaches to teaching, improving clinical performance, and optimizing patient care. [3] Through technologies like personalized learning platforms, intelligent tutoring systems, and machine learning-based diagnostics, AI enhances educational outcomes by advancing diagnostic precision, accelerating skill development, and fostering clinical decision-making. [4] While this integration prepares future dental professionals for a digital healthcare era, it also presents challenges such as ethical considerations, curriculum adaptation, and equitable access. [5] This review

examines the applications, impacts, and challenges of incorporating AI into dental education, emphasizing its potential to redefine the field.

Inclusion Criteria

1. Articles published in English, as it is the primary language of the review.
2. Studies that directly address AI applications, impacts, or challenges in dental education, focusing on using AI to enhance learning, diagnostics, simulation training, patient management, and clinical decision-making within dental curricula.
3. Peer-reviewed articles, including systematic reviews, meta-analyses, empirical studies, case studies, and reviews that provide a comprehensive view of AI integration in dental education.
4. Articles published between 2000-2024

Exclusion Criteria

1. Articles published in languages other than English to maintain consistency in language analysis and interpretation.
2. Studies focused solely on clinical applications of AI in dentistry (e.g., patient treatment) without educational or training implications, as they fall outside the educational scope of the review.
3. Articles discussing technology or digital tools in general without specific emphasis on AI or machine learning applications in dental education.

Data collection

Conducted a comprehensive literature search across the following academic databases: PubMed, IEEE Xplore, ScienceDirect, and Google Scholar. Used keywords such as “Artificial Intelligence in dental education,” “AI in dentistry,” “AI applications in medical training,” “AI challenges in dental education,” and “dental training technology.” Developed a structured data extraction form

to capture essential details from each study, including publication details, study design, AI applications (e.g., diagnostic tools, simulation training), outcomes, benefits, and reported challenges.

Applications and Impacts of AI in Dental Education

The applications of AI in dental education are vast, enhancing both theoretical knowledge and practical training for students. AI-powered teaching tools and systems facilitate real-time analysis of extensive datasets, enabling students to understand oral health conditions better and improve diagnostic accuracy. For example, AI algorithms can analyze dental radiographs, assisting students in identifying cavities, gum diseases, and other pathologies with precision. This technological assistance provides invaluable practice in interpreting complex diagnostic data, reducing the need for extensive clinical hours and fostering early diagnostic skills. [6]

Furthermore, AI-driven virtual and augmented reality (VR/AR) environments allow students to practice complex procedures, such as root canals or extractions, in a risk-free setting. These immersive simulations enhance confidence, problem-solving abilities, and procedural accuracy by offering instant feedback and opportunities to correct mistakes. Unlike traditional training methods, these exercises provide immediate results, enabling learners to quickly adapt and improve, accelerating their skill development. Additionally, AI also supports personalized education through adaptive learning platforms that target individual skill gaps, tailoring the learning process to each student's needs. These platforms offer targeted suggestions to address specific challenges, making the learning experience more efficient and effective. By allowing students to progress at their own pace, this customized approach enhances learning outcomes and boosts motivation and engagement. [7]

Instructors benefit from AI's ability to analyze student performance and adapt teaching techniques

accordingly, fostering a more effective educational environment. Intelligent tutoring systems can simulate diverse clinical cases, enabling learners to develop decision-making skills in controlled settings. Additionally, AI aids students in treatment planning and diagnostic tasks by leveraging machine learning algorithms to analyze patient information, identify diseases, and recommend appropriate treatments. Exposure to such advanced diagnostic tools deepens students' understanding and prepares them for a technology-driven industry. [7]

By integrating AI into dental education, students gain practical skills, faster learning outcomes, and a greater ability to deliver precise, efficient, and high-quality patient care. This integration ultimately elevates the standards of the dental profession, ensuring future professionals are equipped to meet the demands of an evolving healthcare landscape. [6]

*A detailed overview of AI applications (Table 1) and their impacts (Table 2), as discussed in the literature from 2000 to 2024, is presented later in the paper.

Challenges of Integrating AI in Dental Education

Despite AI's numerous advantages in dental education, its integration presents several significant challenges that must be addressed for successful and equitable adoption (Table 3). One major obstacle is the high cost of acquiring and maintaining AI technologies, such as diagnostic tools, simulation software, and adaptive learning platforms, which may create disparities between well-funded institutions and those with limited resources. [8] Additionally, incorporating AI into existing curricula requires careful planning to ensure students utilize these tools effectively and understand their limitations. Educators must strike a balance between fostering reliance on AI for efficiency and emphasizing the importance of fundamental diagnostic and clinical skills. [9]

Another pressing concern involves data privacy and ethical issues, as AI systems often rely on large datasets implement robust data protection policies to prevent breaches and uphold confidentiality. [7]

Furthermore, over-reliance on AI poses risks, potentially undermining students' critical thinking and problem-solving abilities. Educators must teach students to view AI as a supportive tool rather than an ultimate decision-maker, ensuring human oversight remains central in clinical practice. [10]

Lastly, faculty training is essential to prepare educators to integrate AI effectively into their teaching methods, which adds another layer of complexity. Without addressing these challenges, there is a risk of creating an uneven educational landscape and compromising the holistic development of future dental professionals.

containing sensitive patient information. Institutions must

Conclusion

In conclusion, AI is transforming dental education by leveraging tools like personalized learning platforms, intelligent tutoring systems, and machine learning-driven diagnostics. These technologies accelerate student learning, boost diagnostic precision, advance practical skills, and improve clinical decision-making, resulting in significantly better educational outcomes. However, institutions must address the challenges of cost, equitable access, curriculum adaptation, ethical concerns, and resource allocation in order to implement AI in a way that complements traditional education rather than replacing essential skills. Strategic planning and thoughtful consideration are essential for the successful implementation of AI, ensuring its full potential is realized. As the dental profession evolves, AI is poised to become a vital tool in shaping the education of future dentists, equipping them to navigate the demands of a digital-driven healthcare environment.

Application Area	Description	Key Findings	References
Increased learning retention [5]	Meta-analysis on Artificial Intelligence in Dental Education.	AI personalized modules increased learning retention and engagement	Claman et al.,2024
Diagnostics and Radiology [11]	AI-driven diagnostic tools aid in interpreting radiographs and early detection of oral diseases.	AI tools improved diagnostic accuracy by 20% in detecting caries and periodontitis in dental students.	Zhu et al., 2023
Simulation-Based Training [12]	Virtual simulations provide realistic practice environments for complex procedures.	AI-enhanced VR and AR simulations led to a 30% improvement in procedural task performance, such as restorations and root canals.	Alsalleeh et al, 2024
Personalized Learning [13]	Adaptive AI platforms offer individualized pacing and targeted feedback.	Adaptive learning platforms led to a 25% increase in concept understanding amongst students using AI-	Siddiqui et al, 2021

		based learning.	
Diagnostic precision [14]	Artificial Intelligence can be used for precise diagnosis in Dentistry, Orthodontics, and Orthopaedics	Highlighted application of AI in diagnostic accuracy	Siddiqui et al.,2022
Modified dental training [15]	AI can pave the way for a comprehensive vision in the future of dentistry, showcasing numerous opportunities for significant advancements in oral health. AI addresses the Changing Face of Dentistry	Insights on how digital and AI tools are reshaping dental training	LeResche, 2022
AI in dental curriculum [4]	Adopting Artificial Intelligence in Dental Education can result in improved incorporation into the dental curriculum	Positive findings on curriculum adjustments for AI integration	Islam et al.,2022
AI in pedodontics [16]	AI provides valuable insights into pediatric dental health	Importance of AI in Analyzing Children's Dental Health	Mladenovic et al.,2023
Statistical application [17]	AI can be used as a statistical analysis software.	By W-J48 decision tree (DT) method helps in the classification of records	Moayeri et al.,2016
Teaching Purposes [18]	AI can lead to technological Innovations in Endodontics	Uncited study exploring VR and AI tools in endodontics for teaching purposes.	Shah et al.,2021
Enhanced technical skills [19]	VR and AI improved technical skill acquisition and engagement in orthodontic simulations	Experimental study on the Role of Virtual Reality (VR), AR, and AI in Orthodontics.	Gandedkar et al.,2021
Radiographic analysis [20]	AI aids in interpreting radiographic images and has enhanced diagnostic accuracy.	Used deep learning software to examine radiolucent lesions present periapical in panoramic radiographs by 24 craniofacial surgeons	Endres et al.,2020

Dental image diagnostics [21]	AI is useful in the evaluation of imagery and, hence, disease detection.	Convolutional Neural Networks (CNNs) were utilized in diagnostic-assistance systems, helping dentists to evaluate and document dental images more efficiently and swiftly.	Schwendicke et al.,2019
Remote Learning [22]	AI facilitates virtual classrooms and remote feedback.	Remote AI-powered classrooms were used widely for continuity in dental education during pandemic restrictions.	Thurzo et al, 2022
Application in periodontology [23]	AI can be used for diagnosing periodontally compromised teeth.	The prediction accuracy for extraction was 82.8% for premolars and 73.4% for molars.	Lee et al.,2018
Privacy and data handling [24]	Experimental VR simulations aid in understanding privacy and data handling	HIPAA Privacy Rule and the EU GDPR in Dental Education were considered	Tovino, 2017
AI and Dental Implantology [17]	AI can help surgeons gain a better idea of implant success before surgery.	The success of implant placement was determined using W-J48 and Neural Network models.	Moayeri et al.,2016
Classification of oral malodor [25]	AI can prove to be helpful in screening saliva for oral odor.	Oral malodor was determined from saliva, using methyl mercaptan as an indicator. It can then be classified based on the concentrations of methyl mercaptan.	Nakano et al.,2014
Application in Clinical Dentistry [26]	Took the help of ANN to locate the apical foramen and working length accurately	AI measured the working length of teeth during Root canal treatment accurately by 96%	Saghiri et al.,2012
Diagnosing internal derangement in TMJ [27]	Applying artificial intelligence for diagnosing subtypes of TMJ disorders	ANN diagnosed cases with unilateral and bilateral anterior disc displacement	Bas et al.,2011

	might serve as an ancillary diagnostic aid in dental practice	with reduction as well as without reduction with high accuracy	
Treatment planning [28]	AI predicted individual cases for better prognosis of treatment plans.	Tested an AI model to give prediction if tooth extraction is needed or not to achieve a good outcome in a given orthodontic case	Takada et al.,2009
Radiographic diagnosis [29]	AI leads to promising improvement in the diagnosis of proximal caries on the radiograph	To measure the efficacy, a comparison was made between the examiners' diagnoses and the artificial multilayer perceptron neural networks. AI successfully determined the proximal caries on radiographs	Devito et al.,2008
Forensic Odontology [30]	Dental features can be used for the postmortem identification of humans	A prototype automated dental identification system was used for high-level and low-level image feature extraction for postmortem identification using tooth-to-tooth matching, probability models, and adaptive search techniques	Nassar et al.,2008
Detection of caries [31]	AI can be trained to detect and interpret carious lesions	The artificial neural network was used for the detection of artificial caries, but the depth of caries could not be determined	Kositbowor nchai et al. 2006
Used in the analysis of digital morphology [32]	AI helps to make blueprints useful in solving morphological problems	This pilot study utilized an unsupervised learning algorithm to analyze molar sets from primates, demonstrating that the artificial neural network approach provided more biologically meaningful insights than traditional	King et al.,2005

		methods while identifying hierarchical clusters consistent with primate systematics.	
Radiographic accuracy [23]	Took previous intraoral periapical radiographs (IOPAR)	The software's performance was assessed against three oral radiologists. Using random sampling, the CNN achieved high accuracy on the validation data	Lee et al.,2018
Identification of oral bacteria [33]	Lactobacilli in plaque can be identified using neural networks	Bacterial data from dental plaque demonstrated an identification accuracy of over 90%	Yong et al., 2002
Diagnostic accuracy [34]	Using AI software, the accurate diagnosis of periapical diseases can be determined	Assessed the diagnostic accuracy of an artificial intelligence system using the deep convolutional neural network method for identifying periapical pathosis in Cone-Beam Computed Tomography (CBCT) images. The AI system successfully achieved a detection reliability rate of 92.8%.	Carmody et al.,2001
Approximation of dental age [35]	The dental age can help in measuring and fixing occlusal harmony and mastication.	Neural networks helped estimate the dental age with accuracy without exposing patients to x-ray radiations.	Ozaki et al.,2000

Table 1: Applications of AI in Dental Education in the Literature Review

Impact Area	Description	Key Findings	References
Improved Procedural Skills [36]	Simulation-based AI training reduced risks and improved confidence in practical procedures.	Students using AI simulations achieved proficiency 30% faster and performed better in procedural tasks.	Elendu et al., 2024
Self-Directed Learning [37]	AI allowed for customized learning experiences, leading to more engaged and self-directed student learning.	Adaptive AI tools improved student engagement and retention rates, creating more effective learning environments.	Smith et al., 2020
Enhanced Diagnostic Skills [38]	Students developed confidence and accuracy in interpreting radiographs using AI.	AI-driven diagnostic tools allowed early disease detection and analysis, significantly enhancing diagnostic skills.	Zhu et al., 2024
Accessibility during pandemic [39]	AI-based remote learning provided continuity in education during global disruptions.	AI-powered virtual classrooms promoted accessible learning, especially during pandemic constraints.	Ara Shaikh et al, 2022
Remote Learning [23]	Digital education tools with AI increased adaptability in remote learning contexts.	The article discusses Dental Care and Education for those Facing SARS-CoV-2 Variants	Thurzo et al.,2022
Customization in workflow [40]	AI-enhanced personalized workflows in Reconstructive Dentistry	Customizable workflows via AI improved diagnostics in reconstructive dentistry	Joda et al.,2022
Procedural Guidance [41]	Discussed major Organizational Development Framework for AI Integration	AI tools improved diagnostic accuracy and procedural guidance	Tadinada et al.,2023
Enhanced skills in training settings [42]	Review of Artificial Intelligence and Digital Tools in Dentistry.	AI tools led to skill improvement in immersive training settings	Saghiri et al.,2021

Massive subject engagement [43]	Review on The Impact of Digital Technologies in Oral and Maxillofacial Surgery	High student engagement with AI-based models in VR simulations was observed	Tekkeşin et al.,2021
Greater adaptability [44]	Attitudes and Perceptions of Dental Students were positively inclined toward the use of Artificial Intelligence	Students using AI showed greater adaptability and higher engagement in learning modules	Yüzbaşıoğlu et al.,2020
Positive reception towards AI [45]	AI proved beneficial for procedural training	Focused on the quality of Information on YouTube about Artificial Intelligence in Dentistry	Cesur et al.,2020
Prediction of treatment longevity [46]	The AI software enables us to identify the most appropriate restorations and provides insights into their durability.	The anticipated lifespan of the proposed restoration is derived by averaging the tooth longevity from the retrieved cases.	Aliaga et al.,2015
Diagnostic Accuracy [47]	Predictive, Preventive, Personalized, and Participatory Periodontology; the 5Ps age was studied in a quasi-experimental study	AI-assisted diagnostic tools improved diagnostic accuracy in radiology for periodontists	Cafiero et al.,2013
Prediction of recurrent oral ulcerations [48]	ANN was established, incorporating predisposing factors to determine the recurrence of oral aphthous ulcers	Genetic algorithm- ANN was used in the prediction of Recurrent aphthous ulcers using a set of data.	Dar-Odeh et al.,2010

Table 2: Impact of AI on Dental Education in the Literature Review

Challenge Area	Description	Key Findings	References
Data Privacy Concerns [49]	Concerns over ethical data use and protection of patient information.	Data protection and ethical protocols were identified as essential to ensure compliance with regulations and maintain student and patient confidentiality.	Dashti et al, 2024
Over- reliance on AI [50]	Potential for reduced critical thinking and foundational skills due to dependence on AI assistance.	Excessive reliance on AI could reduce manual skill development and critical analysis among students, with educators recommending balanced use of AI.	Al-Zahrani et al., 2024
Faculty Training Needs [49]	The need for educators to be trained in AI tools to facilitate effective integration into curricula.	Faculty training is essential but resource-intensive, as institutions require updated curricula and trained personnel to maintain AI-supported learning environments.	Dashti et al, 2024
High Costs [51]	Initial and maintenance costs of AI tools limit adoption.	60% of surveyed institutions indicated cost as the primary barrier to adopting AI technologies in dental education.	Marín-Rodríguez et al., 2023
Lack of framework for ethical training in AI applications [52]	Focused on RoboEthics in COVID-19: A Case Study in Dentistry	Roboethics highlighted ethical considerations in AI applications in dental education	Maddahi et al.,2021
Limited focus on long-term retention and practical application [53]	Centered on Chances and Challenges of Artificial Intelligence in Dentistry	AI personalized modules increased learning retention and engagement	Schwendicke et al., 2020

Table 3: Challenges of Integrating AI in Dental Education in the Literature Review

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