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Artificial Intelligence and Smart Technologies in Dental Education: Applications, Challenges, and Ethical Considerations

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Abstract

Background: Recent advances in artificial intelligence (AI) and smart technologies are transforming dental education, providing new opportunities for innovative learning experiences and the development of clinical skills. This review examines the applications, challenges, and ethical considerations of AI and smart technologies within dental education, focusing on their effects on educational quality and student preparedness.

Materials and Methods: This narrative review is based on a comprehensive literature search conducted in PubMed, Scopus, Web of Science, and ERIC databases for articles published up to April 2025 in English or French. The search strategy included keywords related to artificial intelligence, smart technologies, dental education, virtual reality, augmented reality, ethics, and associated challenges. Selection of relevant studies was performed independently by two reviewers.

Results: The integration of AI and smart technologies has significantly enhanced learning processes, clinical decision-making, and practical skill acquisition in dental education. AI-based systems, particularly in radiographic interpretation, have improved diagnostic accuracy and consistency while reducing human error. Adaptive learning tools and automated assessments provide personalized education tailored to individual student needs. Virtual and augmented reality technologies offer interactive and safe simulation environments, further strengthening practical training. However, challenges remain, including the need for continuous curriculum updates, faculty training, adequate technological infrastructure, and careful attention to ethical issues such as data privacy, algorithmic bias, and equitable access. Addressing these challenges is crucial for the responsible and effective use of AI in dental education.

Conclusion: The integration of artificial intelligence and smart technologies has enhanced educational quality, diagnostic accuracy, and clinical skills in dental students. However, fully realizing these benefits requires ongoing curriculum updates, faculty training, robust infrastructure, and adherence to ethical principles. Emphasizing these elements is vital for the responsible and sustainable use of AI in dental education.

Key Words: Artificial intelligence, Dental education, Ethical considerations, Smart technologies.

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1- INTRODUCTION

Artificial intelligence (AI) and smart technologies are reshaping dental education by providing advanced tools for diagnostics, treatment planning, and personalized learning. Their adoption requires a comprehensive understanding of both practical benefits and ethical challenges (1). AI is a rapidly evolving field within computer science that enables machines to perform tasks such as learning, reasoning, and decision-making, often mimicking human intelligence. In recent years, AI has gained prominence in dental education by offering advanced tools for clinical decision-making, diagnostic imaging, and individualized learning experiences. For example, AI systems used in radiographic interpretation have been shown to improve diagnostic accuracy and consistency, reduce human error, and enhance the quality of clinical education (1, 2).

Furthermore, technologies like automated facial recognition can assess student comprehension and adapt educational content to individual needs, further personalizing the learning process (3, 4). Alongside AI, immersive technologies such as virtual reality (VR) and augmented reality (AR) are transforming dental education. VR creates interactive simulated environments where students can safely practice clinical procedures, while AR overlays digital information onto real-world settings, enriching hands-on training. These technologies engage multiple senses, facilitate skill acquisition, and help overcome limitations of traditional educational methods (4–6).

The integration of AI, VR, and AR into dental curricula is increasingly emphasized by dental schools worldwide, with the goal of equipping students with skills necessary for future clinical practice (7, 8). However, this transition also presents challenges, including the need for updated curricula, ongoing faculty training, and careful consideration of ethical issues such as data privacy, algorithmic bias, and equitable access (9–11). Addressing these challenges is essential to ensure that the adoption of smart technologies enhances educational quality and prepares students for the evolving landscape of dental practice.

This study aims to comprehensively review and synthesize scientific evidence on the applications, challenges, and ethical considerations of artificial intelligence and smart technologies in dental education, focusing on their impact on educational quality and student preparedness for future advancements in the field.

2- MATERIALS AND METHODS

2-1. Study Design

This research was conducted as a narrative review. A systematic search was performed to identify relevant articles published in English or French up to April 2025. To ensure rigor and minimize bias, two independent reviewers conducted the article selection process. The search strategy employed keywords related to “artificial intelligence,” “smart technologies,” “virtual reality,” “augmented reality,” “dental education,” “ethics,” and “challenges.” Major international databases—including PubMed, Scopus, Web of Science, and ERIC—were comprehensively searched. In addition, reference lists of selected articles were manually screened to capture further pertinent studies.

2-2. Inclusion and Exclusion Criteria

Studies were included if they:

- Addressed the applications, challenges, or ethical considerations of artificial intelligence, virtual reality, or augmented reality in dental education;
- Were published in English or French;
- Provided data or critical discussion relevant to dental education.

Studies were excluded if they:

- Were unrelated to dental education;
- Did not focus on AI, virtual reality, or augmented reality;
- Were published in languages other than English or French;
- Lacked empirical data or scientific analysis (e.g., editorials, commentaries).

2-3. Data Collection and Synthesis

Titles and abstracts were independently screened by two reviewers. Full texts of potentially eligible studies were then evaluated for inclusion. Disagreements were resolved through discussion or consultation with a third reviewer. Data extraction was performed using a standardized form to collect details such as study design, target population, technologies examined, educational outcomes, challenges encountered, and ethical considerations. Due to the heterogeneity of the studies, findings were synthesized narratively.

2-4. Ethical Considerations

As this study is a narrative review based exclusively on published literature and does not involve new data collection from human subjects, formal ethical approval was not required. Nonetheless, the review was conducted following ethical standards, including maintaining scientific integrity, transparency in reporting, and respecting intellectual property rights.

3- RESULTS

Artificial intelligence (AI) is emerging as a transformative force in dental education, enhancing diagnostic accuracy, promoting adaptive and personalized learning, and preparing students for the technological advances of modern dentistry. However, to fully realize these benefits, dental schools must address ethical, practical, and infrastructural challenges to ensure AI is implemented responsibly and equitably. The key findings of this review are summarized in **Table 1**, which provides an overview of the main domains of AI integration in dental education, their outcomes, and supporting references.

3-1. Enhancement of Clinical Decision-Making and Diagnostics

AI-powered systems, particularly convolutional neural networks, have markedly improved the accuracy and consistency of radiographic interpretation, thereby reducing human error and facilitating more reliable diagnoses (1, 2). These technologies enable students to analyze complex clinical images and datasets, supporting the development of critical thinking and analytical skills. AI-driven clinical decision support systems (CDSS) further assist students in making evidence-based decisions, enhancing their diagnostic and therapeutic planning capabilities (12–14).

3-2. Adaptive Learning and Automated Assessment

AI facilitates adaptive learning environments by employing tools such as automated facial recognition to monitor student engagement and comprehension in real time. These systems provide personalized feedback, identify individual strengths and weaknesses, and tailor educational content to optimize each student’s learning trajectory (3, 4).

3-3. Simulation-Based Training with Virtual and Augmented Reality

The integration of AI with virtual reality (VR) and augmented reality (AR) technologies has created immersive, interactive simulation environments that surpass traditional dental education limitations. These platforms allow students to safely and repeatedly practice clinical procedures in controlled settings, fostering

deeper understanding and skill mastery (4–6).

3-4. Curriculum Development and Industry Collaboration

Dental schools are actively updating curricula to incorporate AI and smart technologies, ensuring graduates are well-equipped for future clinical practice (7, 15). Specialized courses focusing on AI applications in diagnostics and treatment planning are being developed (1). Collaborations with technology companies provide access to cutting-edge tools, real-world case studies, and research opportunities, while workshops and seminars with industry experts further enhance competencies among students and faculty (3, 4).

3-5. Ethical and Practical Challenges

The integration of AI in dental education poses several ethical and practical challenges, including data privacy and security, equity and access, professional integrity, and the need for ethical training on AI's limitations and biases (9, 10, 16, 17).

3-6. Implementation Barriers and Solutions

Successful AI integration requires addressing barriers such as faculty development and resource allocation through targeted solutions (15, 18). Proactively addressing these barriers accelerates technology adoption and enhances educational outcomes by equipping students with the skills needed to thrive in an increasingly digital clinical environment (19, 20).

Table-1: Key Findings on the Integration of Artificial Intelligence and Smart Technologies in Dental Education.

Domain	Main Findings	References
Clinical Decision-Making & Diagnostics	- AI, especially convolutional neural networks, improves accuracy and consistency of radiographic interpretation - Reduces human error - Supports critical thinking and analytical abilities - CDSS assist evidence-based diagnostic and therapeutic planning	(1), (2), (12–14)
Adaptive Learning & Automated Assessment	- AI-driven tools (e.g., facial recognition) enable real-time monitoring of engagement and comprehension - Personalized feedback and content tailoring - Identification of individual strengths/weaknesses for optimized learning	(3), (4)
Simulation-Based Training (VR/AR)	- AI integration with VR/AR platforms creates immersive, interactive simulation environments - Repetitive, safe clinical practice fosters deeper skill mastery and understanding - Overcomes limitations of traditional training	(4–6)
Curriculum & Industry Collaboration	- Curricula are updated to include AI and smart tech - Specialized AI-focused courses developed - Partnerships with industry provide access to tools, case studies, and research opportunities - Workshops and seminars with experts enhance competency	(1), (3), (4), (7), (15)
Ethical & Practical Challenges	- Data privacy and security require robust protections - Equity and access concerns must be addressed to avoid widening disparities - Professional autonomy should be preserved: AI as complement, not replacement - Education on ethical, legal, and bias-related issues is crucial	(9), (10), (16), (17)
Implementation Barriers & Solutions	- Faculty need continuous development and training - Investment in infrastructure and resources is essential for successful adoption - Overcoming these barriers improves educational outcomes in the digital clinical environment	(15), (18-20)

Abbreviations: AI: Artificial Intelligence, CNN: Convolutional Neural Network, CDSS: Clinical Decision Support Systems, VR: Virtual Reality, AR: Augmented Reality.

4- DISCUSSION

The integration of artificial intelligence (AI) and smart technologies into dental education has fundamentally transformed the landscape of teaching, learning, and professional development for future dentists. Unlike traditional approaches, AI provides advanced tools for more accurate radiographic interpretation and improved clinical decision-making, thereby enhancing the overall quality of education (1, 2, 20–22). These technologies not only reduce human error but also enable personalized treatment planning and evidence-based education by analyzing complex data and delivering customized feedback (23, 24).

Automated tools such as facial recognition systems for performance analysis and eye-tracking enable more precise and adaptive assessment of student learning, allowing educators to tailor instruction to individual needs (3, 4, 25). Additionally, virtual and augmented reality technologies create interactive simulation environments that provide students with opportunities for repeated, risk-free practice, fostering the development of practical skills and confidence (5, 26, 27).

At the curricular level, dental schools are increasingly incorporating AI-based education and collaborating with industry to evaluate and develop innovative products (15, 20). These collaborations not only improve educational quality but also provide students and faculty access to state-of-the-art tools and research opportunities, thereby fostering enhanced learning outcomes and clinical preparedness (15, 24).

Despite these opportunities, significant challenges remain. A major concern is the risk of students becoming overly reliant on AI outputs, potentially undermining their independent clinical judgment (7). Algorithmic bias and the lack of transparency in AI decision-making processes can also negatively impact educational quality and fairness in patient care (9, 27). Moreover, protecting patient data privacy and upholding ethical standards—including educating students about the limitations and responsibilities associated with AI use—are essential components of responsible integration (9, 10, 16).

Ultimately, the successful integration of AI and smart technologies into dental education depends on continuously updating curricula, providing ample opportunities for faculty professional development, and ensuring the necessary technological infrastructure is in place (7, 15, 28). Active collaboration with industry and leveraging interdisciplinary experiences can accelerate this process, ensuring that students not only become familiar with the latest technological advancements but also develop the ability to use these tools responsibly and critically (1–4, 20). In this way, dental education can keep pace with technological progress and produce a new generation of dentists equipped with both clinical skills and digital literacy, as well as professional responsibility (15, 20, 27).

5- CONCLUSION

The integration of artificial intelligence and smart technologies is fundamentally reshaping dental education, moving it beyond traditional models toward a more dynamic and personalized learning environment. These innovations provide dental students with advanced tools for clinical decision-making, more accurate diagnostics, and individualized treatment planning, while immersive technologies like virtual and augmented reality create interactive, risk-free spaces for developing practical skills. As a result, the overall quality of dental education and students' readiness for the evolving demands of clinical practice have significantly improved.

However, realizing the full potential of these technologies requires ongoing curriculum updates, continuous faculty development, and robust infrastructure. Effective collaboration with industry partners is essential to ensure access to the latest tools and real-world applications. At the same time, ethical considerations—such as data privacy, algorithmic bias, equitable access, and the preservation of human judgment—must remain central to educational strategies. By balancing technological innovation with ethical responsibility and critical thinking, dental schools can prepare a new generation of dentists who are not only clinically competent but also digitally literate and well-equipped for a technology-driven future.

6- CONFLICT OF INTEREST: None.

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