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Artificial Intelligence in Dentistry: Applications, Ethics, and Future Perspectives

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Abstract

Artificial Intelligence (AI) is transforming various domains of healthcare, including dentistry. AI-powered technologies are enhancing diagnostic accuracy, treatment planning, and patient management. This article provides an overview of AI applications in dentistry, including radiographic interpretation, disease prediction, robotic-assisted procedures, and personalized treatment strategies. The challenges and future potential of AI in dentistry are also discussed in detail. With an emphasis on how AI is shaping modern dental practices, this article explores the profound impact of AI on improving efficiency, precision, and patient outcomes.

Keywords: Artificial Intelligence, Dentistry, Machine Learning, Deep Learning.

Introduction

Artificial Intelligence (AI) refers to the simulation of human intelligence by machines, particularly computer systems, to perform tasks that typically require cognitive functions such as learning, reasoning, problem-solving, and decision-making. AI encompasses several subfields, including machine learning, deep learning, and natural language processing, each of which plays a unique role in automating and optimizing various aspects of healthcare and dentistry[1].

Machine learning, a subset of AI, involves training algorithms to recognize patterns in data and make predictions or decisions without explicit programming. Deep learning, a more advanced form of machine learning, utilizes artificial neural networks to process complex datasets with remarkable accuracy. Natural language processing enables machines to understand and interact with human language, making AI-driven chatbots and virtual assistants highly effective in patient communication[2].

The advent of AI has brought significant advancements to dentistry, improving efficiency, precision, and patient outcomes. AI is particularly valuable in addressing diagnostic challenges and streamlining treatment protocols. As digital dentistry continues to evolve, AI-

driven solutions are revolutionizing patient care by reducing human error and optimizing treatment strategies[3]. The integration of AI within the field of dentistry also paves the way for more accurate disease detection, customized treatment planning, and even robotic-assisted procedures, ensuring a seamless transition into a more advanced era of dental healthcare[4,5].

AI technologies are increasingly being integrated into various aspects of dentistry, ranging from diagnostic imaging and predictive analytics to robotic surgery and patient engagement[2,5]. AI-powered diagnostic tools assist clinicians in interpreting radiographs, identifying early signs of oral diseases, and predicting treatment outcomes with enhanced precision[2,5-7]. Additionally, AI-driven robotic systems are being developed to improve the accuracy of dental implant placement and surgical procedures, minimizing complications and improving postoperative recovery[8-12].

Despite its immense potential, the integration of AI into dentistry presents challenges related to data privacy, ethical considerations, cost, and adoption within existing clinical workflows[2,13-15]. Overcoming these challenges will require collaboration between AI developers, dental professionals, regulatory bodies, and policymakers to ensure safe and effective implementation[13,15].

AI Applications in Dentistry

AI technologies are being applied in dentistry in diverse ways, dramatically expanding the capabilities of clinicians. The most prominent uses include diagnostic imaging analysis, predictive analytics for patient care, enhancements in restorative dentistry, robotic assistance in surgery, and orthodontic treatment planning, among others. This section elaborates on these applications and how they are shaping dental care.

A. Diagnostic Imaging

One of the earliest and most widespread applications of AI in dentistry is the analysis of diagnostic images such as radiographs (X-rays), cone-beam CT scans, and intraoral photographs[15-18]. AI systems can be trained to recognize patterns of disease on these images with high accuracy. For instance, deep learning algorithms (particularly convolutional neural networks, CNNs) have been developed to automatically detect dental caries, periapical lesions, periodontal bone loss, root fractures, and other pathologies on radiographs[15,18]. Some studies report that AI can identify early lesions or cavities on X-rays as accurately as experienced dentists, and sometimes even outperform them in consistency[19-21]. Notably, Schwendicke et al. compared an AI algorithm to human dentists for detecting proximal tooth decay on radiographs and found the AI approach to be more cost-effective and equally reliable[22].

Regulatory bodies have begun to recognize the value of such tools. In fact, an AI software platform has been cleared by the U.S. Food and Drug Administration (FDA) to aid in radiographic diagnosis by automatically outlining cavities and quantifying bone loss on dental X-rays[23]. These AI-driven image annotation systems act as a kind of “second pair of eyes,” highlighting areas of concern (e.g. a suspicious shadow that might indicate decay or a tumor) so that the dentist can investigate further. Importantly, the final diagnosis still rests with the dentist – the AI flags potential problems, but does not make definitive diagnoses on its own[2,4,6,24]. By catching subtleties that a busy clinician might overlook and by processing images rapidly, AI-powered diagnostic imaging can lead to earlier detection of dental diseases and more informed treatment decisions, ultimately improving patient outcomes[14,25].

B. Predictive Analytics

Beyond image recognition, AI is also transforming dentistry through predictive analytics – the use of data to forecast future outcomes or risks[26-27]. Dental practices accumulate vast amounts of information about patients (medical histories, treatment records, oral health metrics, etc.), and machine learning can analyze these data for patterns not obvious to humans[28]. For example, AI models can be trained to predict which patients are at higher risk for developing dental caries or periodontal disease by analyzing combinations of factors like diet, oral hygiene habits, genetics, and socio-demographic data[15,19,29,30]. Similarly, predictive models can estimate the likely success or failure of certain treatments[31]. In orthodontics, for instance, AI has been used to help determine optimal treatment plans and predict treatment outcomes, such as how a patient's facial profile might change after orthodontic intervention[32,33]. In one study, a machine learning approach was able to predict the need for orthodontic treatment by analyzing patient records and diagnostic indices[34].

Predictive analytics in dentistry also extends to prognosticating the longevity of restorations or the prognosis of oral diseases[24,35,36]. For example, algorithms have been developed to forecast the chances of restoration failure (such as the debonding of a crown or veneer) based on factors like materials, bite force, and patient habits[2,35]. By leveraging AI in this way, dentists can adopt a more preventive and personalized approach: interventions can be tailored to a patient's predicted risks (for example, intensifying preventive measures for a patient likely to develop gum disease) and treatment plans can be adjusted based on the likelihood of various outcomes[2,4,6,27,30]. While still an emerging field, predictive analytics holds great promise for improving decision-making in dentistry by providing data-driven risk assessments and outcome predictions.

C. Restorative Dentistry

AI is making significant inroads in restorative dentistry – the branch of dentistry concerned with repairing or replacing damaged teeth (including fillings, crowns, bridges, dentures, and implants)[8,9,11,12,15,31,35,37,38]. One application is in Caries detection and management[2,35,37,39,40]: as noted, AI image analysis can identify cavities early, which directly informs restorative treatment decisions (e.g., whether a filling is needed). But AI's role in restorative dentistry goes further. In digital dentistry workflows, AI is used to enhance computer-aided design and manufacturing (CAD/CAM) of restorations[41–43]. For instance, modern intraoral scanners often incorporate AI algorithms to improve the scanning process. These systems can guide the clinician by indicating areas missed during a scan and automatically remove artifacts or unnecessary data, yielding a cleaner digital impression[44–46]. AI can then help delineate the margins of a tooth preparation (the edges of the area where a crown will fit) and even propose a preliminary design for the crown or restoration that mimics the natural tooth anatomy. This speeds up the design process and ensures a more accurate fit for the final prosthesis[47,48].

Another area is shade matching and material selection. Selecting the correct color shade for a dental restoration is crucial for aesthetics, yet can be subjective. AI systems have been developed to analyze images of a patient's teeth and assist in selecting the best matching shade of porcelain or composite, improving the aesthetic outcome. Additionally, as mentioned earlier, AI predictive models can assess factors that might affect a restoration's durability[49,50].

In prosthodontics, AI is being explored to design dentures and implants[2,8–12,31,35,37,39,45,46]. AI-driven software can analyze edentulous patients' jaw scans and even predict facial appearance changes, helping in the design of dentures that restore proper facial support(50–53). Overall, AI contributes to restorative dentistry by improving diagnostic precision, optimizing design and fabrication processes, and enhancing the longevity of restorations, leading to more efficient workflows and potentially better outcomes for patients[35,54–56].

D. Robotic Surgery

Robotics in dentistry represents a cutting-edge application of AI and automation, particularly in the field of oral and maxillofacial surgery and implantology[8–12]. A prime example is the Yomi robotic system, which is the first (and currently only) FDA-cleared robot for dental surgery[57,58]. Yomi is a computer-controlled robotic arm that assists clinicians in dental implant placement. Through detailed preoperative planning and real-time guidance, the robot helps the surgeon in drilling and inserting implants at the exact planned location, angle, and depth. During surgery, Yomi provides haptic (touch) feedback and visual cues, effectively "locking in" the drill's position so that deviations from the plan are minimized. This ensures a high degree of precision, preventing errors such as drilling too deep and risking nerve injury. Since its introduction, Yomi has been used in tens of thousands of implant procedures, improving consistency and confidence in implant surgeries[57–59].

Robotic assistance is not limited to implants. Research prototypes have explored robot-guided tooth preparations, endodontic surgeries, and even robotic aid in orthognathic (jaw) surgery[12,59]. In one advanced example, a soft-tissue robotic manipulator has been used in transoral laser surgery, demonstrating the potential of robotics for delicate intraoral procedures[60–62]. It is important to note that current dental robots, including Yomi, are not autonomous – they do not make independent decisions or operate without human control [57–59]. Instead, the dentist or surgeon remains in charge; the robot serves as an assistive tool to enhance the surgeon's precision and reduce fatigue[63]. By taking over some of the physical execution (under guidance), robots can allow clinicians to focus more on strategic decisions during surgery[63]. As robotic technology and AI algorithms continue to advance, we may see a broader adoption of robots in dentistry for tasks like tooth extractions or periodontal surgeries[8,12,57,58]. For now, robotic surgery in dentistry stands as a testament to how AI can collaborate with human skill to achieve outcomes that might be difficult to attain with human hands alone.

E. Orthodontics

Orthodontics, which deals with the correction of misaligned teeth and jaws, has also embraced AI to augment diagnosis and treatment planning[33,64,65]. Traditionally, orthodontic planning requires tedious analysis of diagnostic records – including cephalometric radiographs (side-view head X-rays) where the orthodontist manually identifies anatomical landmarks and measurements[66]. AI has greatly accelerated this process: deep learning models can automatically detect and annotate cephalometric landmarks on X-rays with high accuracy, saving practitioners considerable time. By automating the analysis of radiographs and 3D scans, AI helps orthodontists evaluate malocclusions (bite problems) more efficiently and consistently[67–69].

In treatment planning, AI is used to predict the outcomes of orthodontic interventions[32–34,64]. Machine learning algorithms can simulate how a patient's dentition and facial structure might change after braces or aligners[2,67–72]. For example, one application involves using neural

networks to predict post-treatment facial aesthetics or the movement of teeth, given pre-treatment data[73]. Such tools can assist in deciding whether tooth extractions are necessary or how long treatment might take by comparing numerous similar cases in their database[73]. Additionally, AI can help design custom orthodontic appliances: companies have developed AI-driven software to plan the sequence of tooth movements in clear aligner therapy, optimizing each step to move teeth efficiently[65,74,75].

Orthodontic AI systems can also improve patient monitoring. Some smartphone applications use AI to analyze photos of patients' teeth taken at home, detecting if an aligner isn't fitting well or if tooth movement is off track, allowing timely interventions by the orthodontist[3,33,65,75]. Overall, AI in orthodontics serves as an "ideal tool" for handling complex variables and large data in treatment planning. It can provide a more data-informed roadmap for moving teeth, thereby potentially improving treatment outcomes and reducing the total time a patient spends in braces[76]. As with other fields, these AI tools work in tandem with the clinician's expertise – final decisions are made by orthodontists, who incorporate AI findings into their clinical judgment.

Other Emerging Applications

In addition to the areas above, AI is being explored in virtually every dental specialty[2,16,23]. In periodontics, for instance, AI algorithms have been trained to interpret periodontal charts and radiographs to diagnose gum disease and even predict progression of bone loss[77–80]. In oral pathology, researchers have used AI to analyze histopathology slides and intraoral images to detect oral cancer and precancerous lesions at an early stage, aiding pathologists in identifying malignant changes[24,81]. Endodontics (root canal therapy) stands to benefit from AI systems that can read 3D scans to locate tiny root canals or detect periapical infections that might be missed by the human eye[82,83]. There are also administrative and educational applications: AI chatbots can handle patient inquiries or scheduling, and dental schools are experimenting with AI tutors and simulators that help train students in diagnosing cases or performing virtual procedures[84,85].

Collectively, these examples underscore that AI's impact on dentistry is broad and continually evolving. From enhancing clinical imaging to automating routine tasks, AI acts as a force multiplier for dental professionals – extending their capabilities and providing new insights[2,49]. However, with these powerful tools come new challenges and responsibilities, particularly concerning the ethics and limitations of AI in a healthcare setting. The following sections will delve into those considerations, as well as the broader question of AI's role relative to human dentists.

Ethical Concerns and Limitations

While AI offers exciting opportunities in dentistry, it also raises important ethical questions and practical limitations that must be addressed. As dental practitioners begin to rely on AI tools for diagnosis and treatment, they need to remain aware of issues such as data privacy, algorithmic bias, diagnostic errors, and the implications for doctor-patient interactions[2,3,6,86]. This section discusses these concerns, along with the inherent limitations of current AI systems.

A. Data Privacy and Security

AI systems in dentistry often require large amounts of patient data – including medical histories, imaging data, and treatment plans – to train algorithms and make accurate predictions[2,6,63,85–87]. This reliance on data brings forth serious concerns about patient privacy and data security. Dental records contain sensitive personal health information that must be protected under laws like

HIPAA[88–91]. If these data are uploaded to cloud-based AI services or shared with tech companies for algorithm development, there is a risk of unauthorized access or breaches. Ensuring robust encryption and informed consent for any data used in AI development is essential[2]. Recent discussions have highlighted that using open-source or public AI tools (for example, generic machine learning APIs or even large language models like ChatGPT) with patient data can be perilous, as these tools might integrate the data into their knowledge base without proper safeguards[92]. Thus, dental professionals must be cautious to use only HIPAA-compliant, secure AI platforms for clinical purposes[2,91].

Another aspect of data ethics is ownership and usage[93–95]. When dental practitioners contribute patient data to improve an AI system, questions arise: Who owns the improved algorithm or the insights generated? There is also concern about intellectual property – if a practitioner develops a novel treatment approach and inputs it into an AI system, could that idea be disseminated without credit?[93–95] These issues are prompting the development of guidelines and regulations to ensure that AI adoption in dentistry does not compromise patient confidentiality or practitioner rights. Dental AI systems should be transparent about how data are used, and practitioners should educate patients about any AI involvement in their care, obtaining consent when appropriate[2,14]. In summary, maintaining trust requires that the integration of AI into dental practice upholds the same standards of privacy and security that patients expect when confiding in a human dentist.

B. Accuracy, Bias, and Liability

The accuracy of AI algorithms in dentistry is a critical concern[2,15]. An AI system is only as good as the data it was trained on and the assumptions built into its design. If the training data are flawed, incomplete, or unrepresentative, the AI's recommendations could be incorrect or biased[96]. For example, if an image analysis AI is trained mostly on radiographs from adults, it may underperform when analyzing children's X-rays, potentially missing pediatric conditions[97]. There have been well-publicized instances outside dentistry where AI image recognition demonstrated racial bias due to skewed training data[98]. In a dental context, bias might mean the AI is less accurate for certain patient groups (e.g., certain ethnicities, ages, or those with uncommon conditions), which is an ethical and clinical problem[26,27]. Researchers have noted that the fast advancement of dental AI has not always been matched by rigorous incorporation of AI Ethics considerations, raising the risk of reinforcing existing healthcare inequalities if biases are not addressed[2].

Moreover, no AI is infallible – there is always a risk of false positives or false negatives in diagnosis. Over-reliance on an AI's judgment could lead to misdiagnosis. For instance, an AI might flag a healthy area as a cavity (false positive), potentially leading to unnecessary intervention, or it might miss a subtle lesion (false negative) that a skilled human would catch[19]. Dentists must therefore use AI as an aid, not an absolute authority[2,5,15,19]. Ethically, the principle of "non-maleficence" (do no harm) means that dentists should validate AI findings with their own examination to avoid harm from AI errorsm[2,99,100]. This also ties into the question of liability: if an AI tool fails to detect a disease or suggests an incorrect treatment and a patient is harmed as a result, who is responsible – the dentist using the tool, or the software developer, or both?[100] Currently, the responsibility still lies largely with the practitioner, as they are expected to exercise professional judgment[2,100]. This means dentists must be adequately

trained to understand the output of AI systems and recognize when it may be wrong.

To mitigate these issues, validation of AI tools through clinical trials and regulatory oversight is crucial before widespread adoption[101]. Many AI dental products undergo rigorous testing to achieve regulatory clearance, but even after approval, continuous monitoring of their performance in diverse patient populations is needed[2,5,102]. The concept of explainability is also important: AI systems should ideally provide some rationale for their recommendations (for example, highlighting which features of an X-ray led to a diagnosis) so that clinicians can judge whether it makes sense[103]. As guidelines for "trustworthy AI" emphasize, transparency and explainability help practitioners and patients trust the technology. In practice, dentists integrating AI must remain critical thinkers – using AI outputs as supportive information while ultimately relying on their clinical training and patient knowledge to make decisions[104].

C. Humanistic and Professional Considerations

Dentistry is not just about diagnosing and treating teeth; it's fundamentally a human-centered practice involving communication, empathy, and trust-building with patients. One concern raised by the integration of AI is the potential reduction in the human touch of dental care [2,86]. If dentists become too reliant on AI recommendations or automated systems, they might spend less time communicating with patients, explaining diagnoses, or exercising the nuanced judgment that comes from years of clinical experience[14]. For example, an AI might quickly outline a treatment plan based on data, but a dentist needs to discuss options with the patient, understanding their preferences and anxieties – something no algorithm can do authentically[14]. Overuse of AI without maintaining personal interaction could risk eroding the dentist–patient relationship, which is critical for patient compliance and satisfaction[14,86].

There's also the issue of patient autonomy and informed consent. Ethical practice requires that patients are informed about how decisions are made about their care. If an AI is involved in diagnosing a condition or suggesting a treatment, should the patient be told that an algorithm contributed to the decision?[105,106] Many ethicists argue yes – patients should know if AI was used and have the right to ask for human reevaluation if they are uncertain. Some worry that patients might place undue trust in "computer findings" or, conversely, be uncomfortable with it; thus dentists need to navigate these conversations carefully, framing AI as an assistive tool under the dentist's control[107].

From the professional standpoint, dentists must consider how AI will shape their roles. The advent of AI means that some routine tasks (like interpreting a straightforward cavity on an X-ray) might be partially automated. This should free up time for dentists to focus on more complex tasks and patient interaction, but it also requires that dentists stay educated about technology[2,15,99]. Lifelong learning will increasingly include AI literacy – understanding how to use and interpret AI tools. Dental curricula and continuing education programs are beginning to incorporate AI training, so practitioners are prepared to work alongside these systems[14,85]. Another professional concern is accessibility: high-tech AI systems may be costly, potentially widening the gap between well-resourced clinics and those with fewer resources. Ensuring equitable access to AI's benefits across different practice settings is an ethical challenge that the dental community must address, perhaps through shared resources or public health initiatives[108].

In summary, the integration of AI in dentistry must be managed in a way that preserves the core values of dental practice: patient welfare, autonomy, and the dentist's professional judgment. Ethical guidelines for AI in healthcare – emphasizing principles like beneficence, justice, autonomy, and explicability – are being developed to guide practitioners. By following these principles, dentists can harness AI's advantages while mitigating risks, ensuring that the quality of care is enhanced rather than compromised.

1. Can AI Replace Human Dentists?

With AI systems performing increasingly sophisticated dental tasks, a pressing question emerges: Could AI ever fully replace human dentists? The consensus among experts is that while AI will transform the practice of dentistry, it is unlikely to replace dentists entirely. The role of AI in dentistry is best seen as augmentative – AI can enhance diagnostic accuracy, improve treatment planning, and automate routine tasks – but the human dentist remains essential for comprehensive patient care. There are several reasons for this[109].

First, dentistry involves a high degree of hands-on skill and tactile perception[2,68,109]. Procedures like extracting a tooth, drilling a cavity, or sculpting a filling require fine motor skills, adaptability, and real-time judgment calls that current AI and robots cannot replicate in full. While a robot-like Yomi can guide an implant placement, it does so under the supervision and control of a human surgeon, and it cannot autonomously handle unexpected situations (such as unforeseen bleeding or anatomical variants) the way a trained dentist can[8,33,57,110]. As one clinician noted in the context of robotic surgery, "the robot will not allow the dentist to make a mistake… As amazing as this robot is, its skills don't replace that of a dental professional. You always need humans to give instructions to the robot". This underscores that human oversight and expertise are indispensable[111,112].

Second, beyond the mechanical aspects, dentists provide empathy, reassurance, and ethical judgment – qualities that machines do not possess. Patients often come to dentists with anxiety or fear; the compassionate communication and trust that a dentist provides cannot be delivered by an AI[113]. Moreover, clinical decision-making is not a purely data-driven endeavor; it often involves considering patient preferences, values, financial considerations, and systemic health factors[100,114,115]. A human dentist can integrate these complex, subjective factors into a treatment recommendation in a way an AI cannot[2,13,26,63]. AI lacks true understanding and common-sense reasoning; it cannot fully grasp the context of a patient's life or the moral dimensions of care[116,117]. For example, deciding not to treat an aggressive tumor in an elderly patient might be a humane choice factoring quality of life – a machine learning algorithm would have difficulty making such value-laden decisions.

In addition, current AI systems are narrow in scope. An AI that excels at analyzing dental x-rays won't be able to clean teeth or manage a dental office or handle the myriad tasks a dentist does every day[15]. Even as AI advances, creating a single system that can perform the wide array of clinical and interpersonal tasks of a dentist is extraordinarily challenging. It would require not just technical precision but also general intelligence and emotional intelligence at human levels, which remains the realm of science fiction for now. In the foreseeable future, what we are likely to see is a synergy between AI and dentists[118]: AI will handle data-heavy and pattern-recognition tasks (like scanning records, analyzing images, suggesting probable diagnoses or treatment options), and dentists will use those inputs to work more

effectively and efficiently. Dentists who embrace AI may have an edge in providing faster, more accurate care, whereas those who do not may find themselves at a disadvantage – as one commentary put it, "AI will not take jobs away from dentists, but dentists who utilize AI will take patients away from those who don't"[119]. In essence, AI in dentistry should be viewed as a powerful assistant rather than a replacement. The dentist's role will evolve – focusing more on supervision of AI outputs, complex decision-making, and patient interaction – but the need for the dentist remains[54,99,120–122]. The art of dentistry, with its personal touch and holistic judgment, ensures that human dentists will continue to be irreplaceable in delivering patient-centered care.

Conclusion and Practical Perspectives

Artificial intelligence has firmly established itself as a transformative tool in dentistry, offering improvements in diagnostic capability, treatment precision, and operational efficiency[3,15]. From analyzing radiographs with expert-level accuracy to guiding the placement of dental implants, AI-driven technologies are enabling dentists to deliver care that can be more predictive, personalized, and consistent[2,3,123]. The applications reviewed – diagnostic imaging, predictive analytics, restorative dentistry, robotic surgery, and orthodontics – illustrate the breadth of AI's impact on the field[2,54,64,124]. At the same time, integrating AI into dental practice necessitates careful consideration of ethical issues and acknowledgement of the technology's limitations[125]. Data privacy must be safeguarded, AI recommendations must be validated by professionals, and the dentist–patient relationship must remain at the forefront of care. Current evidence strongly suggests that AI is a complement to, not a substitute for, the human dentist. Even the most advanced AI systems lack the holistic judgment, dexterity, and empathy that define quality dental care[121,122,126,127].

From a practical perspective, dental practitioners should approach AI with informed optimism. In day-to-day practice, this means staying updated on validated AI tools that could enhance patient care – for example, exploring software that provides AI-based radiographic analysis or considering the use of digital impression systems with AI enhancements for restorative work[6,64,126,128]. Dentists may want to participate in training sessions or continuing education courses on dental AI to become comfortable with interpreting AI outputs and integrating them into clinical workflows[129]. It is wise to start with AI as an adjunct: use it to double-check diagnoses, to streamline record-keeping, or to suggest treatment options, but always review its contributions critically. Practitioners should also educate their staff and patients about any new AI tools being used, ensuring transparency and managing expectations that these are aids under the dentist's supervision[2,107,126,128].

For the dental community at large, embracing AI also means contributing to its responsible development[109,113,117,127]. Clinicians can collaborate with developers by providing quality data and real-world feedback, helping to improve AI models' accuracy and fairness[113,117]. Professional associations and regulatory bodies are developing guidelines for AI use in dentistry – practitioners should keep an eye on these and adhere to best practices recommended for safe and ethical AI integration[93,95,100,106,107,115,116,121,125,126]. Notably, dental educators are already acknowledging the importance of AI; dental schools are introducing students to these technologies so that the next generation of dentists is AI-savvy[85,113,129,130]. As one educator pointed out, AI in dentistry "isn't the future – it's the present," and new

dentists should feel comfortable using these tools as they launch their careers[112].

In conclusion, AI in dentistry is here to stay and will undoubtedly continue to advance. Its proper utilization can lead to earlier disease detection, more effective treatments, and streamlined clinic management, all of which benefit patients. However, the guiding principle should be that technology serves the practice of dentistry, not the other way around. By combining the strengths of AI – speed, data processing, consistency – with the irreplaceable human elements of clinical expertise and compassionate care, dental practitioners can ensure the highest standard of care in the modern era. The foreseeable future is one of human-AI collaboration, where dentists who skill fully leverage AI will likely set the standard for excellence in oral health care. The challenge and opportunity for every dentist is to integrate these innovations in a way that enhances their practice and outcomes, while upholding the trust and individualized attention that each patient deserves.

References

1. Rupali M, Amit P. A Review Paper on General Concepts of “Artificial Intelligence and Machine Learning.” International Advanced Research Journal in Science, Engineering and Technology. 2017 Jan 27;4(4):79–82.
2. Ghaffari M, Zhu Y, Shrestha A. A review of advancements of artificial intelligence in dentistry. Dentistry Review. 2024 Jun;4(2):100081.
3. Kaushik R, Rapaka R. AI-driven evolution in teledentistry: A comprehensive overview of technology and clinical applications. Dentistry Review. 2025 Jun;5(2):100154.
4. Sharma S, Kumari P, Sabira K, Parihar AS, Divya Rani P, Roy A, et al. Revolutionizing Dentistry: The Applications of Artificial Intelligence in Dental Health Care. J Pharm Bioallied Sci. 2024 Jul;16(Suppl 3):S1910–2.
5. Rahim A, Khatoon R, Khan TA, Syed K, Khan I, Khalid T, et al. Artificial intelligence-powered dentistry: Probing the potential, challenges, and ethicality of artificial intelligence in dentistry. Digit Health. 2024;10:20552076241291345.
6. Surdu A, Budala DG, Luchian I, Foia LG, Botnariu GE, Scutariu MM. Using AI in Optimizing Oral and Dental Diagnoses—A Narrative Review. Diagnostics. 2024 Dec 13;14(24):2804.
7. Eggmann F, Weiger R, Zitzmann NU, Blatz MB. Implications of large language models such as ChatGPT for dental medicine. J Esthet Restor Dent. 2023 Oct;35(7):1098–102.
8. Liu C, Liu Y, Xie R, Li Z, Bai S, Zhao Y. The evolution of robotics: research and application progress of dental implant robotic systems. Int J Oral Sci. 2024 Apr 8;16(1):28.
9. Sankar H, Shalini M, Rajagopalan A, Gupta S, Kumar A, Shouket R. Dental implant placement accuracy with robotic surgery compared to free-hand, static and dynamic computer assisted techniques: Systematic review and meta-analysis. Journal of Oral Biology and Craniofacial Research. 2025 Jan;15(1):69–76.
10. Li Z, Xie R, Bai S, Zhao Y. Implant placement with an autonomous dental implant robot: A clinical report. The Journal of Prosthetic Dentistry. 2025 Feb;133(2):340–5.
11. Wu Y, Zou S, Lv P, Wang X. Accuracy of an autonomous dental implant robotic system in dental implant surgery. The Journal of Prosthetic Dentistry. 2025 Mar;133(3):764–70.
12. Saeed A, Alkhurays M, AlMutlaqah M, AlAzbah M, Alajlan SA. Future of Using Robotic and Artificial

Intelligence in Implant Dentistry. Cureus. 2023 Aug;15(8):e43209.

13. Tuygunov N, Samaranayake L, Khurshid Z, Rewthamrongsris P, Schwendicke F, Osathanon T, et al. The Transformative Role of Artificial Intelligence in Dentistry: A Comprehensive Overview Part 2: The Promise and Perils, and the International Dental Federation Communique. International Dental Journal. 2025 Apr;75(2):397–404.
14. Thorat V, Rao P, Joshi N, Talreja P, Shetty AR. Role of Artificial Intelligence (AI) in Patient Education and Communication in Dentistry. Cureus. 2024 May;16(5):e59799.
15. Mallineni SK, Sethi M, Punugoti D, Kotha SB, Alkhayal Z, Mubaraki S, et al. Artificial Intelligence in Dentistry: A Descriptive Review. Bioengineering (Basel). 2024 Dec 13;11(12):1267.
16. Al-Jallad N, Ly-Mapes O, Hao P, Ruan J, Ramesh A, Luo J, et al. Artificial intelligence-powered smartphone application, AICaries, improves at-home dental caries screening in children: Moderated and unmoderated usability test. PLOS Digit Health. 2022;1(6):e0000046.
17. Reyes LT, Knorst JK, Ortiz FR, Ardenghi TM. Scope and challenges of machine learning-based diagnosis and prognosis in clinical dentistry: A literature review. J Clin Transl Res. 2021 Aug 26;7(4):523–39.
18. Rodrigues JA, Krois J, Schwendicke F. Demystifying artificial intelligence and deep learning in dentistry. Braz Oral Res. 2021;35:e094.
19. Al-Khalifa KS, Ahmed WM, Azhari AA, Qaw M, Alsheikh R, Alqudaihi F, et al. The Use of Artificial Intelligence in Caries Detection: A Review. Bioengineering (Basel). 2024 Sep 18;11(9):936.
20. Mertens S, Krois J, Cantu AG, Arsiwala LT, Schwendicke F. Artificial intelligence for caries detection: Randomized trial. J Dent. 2021 Dec;115:103849.
21. Cantu AG, Gehrung S, Krois J, Chaurasia A, Rossi JG, Gaudin R, et al. Detecting caries lesions of different radiographic extension on bitewings using deep learning. J Dent. 2020 Sep;100:103425.
22. Schwendicke F, Rossi JG, Göstemeyer G, Elhennawy K, Cantu AG, Gaudin R, et al. Cost-effectiveness of Artificial Intelligence for Proximal Caries Detection. J Dent Res. 2021 Apr;100(4):369–76.
23. MIT News | Massachusetts Institute of Technology [Internet]. 2022 [cited 2025 Apr 10]. Taking the guesswork out of dental care with artificial intelligence. Available from: https:// news.mit.edu/ 2022/overjet-dental-artificial-intelligence-0624
24. Patil S, Albogami S, Hosmani J, Mujoo S, Kamil MA, Mansour MA, et al. Artificial Intelligence in the Diagnosis of Oral Diseases: Applications and Pitfalls. Diagnostics (Basel). 2022 Apr 19;12 (5):1029.
25. Alharbi SS, Alhasson HF. Exploring the Applications of Artificial Intelligence in Dental Image Detection: A Systematic Review. Diagnostics (Basel). 2024 Oct 31;14(21):2442.
26. Bamashmous M. The Role of Artificial Intelligence in Transforming Dental Public Health: Current Applications, Ethical Considerations, and Future Directions. [cited 2025 Apr 10]; Available from: https://opendentistryjournal.com/VOLUME/19/ELOCATOR/e18742106363413/
27. Seth N, Verma S, Varshney DK, Sharma S, Kale* P. Artificial intelligence in dental imaging: A new era of precision and predictive diagnosis. IP

International Journal of Maxillofacial Imaging. 10(3):86–91.

28. Finkelstein J, Zhang F, Levitin SA, Cappelli D. Using big data to promote precision oral health in the context of a learning healthcare system. J Public Health Dent. 2020 Mar;80 Suppl 1(Suppl 1):S43–58.
29. Çiftçi BT, Aşantoğrol F. Utilization of machine learning models in predicting caries risk groups and oral health-related risk factors in adults. BMC Oral Health. 2024 Apr 8;24(1):430.
30. Surdilovic D, Abdelaal H, D'Souza J. Using artificial intelligence in preventive dentistry: A narrative review. J Datta Meghe Inst Med Sci Univ. 2023;18(1):146.
31. Zhu Y, Du M, Li P, Lu H, Li A, Xu S. Prediction models for the complication incidence and survival rate of dental implants-a systematic review and critical appraisal. Int J Implant Dent. 2025 Jan 23;11(1):5.
32. Fawaz P, Sayegh PE, Vannet BV. Artificial intelligence in revolutionizing orthodontic practice. World Journal of Methodology [Internet]. 2025 Sep 20 [cited 2025 Apr 10];15(3). Available from: https://www.wjgnet.com/2222-0682/full/ v15/i3/ 100 598.htm
33. Liu J, Zhang C, Shan Z. Application of Artificial Intelligence in Orthodontics: Current State and Future Perspectives. Healthcare (Basel). 2023 Oct 18;11(20):2760.
34. Volovic J, Badirli S, Ahmad S, Leavitt L, Mason T, Bhamidipalli SS, et al. A Novel Machine Learning Model for Predicting Orthodontic Treatment Duration. Diagnostics (Basel). 2023 Aug 23;13(17):2740.
35. Arjumand B. The Application of artificial intelligence in restorative Dentistry: A narrative review of current research. The Saudi Dental Journal. 2024 Jun;36(6):835–40.
36. Lee SJ, Chung D, Asano A, Sasaki D, Maeno M, Ishida Y, et al. Diagnosis of Tooth Prognosis Using Artificial Intelligence. Diagnostics (Basel). 2022 Jun 9;12(6):1422.
37. Aziz AM, Hamdoon Z, Husein AB, Dheyab S, Obaid F. Applications of artificial intelligence in restorative dentistry: a scoping review. Quintessence Int. 2024 Jun 28;55(6):430–40.
38. Tabatabaian F, Vora SR, Mirabbasi S. Applications, functions, and accuracy of artificial intelligence in restorative dentistry: A literature review. J Esthet Restor Dent. 2023 Sep;35(6):842–59.
39. Azhari AA, Helal N, Sabri LM, Abduljawad A. Artificial intelligence (AI) in restorative dentistry: Performance of AI models designed for detection of interproximal carious lesions on primary and permanent dentition. Digit Health. 2023; 9:20552 076231216681.
40. Alqutaibi AY, Aboalrejal AN. ARTIFICIAL INTELLIGENCE (AI) AS AN AID IN RESTORATIVE DENTISTRY IS PROMISING, BUT STILL A WORK IN PROGRESS. Journal of Evidence-Based Dental Practice. 2023 Mar; 23(1):101837.
41. Yeslam HE, Freifrau von Maltzahn N, Nassar HM. Revolutionizing CAD/CAM-based restorative dental processes and materials with artificial intelligence: a concise narrative review. PeerJ. 2024;12:e17793.
42. Regassa Hunde B, Debebe Woldeyohannes A. Future prospects of computer-aided design (CAD) – A review from the perspective of artificial intelligence (AI), extended reality, and 3D printing. Results in Engineering. 2022 Jun;14:100478.

43. Naidu V, Jaju S. CAD/CAM Engineering And Artificial Intelligence In Dentistry. IOP Conf Ser: Mater Sci Eng. 2022 Oct 1;1259(1):012018.
44. Alghauli MA, Aljohani W, Almutairi S, Aljohani R, Alqutaibi AY. Advancements in digital data acquisition and CAD technology in Dentistry: Innovation, clinical Impact, and promising integration of artificial intelligence. Clinical eHealth. 2025 Dec;8:32–52.
45. Róth I, Géczi Z, Végh DC, Hegedüs T, Pál A, Hermann P, et al. The role of artificial intelligence in intraoral scanning for complete-arch digital impressions: An in vitro study. J Dent. 2025 Mar 23;156:105717.
46. Revilla-León M, Gómez-Polo M, Sailer I, Kois JC, Rokhshad R. An overview of artificial intelligence based applications for assisting digital data acquisition and implant planning procedures. J Esthet Restor Dent. 2024 Dec;36(12):1666–74.
47. Kong HJ, Kim YL. Application of artificial intelligence in dental crown prosthesis: a scoping review. BMC Oral Health. 2024 Aug 13;24(1):937.
48. Wu Z, Zhang C, Ye X, Dai Y, Zhao J, Zhao W, et al. Comparison of the Efficacy of Artificial Intelligence-Powered Software in Crown Design: An In Vitro Study. Int Dent J. 2025 Feb;75(1):127–34.
49. Ahmed N, Abbasi MS, Zuberi F, Qamar W, Halim MSB, Maqsood A, et al. Artificial Intelligence Techniques: Analysis, Application, and Outcome in Dentistry-A Systematic Review. Biomed Res Int. 2021;2021:9751564.
50. Aljulayfi IS, Almatrafi AH, Althubaitiy RO, Alnafisah F, Alshehri K, Alzahrani B, et al. The Potential of Artificial Intelligence in Prosthodontics: A Comprehensive Review. Med Sci Monit. 2024 Jun 6;30:e944310.
51. Iosif L, Țâncu AMC, Amza OE, Gheorghe GF, Dimitriu B, Imre M. AI in Prosthodontics: A Narrative Review Bridging Established Knowledge and Innovation Gaps Across Regions and Emerging Frontiers. Prosthesis. 2024 Oct 28;6(6):1281–99.
52. Revilla-León M, Gómez-Polo M, Vyas S, Barmak AB, Gallucci GO, Att W, et al. Artificial intelligence models for tooth-supported fixed and removable prosthodontics: A systematic review. The Journal of Prosthetic Dentistry. 2023 Feb;129(2):276–92.
53. Alshadidi AAF, Alshahrani AA, Aldosari LIN, Chaturvedi S, Saini RS, Hassan SAB, et al. Investigation on the Application of Artificial Intelligence in Prosthodontics. Applied Sciences. 2023 Apr 16;13(8):5004.
54. Najeeb M, Islam S. Artificial intelligence (AI) in restorative dentistry: current trends and future prospects. BMC Oral Health. 2025 Apr 18;25(1):592.
55. Samaranayake L, Tuygunov N, Schwendicke F, Osathanon T, Khurshid Z, Boymuradov SA, et al. The Transformative Role of Artificial Intelligence in Dentistry: A Comprehensive Overview. Part 1: Fundamentals of AI, and its Contemporary Applications in Dentistry. International Dental Journal. 2025 Apr;75(2):383–96.
56. Cervino G, Peditto M, Portelli M, Militi A, Matarese G, Fiorillo L, et al. The Use of AI for Prosthodontic Restoration: Predictable and Safer Dentistry. In: ASEC 2023 [Internet]. MDPI; 2023 [cited 2025 Apr 26]. p. 68. Available from: https:// www.mdpi.com/2673-4591/56/1/68
57. Bahrami R, Pourhajibagher M, Nikparto N, Bahador A. Robot-assisted dental implant surgery procedure: A literature review. Journal of Dental Sciences. 2024 Jul;19(3):1359–68.

58. Dibart S, Kernitsky-Barnatan J, Di Battista M, Montesani L. Robot assisted implant surgery: Hype or hope? Journal of Stomatology, Oral and Maxillofacial Surgery. 2023 Dec;124(6):101612.
59. Jain S, Sayed ME, Ibraheem WI, Ageeli AA, Gandhi S, Jokhadar HF, et al. Accuracy Comparison between Robot-Assisted Dental Implant Placement and Static/Dynamic Computer-Assisted Implant Surgery: A Systematic Review and Meta-Analysis of In Vitro Studies. Medicina (Kaunas). 2023 Dec 20;60(1):11.
60. Fang G, Chow MCK, Ho JDL, He Z, Wang K, Ng TC, et al. Soft robotic manipulator for intraoperative MRI-guided transoral laser microsurgery. Sci Robot. 2021 Aug 11;6(57):eabg5575.
61. Cepolina F, Razzoli R. Review of robotic surgery platforms and end effectors. J Robot Surg. 2024 Feb 13;18(1):74.
62. Rivera-Serrano CM, Johnson P, Zubiate B, Kuenzler R, Choset H, Zenati M, et al. A transoral highly flexible robot: Novel Technology and Application. The Laryngoscope. 2012 May;122(5):1067–71.
63. Ding Y, Zheng Y, Chen R, Cao R, Chen J, Wang L, et al. Accuracy of a novel semi-autonomous robotic-assisted surgery system for single implant placement: A case series. Journal of Dentistry. 2023 Dec;139:104766.
64. Kazimierczak N, Kazimierczak W, Serafin Z, Nowicki P, Nożewski J, Janiszewska-Olszowska J. AI in Orthodontics: Revolutionizing Diagnostics and Treatment Planning-A Comprehensive Review. J Clin Med. 2024 Jan 7;13(2):344.
65. Tomášik J, Zsoldos M, Oravcová Ľ, Lifková M, Pavleová G, Strunga M, et al. AI and Face-Driven Orthodontics: A Scoping Review of Digital Advances in Diagnosis and Treatment Planning. AI. 2024 Jan 5;5(1):158–76.
66. Ghodasra R, Brizuela M. Orthodontics, Cephalometric Analysis. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 [cited 2025 Apr 27]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK594272/
67. S. J, Kurian B, Michael T. Automated Cephalometric Landmark Detection: A Novel Software Model Compared with Manual Annotation Method. J Indian Orthod Soc. 2024 Apr;58(2):140–9.
68. Rauniyar S, Jena S, Sahoo N, Mohanty P, Dash BP. Artificial Intelligence and Machine Learning for Automated Cephalometric Landmark Identification: A Meta-Analysis Previewed by a Systematic Review. Cureus. 2023 Jun;15(6):e40934.
69. Alsubai S. A Critical Review on the 3D Cephalometric Analysis Using Machine Learning. Computers. 2022 Oct 28;11(11):154.
70. Mourgues T, González-Olmo MJ, Huanca Ghislanzoni L, Peñacoba C, Romero-Maroto M. Artificial Intelligence in Aesthetic Dentistry: Is Treatment with Aligners Clinically Realistic? J Clin Med. 2024 Oct 12;13(20):6074.
71. Bagdy-Bálint R, Szabó G, Zováthi ÖH, Zováthi BH, Somorjai Á, Köpenczei C, et al. Accuracy of automated analysis in cephalometry. Journal of Dental Sciences. 2025 Apr;20(2):830–43.
72. Ramasubbu N, Kasim SAV, Thavarajah R, Rengarajan KN. Applying artificial intelligence to predict the outcome of orthodontic treatment. APOS. 2024 Apr 8;14:264–72.
73. Xie X, Wang L, Wang A. Artificial neural network modeling for deciding if extractions are necessary

prior to orthodontic treatment. Angle Orthod. 2010 Mar;80(2):262–6.

74. Ruiz DC, Mureșanu S, Du X, Elgarba BM, Fontenele RC, Jacobs R. Unveiling the role of artificial intelligence applied to clear aligner therapy: A scoping review. Journal of Dentistry. 2025 Mar;154:105564.
75. Thurzo A, Kurilová V, Varga I. Artificial Intelligence in Orthodontic Smart Application for Treatment Coaching and Its Impact on Clinical Performance of Patients Monitored with AI-TeleHealth System. Healthcare (Basel). 2021 Dec 7;9(12):1695.
76. Phatak S, Daokar S. Orthodontic apps: A stairway to the future. Int J Orthod Rehabil. 2019;10(2):75.
77. Albandar JM, Susin C, Hughes FJ. Manifestations of systemic diseases and conditions that affect the periodontal attachment apparatus: Case definitions and diagnostic considerations. J Clin Periodontol. 2018 Jun;45:S171–89.
78. Berahim Z, Moharamzadeh K, Rawlinson A, Jowett AK. Biologic interaction of three-dimensional periodontal fibroblast spheroids with collagen-based and synthetic membranes. J Periodontol. 2011 May;82(5):790–7.
79. Chacko NL, Abraham S, Rao HNS, Sridhar N, Moon N, Barde DH. A Clinical and Radiographic Evaluation of Periodontal Regenerative Potential of PerioGlas®: A Synthetic, Resorbable Material in Treating Periodontal Infrabony Defects. J Int Oral Health. 2014 Jun;6(3):20–6.
80. Scott J, Biancardi AM, Jones O, Andrew D. Artificial Intelligence in Periodontology: A Scoping Review. Dent J (Basel). 2023 Feb 8;11(2):43.
81. Abdul NS, Shivakumar GC, Sangappa SB, Di Blasio M, Crimi S, Cicciù M, et al. Applications of artificial intelligence in the field of oral and maxillofacial pathology: a systematic review and meta-analysis. BMC Oral Health. 2024 Jan 23;24(1):122.
82. Parinitha MS, Doddawad VG, Kalgeri SH, Gowda SS, Patil S. Impact of Artificial Intelligence in Endodontics: Precision, Predictions, and Prospects. J Med Signals Sens. 2024;14:25.
83. Asgary S. Artificial Intelligence in Endodontics: A Scoping Review. Iran Endod J. 2024;19(2):85–98.
84. Authors, Clark M, Bailey S. Chatbots in Health Care: Connecting Patients to Information: Emerging Health Technologies [Internet]. Ottawa (ON): Canadian Agency for Drugs and Technologies in Health; 2024 [cited 2025 Apr 29]. (CADTH Horizon Scans). Available from: http:// www. ncbi. nlm. nih.gov/books/NBK602381/
85. Thurzo A, Strunga M, Urban R, Surovková J, Afrashtehfar KI. Impact of Artificial Intelligence on Dental Education: A Review and Guide for Curriculum Update. Education Sciences. 2023 Jan 31;13(2):150.
86. Vodanović M, Subašić M, Milošević D, Savić Pavičin I. Artificial Intelligence in Medicine and Dentistry. Acta Stomatol Croat. 2023 Mar;57(1):70–84.
87. Gao S, Wang X, Xia Z, Zhang H, Yu J, Yang F. Artificial Intelligence in Dentistry: A Narrative Review of Diagnostic and Therapeutic Applications. Med Sci Monit. 2025 Apr 8;31:e946676.
88. Shojaei P, Vlahu-Gjorgievska E, Chow YW. Security and Privacy of Technologies in Health Information Systems: A Systematic Literature Review. Computers. 2024 Jan 31;13(2):41.
89. Basil NN, Ambe S, Ekhator C, Fonkem E. Health Records Database and Inherent Security Concerns:

A Review of the Literature. Cureus. 2022 Oct;14(10):e30168.

90. Care I of M (US) R on V& SDH. Healthcare Data as a Public Good: Privacy and Security. In: Clinical Data as the Basic Staple of Health Learning: Creating and Protecting a Public Good: Workshop Summary [Internet]. National Academies Press (US); 2010 [cited 2025 Apr 29]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK54293/
91. Ertl B. Your Complete Checklist for Achieving HIPAA Compliance [Internet]. Kiteworks | Your Private Data Network. 2025 [cited 2025 Apr 29]. Available from: https://www.kiteworks.com/hipaa-compliance/hipaa-compliance-requirements/
92. Yadav N, Pandey S, Gupta A, Dudani P, Gupta S, Rangarajan K. Data Privacy in Healthcare: In the Era of Artificial Intelligence. Indian Dermatol Online J. 2023;14(6):788–92.
93. Liaw ST, Liyanage H, Kuziemsky C, Terry AL, Schreiber R, Jonnagaddala J, et al. Ethical Use of Electronic Health Record Data and Artificial Intelligence: Recommendations of the Primary Care Informatics Working Group of the International Medical Informatics Association. Yearb Med Inform. 2020 Aug;29(1):51–7.
94. Khalid N, Qayyum A, Bilal M, Al-Fuqaha A, Qadir J. Privacy-preserving artificial intelligence in healthcare: Techniques and applications. Computers in Biology and Medicine. 2023 May;158:106848.
95. Naik N, Hameed BMZ, Shetty DK, Swain D, Shah M, Paul R, et al. Legal and Ethical Consideration in Artificial Intelligence in Healthcare: Who Takes Responsibility? Front Surg [Internet]. 2022 Mar 14 [cited 2025 Apr 29];9. Available from: https://www.frontiersin.orghttps://www.frontiersin.org/journals/surgery/articles/10.3389/fsurg.2022.862322/full
96. Ferrara E. Fairness and Bias in Artificial Intelligence: A Brief Survey of Sources, Impacts, and Mitigation Strategies. Sci. 2023 Dec 26;6(1):3.
97. Davendralingam N, Sebire NJ, Arthurs OJ, Shelmerdine SC. Artificial intelligence in paediatric radiology: Future opportunities. Br J Radiol. 2021 Jan 1;94(1117):20200975.
98. Chen P, Wu L, Wang L. AI Fairness in Data Management and Analytics: A Review on Challenges, Methodologies and Applications. Applied Sciences. 2023 Sep 13;13(18):10258.
99. Möllmann NR, Mirbabaie M, Stieglitz S. Is it alright to use artificial intelligence in digital health? A systematic literature review on ethical considerations. Health Informatics J. 2021 Oct;27(4):14604582211052391.
100. Mennella C, Maniscalco U, De Pietro G, Esposito M. Ethical and regulatory challenges of AI technologies in healthcare: A narrative review. Heliyon. 2024 Feb 29;10(4):e26297.
101. Foote HP, Hong C, Anwar M, Borentain M, Bugin K, Dreyer N, et al. Embracing Generative Artificial Intelligence in Clinical Research and Beyond. JACC: Advances. 2025 Mar;4(3):101593.
102. Brady AP, Allen B, Chong J, Kotter E, Kottler N, Mongan J, et al. Developing, Purchasing, Implementing and Monitoring AI Tools in Radiology: Practical Considerations. A Multi-Society Statement from the ACR, CAR, ESR, RANZCR and RSNA. Radiology: Artificial Intelligence. 2024 Jan 1;6(1):e230513.
103. Amann J, Blasimme A, Vayena E, Frey D, Madai VI, the Precise4Q consortium. Explainability for artificial intelligence in healthcare: a

multidisciplinary perspective. BMC Medical Informatics and Decision Making. 2020 Nov 30;20(1):310.

104. Mora-Cantallops M, García-Barriocanal E, Sicilia MÁ. Trustworthy AI Guidelines in Biomedical Decision-Making Applications: A Scoping Review. BDCC. 2024 Jul 1;8(7):73.

105. Park HJ. Patient perspectives on informed consent for medical AI: A web-based experiment. Digit Health. 2024;10:20552076241247938.

106. Adegbesan A, Akingbola A, Ojo O, Jessica OU, Alao UH, Shagaya U, et al. Ethical Challenges in the Integration of Artificial Intelligence in Palliative Care. Journal of Medicine, Surgery, and Public Health. 2024 Dec 1;4:100158.

107. Farhud DD, Zokaei S. Ethical Issues of Artificial Intelligence in Medicine and Healthcare. Iran J Public Health. 2021 Nov;50(11):i–v.

108. Olawade DB, David-Olawade AC, Wada OZ, Asaolu AJ, Adereni T, Ling J. Artificial intelligence in healthcare delivery: Prospects and pitfalls. Journal of Medicine, Surgery, and Public Health. 2024 Aug;3:100108.

109. Nielsen M. Will AI Replace Dentists? The Truth About AI in Dentistry - My Social Practice - Social Media Marketing for Dental & Dental Specialty Practices [Internet]. 2025 [cited 2025 May 3]. Available from: https:// mysocialpractice. com/2025/01/will-ai-replace-dentists/

110. Yomi By Neocis [Internet]. [cited 2025 Jun 1]. Yomi Dental Robot - Next Gen Dental Implant Surgery - Neocis. Available from: https:// www. neocis.com/

111. Griffin M. A fully autonomous robot dentist just completed its first human procedure [Internet]. Matthew Griffin | Keynote Speaker & Master Futurist. 2025 [cited 2025 May 3]. Available from: https://www.fanaticalfuturist.com/2025/01/a-fully-autonomous-robot-dentist-just-completed-its-first-human-procedure/

112. Robot demonstrates dental implant procedures [Internet]. [cited 2025 Jun 1]. Available from: https://www.buffalo.edu/ubnow/stories/2025/03/andrade-dental-implants-robots.html

113. Chan CKY. AI as the Therapist: Student Insights on the Challenges of Using Generative AI for School Mental Health Frameworks. Behavioral Sciences. 2025 Feb 28;15(3):287.

114. Mosavi NS, Santos MF. Enhancing Clinical Decision Support for Precision Medicine: A Data-Driven Approach. Informatics. 2024 Sep 13;11(3):68.

115. Ferrario A, Gloeckler S, Biller-Andorno N. Ethics of the algorithmic prediction of goal of care preferences: from theory to practice. Journal of Medical Ethics. 2023 Mar 1;49(3):165–74.

116. Xu H, Shuttleworth KMJ. Medical artificial intelligence and the black box problem: a view based on the ethical principle of "do no harm." Intelligent Medicine. 2024 Feb;4(1):52–7.

117. Montemayor C, Halpern J, Fairweather A. In principle obstacles for empathic AI: why we can't replace human empathy in healthcare. AI Soc. 2022;37(4):1353–9.

118. Kale P, Reddy KS, Ghosh S. Exploring the synergy between artificial intelligence and periodontal treatment. IJPI. 2025 Apr 28;10(1):27–30.

119. Nielsen M. Dental AI Tech Won't Replace You, It Will Make Your Job Easy [Internet]. 2025 [cited 2025 Jun 1]. Available from: https:// mysocial practice.om/2025/01/dental-ai-tech/

120. Agrawal P, Nikhade P. Artificial Intelligence in Dentistry: Past, Present, and Future. Cureus. 2022 Jul;14(7):e27405.

121. Rokhshad R, Ducret M, Chaurasia A, Karteva T, Radenkovic M, Roganovic J, et al. Ethical considerations on artificial intelligence in dentistry: A framework and checklist. Journal of Dentistry. 2023 Aug;135:104593.

122. Bonny T, Al Nassan W, Obaideen K, Al Mallahi MN, Mohammad Y, El-Damanhoury HM. Contemporary Role and Applications of Artificial Intelligence in Dentistry. F1000Res. 2023;12:1179.

123. Altalhi AM, Alharbi FS, Alhodaithy MA, Almarshedy BS, Al-Saaib MY, Al Jfshar RM, et al. The Impact of Artificial Intelligence on Dental Implantology: A Narrative Review. Cureus. 2023 Oct;15(10):e47941.

124. Wang L, Xu Y, Wang W, Lu Y. Application of machine learning in dentistry: insights, prospects and challenges. Acta Odontol Scand. 2025 Mar 27;84:145–54.

125. Krishnakumar S, Vc D. Ethical aspects and applications of artificial intelligence in maxillofacial imaging. Journal of Orofacial and Health Sciences. 11(3):112–9.

126. El Khoury N, Hadid D, El-Outa A. Exploring the Ethical Landscape of Artificial Intelligence in Dentistry: Insights From a Cross-Sectional Study. Cureus. 2025 Apr;17(4):e82667.

127. Williamson SM, Prybutok V. Balancing Privacy and Progress: A Review of Privacy Challenges, Systemic Oversight, and Patient Perceptions in AI-Driven Healthcare. Applied Sciences. 2024 Jan 12;14(2):675.

128. Farhadi Nia M, Ahmadi M, Irankhah E. Transforming dental diagnostics with artificial intelligence: advanced integration of ChatGPT and large language models for patient care. Front Dent Med [Internet]. 2025 Jan 6 [cited 2025 Jun 1];5. Available from: https:// www. frontiersin. org/ journals/dental-medicine/articles/10.3389/fdmed.2024.1456208/full

129. Schwendicke F, Chaurasia A, Wiegand T, Uribe SE, Fontana M, Akota I, et al. Artificial intelligence for oral and dental healthcare: Core education curriculum. Journal of Dentistry. 2023 Jan; 128:104363.

130. Qamar W, Khaleeq N, Nisar A, Tariq SF, Lajber M. Exploring dental professionals' outlook on the future of dental care amidst the integration of artificial intelligence in dentistry: a pilot study in Pakistan. BMC Oral Health. 2024 May 8;24(1):542.