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ARTIFICIAL INTELLIGENCE IN HEALTHCARE AND DENTISTRY: APPLICATIONS, CHALLENGES AND RESPONSIBLE CLINICAL INTEGRATION

Running title: AI in Healthcare and Dentistry

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ABSTRACT

Artificial intelligence (AI) is becoming a practical clinical technology rather than a distant computational concept. Across medicine and dentistry, AI systems are increasingly used to analyse electronic health records, medical and dental images, pathology slides, genomic data, patient-reported outcomes and operational datasets. These tools have the potential to support earlier diagnosis, risk prediction, treatment planning, documentation, patient communication and resource allocation. This narrative review provides a concise but expanded overview of the current applications of AI in healthcare, with a dedicated emphasis on dentistry, and discusses the ethical, validation and implementation requirements necessary for safe clinical integration. AI has shown promising performance in diagnostic imaging, clinical decision support, nursing workflows, mental health screening, drug discovery and administrative automation. In dentistry, AI is particularly relevant to radiographic interpretation, caries detection, periodontal assessment, endodontic diagnosis, cephalometric analysis, implant planning, prosthodontic design, oral lesion screening, patient triage and dental education. However, much of the current evidence remains retrospective, single-centre or based on curated datasets, and reported performance may not translate directly to daily clinical practice. AI should be adopted as an assistive, auditable and clinician-supervised tool. Successful implementation requires high-quality data, external validation, transparent reporting, bias assessment, data governance, clinician training, patient-centered consent processes and post-deployment monitoring. When these safeguards are embedded into practice, AI can improve efficiency and consistency while preserving professional judgment, accountability and the human relationship at the centre of care.

Keywords: Artificial intelligence; healthcare; dentistry; machine learning; deep learning; clinical decision support; dental radiology; ethics; validation; generative AI

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INTRODUCTION

Artificial intelligence (AI) refers to computational systems that can perform tasks commonly associated with human intelligence, including pattern recognition, classification, prediction, reasoning and language generation. In healthcare, the growth of AI has been driven by the digitisation of clinical records, rapid advances in imaging, wider use of genomic and other omics technologies, and the development of algorithms capable of learning complex relationships from large datasets. Contemporary AI includes machine learning, deep learning, natural language processing, computer vision and generative AI. These techniques are being investigated for diagnostic support, prognosis, treatment selection, workflow redesign and patient engagement [1, 2, 3, 4].

The appeal of AI is especially strong in areas where clinicians must interpret large volumes of data under time pressure. Algorithms can highlight suspicious findings on radiographs, segment anatomical structures, detect deterioration from vital signs, identify patients at high risk of complications and summarize clinical documentation. Used appropriately, these functions may reduce cognitive burden and improve consistency. Used inappropriately, they may create new forms of error, worsen inequities or lead to uncritical automation of clinical decisions. Therefore, the central question is not whether AI will enter healthcare, but how it can be integrated in a way that is safe, fair, transparent and clinically useful.

Dentistry provides a particularly relevant example of AI translation. Dental practice generates structured and unstructured data through intraoral radiographs, panoramic imaging, cone-beam computed tomography (CBCT), intraoral scans, photographs, periodontal charts, treatment notes and laboratory workflows. Many dental diagnoses also depend on repeated visual interpretation, which makes the field well suited to computer vision. At the same time, dental care is highly operator dependent and patient centered; therefore, AI must support rather than replace clinical judgment. This review expands the previous concise overview into a submission-ready narrative article by summarizing major healthcare applications, adding a dedicated dentistry component, and outlining practical principles for responsible implementation.

Core technologies and data sources

AI in healthcare depends on the interaction between data, algorithms and clinical context. Traditional machine learning methods can analyze tabular variables such as age, laboratory values, comorbidities and coded diagnoses. Deep learning is particularly useful for high-dimensional inputs such as radiographs, histopathology images, retinal photographs, CBCT volumes, electrocardiograms and free-text notes. Natural language processing can extract information from clinical narratives, generate summaries and support documentation. Generative AI, including large language models and large multimodal models, can produce text, images or other outputs from complex prompts, but its fluent responses require careful verification because generated content may be inaccurate or unsupported [5, 6, 7].

Electronic health records (EHRs) have become a central data source for longitudinal risk prediction. Models trained in repeated measurements can identify patients at risk of diabetes, kidney disease, circulatory disorders, mental health deterioration or hospital readmission before overt clinical presentation [8]. In imaging, AI can classify disease, detect lesions, quantify anatomical structures and prioritise abnormal examinations. Multimodal approaches that combine images with EHR variables, symptoms or laboratory data often outperform single-modality systems because they approximate the way clinicians integrate information in practice [9].

However, each data source also introduces limitations: missing values, inconsistent coding, imaging artefacts, class imbalance, demographic skew and changes in equipment or clinical workflow can all reduce model reliability.

Clinical applications across healthcare

The strongest early evidence for AI has emerged from image-rich specialties. In radiology, dermatology, ophthalmology, pathology and oncology, deep learning systems have been developed to detect lesions, segment tumours, classify disease patterns and support triage. In some experimental settings, AI systems have matched or exceeded specialist-level performance for narrowly defined tasks, such as image classification or detection of predefined abnormalities [10, 11, 12]. These results should be interpreted cautiously. High performance on curated datasets does not automatically indicate safety in varied clinical environments where disease prevalence, image quality, patient demographics and operator skill differ.

Prediction models are another major area of application. AI can estimate the likelihood of clinical deterioration, sepsis, perioperative complications, cardiovascular events or treatment response. When embedded into decision support systems, these models may prompt earlier review, additional testing or preventive intervention. In nursing practice, AI-enabled tools can support monitoring, documentation, workload allocation, fall-risk prediction, pressure-injury prevention and remote patient follow-up [13, 14]. The value of such tools depends not only on statistical accuracy but also on alert fatigue, usability, integration with clinical routines and clarity about responsibility when AI recommendations are accepted or rejected.

Mental health applications illustrate both promise and concern. AI can analyse questionnaire data, speech, text, activity patterns or EHR variables to identify risk of depression, anxiety, self-harm or relapse. Chatbots and conversational agents may improve access to low-intensity support, psychoeducation and monitoring, particularly when human services are overstretched [15]. Nevertheless, mental health care requires empathy, contextual interpretation, safeguarding and escalation pathways. AI tools in this area must therefore be designed with clear limits, clinician oversight and robust crisis protocols.

AI also supports biomedical discovery. Machine learning and deep learning are used in drug target identification, virtual screening, protein structure prediction, radiomics and personalised medicine. These applications may accelerate research pipelines and assist in matching patients to therapies. In health-system administration, AI can optimise appointment scheduling, coding, billing, inventory, discharge planning and workforce deployment. Generative AI may assist with clinical letters, referral summaries, patient information sheets and education material. Such administrative uses may reduce professional burnout, but quality assurance is essential because errors in documentation can directly affect patient care, legal records and reimbursement.

Artificial intelligence in dentistry

Dentistry is increasingly recognised as a distinct domain for AI development. Dental diagnosis relies heavily on imaging, pattern recognition and longitudinal monitoring, and many dental procedures are planned to use digital workflows. AI is being studied in oral and maxillofacial radiology, cariology, periodontology, endodontics, prosthodontics, orthodontics, implantology, oral medicine, oral surgery and dental education [16, 17, 18]. This breadth makes dentistry an ideal field for integrated clinical AI, but it also creates a need for rigorous validation across equipment types, patient groups and practice settings.

Dental radiology is the most mature area. Computer vision systems can assist in detecting caries, periapical radiolucencies, periodontal bone loss, impacted teeth, anatomical landmarks, cystic or tumour-like lesions, maxillary sinus findings and root morphology. A recent meta-analysis of AI platforms for caries detection reported wide variability in performance across systems and modalities, with 45 included studies, accuracy ranging from 41.5% to 98.6%, and pooled estimates showing promising but heterogeneous results [19]. These findings support the use of AI as a second reader or triage aid rather than an autonomous diagnostic authority. In routine practice, the clinician must still correlate AI-highlighted findings with clinical examination, symptoms, caries risk, vitality tests and patient preferences.

Endodontics offers another practical use case. AI may assist in identifying periapical lesions, locating canals, assessing root canal morphology, estimating working length from images, detecting vertical root fractures and predicting outcomes. However, endodontic diagnosis is rarely radiographic alone. Pulp status, tenderness to percussion, periodontal probing, restorability, occlusion, cracks, previous treatment and patient history all influence decisions. Therefore, AI tools that detect radiographic patterns should be positioned within a broader diagnostic process rather than treated as definitive evidence.

In periodontology, AI can support measurement of alveolar bone levels, classification of periodontal staging, detection of calculus or furcation defects, and prediction of disease progression. In orthodontics, AI is used for cephalometric landmark identification, skeletal classification, growth assessment, aligner planning and treatment monitoring. In implant dentistry and oral surgery, AI can help segment CBCT data, identify anatomical structures such as the inferior alveolar canal, estimate bone availability, support virtual implant positioning and assist in surgical guide design. In prosthodontics and restorative dentistry, AI-enabled computer-aided design can propose crown morphology, occlusal anatomy and smile-design options, potentially improving efficiency in digital laboratories.

Oral medicine and oral pathology are emerging areas with high clinical importance. AI-assisted image analysis may support early screening of potentially malignant disorders and oral cancer using photographs, cytology, histopathology or multimodal data. The potential benefit is substantial because earlier recognition of suspicious lesions can shorten referral pathways. However, these systems require caution. Oral lesions are influenced by ethnicity, mucosal pigmentation, tobacco and areca nut habits, inflammation, trauma, candidiasis and image capture conditions. A false reassurance from AI could delay biopsy, while excessive false positives could overload specialist services. Dental AI for oral lesion screening should therefore be evaluated prospectively and linked to clear referral protocols.

Dental education and communication are also being reshaped by AI. Generative tools can create case-based quizzes, explain procedures in patient-friendly language, simulate viva questions, draft reflective notes and support student feedback. For experienced clinicians, AI may assist with literature searching, treatment-plan comparison and patient information leaflets. Nevertheless, students and practitioners must be trained to verify AI outputs, identify hallucinated references, protect patient confidentiality and understand that professional accountability cannot be delegated to software.

An AI-generated explanation may be useful, but the dentist remains responsible for diagnosis, consent, treatment and follow-up.

Dental AI may also have a public health role. If validated responsibly, algorithms could help prioritise school dental screening, identify communities with high untreated caries burden, support teledentistry triage and monitor outcomes across preventive programmes. These uses are attractive in regions with limited access to dental specialists; however, they also raise equity concerns. A model that performs well in privately insured or urban populations may be less reliable for rural, paediatric, elderly or medically compromised patients. Dental public health applications should therefore be evaluated with community representation, culturally appropriate consent processes and clear pathways for referral and follow-up.

Table 1. AI used in clinical dentistry

Dental domain	Potential AI contribution	Key caution before clinical use
Dental radiology and cariology	Detection of proximal caries, periapical lesions, bone loss, impacted teeth and anatomical landmarks on intraoral, panoramic and CBCT images.	Validate across imaging devices, exposure quality, dentition stage and local disease prevalence.
Endodontics	Support for periapical lesion detection, canal morphology assessment, fracture suspicion and outcome prediction.	Do not replace clinical tests, history, periodontal assessment and restorability evaluation.
Periodontology	Automated bone-level measurement, staging support, risk stratification and longitudinal monitoring.	Ensure periodontal definitions, radiographic angulation and demographic bias are addressed.
Orthodontics and implantology	Cephalometric landmarking, aligner monitoring, CBCT segmentation, anatomical nerve-canal detection and virtual planning.	Confirm recommendations against clinician planning, patient goals and surgical/anatomical constraints.
Prosthodontics and restorative dentistry	Digital smile design, crown morphology proposals, occlusal design and laboratory workflow efficiency.	AI-generated designs require occlusal, aesthetic, biological and material assessment by the dentist.
Oral medicine and oral pathology	Screening support for potentially malignant disorders, oral cancer triage and lesion documentation.	False reassurance can delay biopsy; referral pathways and prospective validation are essential.

Ethical, legal and validation challenges

The responsible use of AI in healthcare begins with data governance. AI systems often require large datasets, but clinical and dental data are sensitive. Consent, privacy, cybersecurity, de-identification, storage, cross-border transfer and secondary use must be addressed before model development or deployment. In dentistry, intraoral photographs, radiographs, facial scans and CBCT images may be identifiable, particularly when combined with demographic or appointment information. Data governance should therefore cover not only EHR records but also imaging archives, laboratory files and cloud-based digital dentistry platforms.

Bias is a persistent concern. AI models learn from the data used to train them; if those data under-represent certain age groups, ethnicities, socioeconomic groups, disease severities or imaging devices, the model may perform unequally. Bias can be particularly relevant in oral healthcare because caries, periodontal disease, oral cancer risk and access to care differ across populations. A model developed in a specialist academic centre may not generalise to a community dental clinic or a low-resource setting. Ethical analyses in dentistry have highlighted the need for prudence, justice, data protection, responsibility, participation and solidarity when AI is introduced into practice [20].

Explainability and transparency are also important. Many deep learning systems are described as black boxes because their internal reasoning is difficult to interpret. Heatmaps, confidence scores and case-based explanations may help clinicians understand why a model has flagged a finding, but these aids are not perfect explanations. A visually persuasive heatmap may still be misleading. Clinicians need information about the intended use, training data, validation data, performance metrics, limitations, contraindications and update history of the software. For dental AI, this should include details about imaging modality, radiographic projection, exposure quality, age range, dentition stage and disease definitions.

Validation is the central bridge between technical promise and clinical adoption. Many AI studies are retrospective and evaluate performance on archived images or records. Although such studies are useful for early development, they cannot establish real-world benefit. External validation across independent sites, prospective evaluation, workflow assessment and post-market monitoring are required. The healthcare AI community has developed reporting frameworks to improve transparency, including CONSORT-AI and SPIRIT-AI for clinical trials, TRIPOD+AI for prediction models, CLAIM for imaging studies, DECIDE-AI for early-stage decision-support evaluation, and STARD-AI for diagnostic accuracy studies [21, 22, 23, 24, 25]. Dental AI studies should increasingly align with these standards.

Implementation framework for responsible clinical integration

A practical implementation framework should begin with a clearly defined clinical problem. AI should not be adopted merely because it is novel. The intended use must specify the patient population, data input, decision point, output, user and expected action. For example, a dental caries detection tool may be intended to highlight suspected proximal lesions on bitewing radiographs for review by a dentist, not to diagnose caries independently or prescribe restoration. Clear scope prevents overuse and supports safe consent and training [26].

The second step is local validation. Before implementation, the software should be tested on data from the intended setting. Dental clinics should evaluate whether the tool performs adequately with their sensors, panoramic machines, CBCT protocols, patient demographics and record systems. Metrics should include sensitivity, specificity, positive predictive value, negative predictive value, calibration, false-positive burden, time impact and user acceptability. For clinical decision support, the relevant question is not only whether the AI is accurate, but whether it improves decisions, outcomes or efficiency compared with existing practice [27,28].

The third step is workflow design. AI outputs should appear at the right time and in a format that supports clinical reasoning. Poorly timed alerts may be ignored; excessive prompts may increase fatigue; unclear confidence scores may confuse users. Dental applications should allow clinicians to accept, reject or annotate AI findings and should preserve a record of final human interpretation. Patient communication should be transparent: clinicians may explain that AI-assisted tools were used to support image review or planning, while making clear that responsibility remains with the treating professionals [29,30].

The fourth step is governance after deployment. AI performance can drift when patient populations, equipment, software versions or clinical protocols change. Organisations should monitor errors, near misses, user feedback, demographic performance and update logs. There should be a process for reporting concerns, pausing use if safety issues emerge and retraining staff when systems change. For generative AI, additional safeguards are needed: patient-identifiable information should not be entered into unsecured public tools, generated clinical content should be reviewed before use, and references or medical claims should be verified. [30,31].

Future directions

The future of AI in healthcare and dentistry is likely to be multimodal, personalised and increasingly embedded in routine software. Rather than isolated algorithms that perform one narrow task, future systems may combine radiographs, photographs, scans, periodontal data, notes, risk factors and patient-reported outcomes to support longitudinal care. In dentistry, integrated AI could help identify patients at high risk of caries or periodontitis, monitor orthodontic progress remotely, detect implant complications, support maintenance scheduling and personalise preventive advice. [26,28,32].

Research should move beyond technical accuracy toward patient-centred outcomes. Important questions include whether AI reduces missed disease, improves communication, shortens referral delays, decreases unnecessary treatment, improves access in underserved areas or reduces clinician burnout. Dental AI also requires better shared datasets, common annotation standards, external validation cohorts and prospective trials. Collaboration among clinicians, dental educators, computer scientists, regulators, patients and industry will be necessary to ensure that AI tools are clinically meaningful and ethically acceptable.

CONCLUSION

AI is transforming healthcare by improving the analysis of complex data, supporting diagnostic and predictive tasks, streamlining documentation and opening new possibilities for personalized care. Dentistry is a major area of opportunity because dental practice is increasingly digital and image based. AI can support radiographic interpretation, caries detection, endodontic and periodontal assessment, orthodontic analysis, implant planning, prosthodontic design, oral lesion screening and education. However, the profession should avoid both exaggerated enthusiasm and unnecessary resistance. Current AI systems are best understood as assistive tools that can enhance consistency and efficiency when supervised by trained clinicians.

Safe adoption requires robust data governance, external validation, transparent reporting, bias assessment, clinician training, patient-centered communication and continuous monitoring. The goal is not to replace healthcare professionals, but to strengthen their ability to deliver timely, accurate, equitable and compassionate care. For dentistry, the most successful AI systems will be those that respect the complexity of oral diagnosis, integrate smoothly into clinical workflows and preserve the dentist-patient relationship as the foundation of care.

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