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Artificial intelligence in Oral Medicine and Oral Radiology: Transforming Diagnosis, Risk Prediction and Patient Care

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ABSTRACT

Artificial intelligence (AI) has emerged as one of the most transformative technologies in contemporary healthcare, revolutionizing diagnostic accuracy, clinical decision-making, and personalized treatment planning. Within Oral Medicine and Oral and Maxillofacial Radiology (OMR), AI has demonstrated significant potential in enhancing the detection, characterization, and management of oral diseases. This narrative review synthesizes evidence from recent literature focusing on the integration of AI into oral healthcare and explores its impact on diagnostic imaging, oral potentially malignant disorders (OPMDs), oral cancer, salivary diagnostics, temporomandibular disorders, and digital dentistry.

Recent advancements in machine learning, deep learning, convolutional neural networks, computer vision, and predictive analytics have enabled the development of intelligent systems capable of analyzing complex clinical and radiographic datasets with remarkable precision. AI-assisted technologies have demonstrated promising results in detecting dental caries, periodontal bone loss, periapical lesions, maxillofacial pathologies, and oral malignancies while simultaneously supporting treatment planning and prognostic assessment. Furthermore, the integration of AI with digital imaging modalities such as cone-beam computed tomography (CBCT), magnetic resonance imaging (MRI), intraoral scanning, and digital pathology has significantly enhanced diagnostic efficiency and workflow optimization. Beyond diagnosis, AI facilitates predictive modeling and precision medicine by integrating clinical findings, radiological information, histopathological data, and molecular biomarkers. Emerging technologies including radiomics, salivary biosensors, lab-on-chip diagnostics, wearable monitoring devices, and digital twins are expected to further transform oral healthcare. However, challenges related to data quality, algorithmic bias, explainability, privacy concerns, regulatory frameworks, and clinician acceptance remain important barriers to widespread implementation.

AI should be viewed as a complementary clinical decision-support tool rather than a replacement for professional expertise. The future of Oral Medicine and Oral Radiology lies in the convergence of intelligent technologies, precision diagnostics, and personalized therapeutic strategies that enable earlier disease detection, improved prognostication, and optimized patient-centered care.

Keywords

Artificial Intelligence, Oral Medicine, Oral Radiology, Oral Cancer, Precision Dentistry, Machine Learning, CBCT, Predictive Diagnostics.

Introduction

Oral Medicine and Oral and Maxillofacial Radiology occupy a unique position within dentistry because of their central role in the diagnosis and management of oral diseases. The specialty frequently [1-3] encounters complex disorders such as oral potentially malignant disorders (OPMDs), oral cancer, salivary gland diseases, temporomandibular disorders, and maxillofacial pathologies that require accurate clinical examination, imaging interpretation, histopathological assessment, and longitudinal follow-up. Despite advances in diagnostic methodologies, conventional approaches remain susceptible to observer variability, delayed diagnosis, and

limitations in predicting disease progression [4,5].

The rapid evolution of artificial intelligence (AI) has introduced unprecedented opportunities to address these challenges. AI refers to computational systems capable of performing tasks that traditionally require human intelligence, including pattern recognition, decision-making, image analysis, and predictive modeling. Through machine learning (ML) and deep learning (DL) algorithms, AI can analyze large volumes of clinical and radiographic data with speed and consistency that surpass conventional methods [6-7].

The transition from traditional diagnostic paradigms to AI-assisted healthcare represents a major milestone in oral healthcare. Rather than relying solely on clinician interpretation, modern diagnostic systems increasingly integrate AI-based image analysis, predictive analytics, digital pathology, and biomarker assessment. This transformation aligns with the broader concept of precision medicine, which seeks to provide individualized healthcare based on patient-specific biological, clinical, and environmental factors [2,8-10].

This narrative review critically synthesizes current evidence regarding AI applications in Oral Medicine and Oral Radiology and explores future directions toward precision oral healthcare.

Fundamentals of Artificial Intelligence in Dentistry

Artificial intelligence encompasses several interconnected technologies that have found applications in oral healthcare (Table 1).

Artificial Intelligence in Oral Medicine

Oral Potentially Malignant Disorders

Early diagnosis of OPMDs remains one of the most important responsibilities of oral physicians. Conditions such as leukoplakia, oral submucous fibrosis, oral lichen planus, and erythroplakia exhibit varying risks of malignant transformation and often present diagnostic challenges (Table 2). AI-powered image analysis systems can identify subtle clinical changes that may be overlooked during routine examination. Deep learning models trained on large image databases have demonstrated the ability to classify lesions based on morphological and colorimetric characteristics. More importantly [1,9], AI can integrate clinical photographs, histopathological findings, demographic information, and molecular biomarkers to generate individualized risk profiles. Such predictive systems may enable clinicians to identify high-risk lesions earlier and implement targeted surveillance protocols, thereby improving outcomes through timely intervention [10-12]. Oral squamous cell carcinoma remains a major global health burden, particularly in regions with high tobacco and areca nut consumption. Delayed diagnosis continues to contribute significantly to poor survival rates.

AI applications in oral oncology extend beyond lesion detection. Machine learning algorithms have demonstrated potential in screening, diagnosis, grading, staging, margin assessment, recurrence prediction, and survival estimation. Digital pathology platforms equipped with AI can analyze histopathological slides, identify dysplastic changes, quantify tumor characteristics, and assist pathologists in diagnostic interpretation. Furthermore, predictive AI models combining clinical, radiological, histopathological, and molecular information can support precision oncology by forecasting treatment response and disease progression [13-17]. Saliva is increasingly recognized as a valuable diagnostic medium containing proteins, nucleic acids, metabolites, cytokines, and biomarkers associated with oral and systemic diseases. AI-driven biosensor systems can analyze complex salivary datasets and identify disease-specific biomarker signatures. Integration of AI with lab-on-chip technologies offers the possibility of rapid chairside diagnostics for oral cancer, Sjögren syndrome, periodontal diseases, and other oral conditions [13,18]. This non-invasive approach represents an important step toward personalized and preventive oral healthcare.

Temporomandibular disorders (TMDs) are multifactorial conditions requiring comprehensive assessment of clinical, functional, and radiographic findings. AI-assisted interpretation of CBCT and MRI datasets has shown promise in identifying condylar abnormalities, disc displacement, osteoarthritic changes, and joint degeneration. By integrating imaging findings with clinical parameters, AI may facilitate more accurate diagnosis and individualized treatment planning. Among all dental specialties, Oral and Maxillofacial Radiology has witnessed the most extensive implementation of AI technologies [1,12,15]. Deep learning algorithms have demonstrated high sensitivity and specificity in detecting dental caries, periapical lesions, root fractures, and periodontal bone loss. Automated interpretation reduces observer variability and improves diagnostic consistency. AI systems have successfully identified impacted teeth, odontogenic cysts, jaw tumors, osteoporosis-related changes, and maxillary sinus

Table 1: Core AI Technologies and Applications in Oral Healthcare.

Technology	Definition	Oral Medicine Application
Artificial Intelligence	Simulation of human intelligence by machines	Clinical decision support
Machine Learning	Learning patterns from data without explicit programming	Disease prediction
Deep Learning	Multi-layer neural networks for complex analysis	Oral lesion classification
CNNs	Specialized neural networks for image analysis	Radiographic interpretation
Computer Vision	Automated image recognition	Oral cancer screening
Natural Language Processing	Analysis of textual information	Clinical documentation
Generative AI	Content and decision-support generation	Treatment planning assistance
Predictive Analytics	Forecasting future outcomes	Malignant transformation prediction

pathologies on panoramic images. Automated landmark detection and tooth numbering further enhance workflow efficiency. CBCT generates large datasets requiring extensive interpretation. AI-driven software can automate segmentation, anatomical mapping, pathology detection, and volumetric analysis. Applications include Implant planning, TMJ evaluation, Airway assessment, Maxillofacial surgical planning [13-17,19].

Magnetic Resonance Imaging

MRI remains the gold standard for soft tissue evaluation of the temporomandibular joint. AI-assisted MRI interpretation improves identification of disc displacement, inflammatory changes, and degenerative joint disorders. And in other radiological imaging modalities (Table 3).

Table 2: AI Applications in Oral Medicine.

Clinical Area	AI Application	Clinical Benefit
Leukoplakia	Risk assessment	Early intervention
OSMF	Disease progression prediction	Improved monitoring
Oral Lichen Planus	Lesion classification	Enhanced diagnosis
Oral Cancer	Screening and prognosis	Improved survival
Salivary Disorders	Biomarker analysis	Non-invasive diagnosis
TMDs	MRI interpretation	Better treatment planning

Table 3: AI Applications in Oral Radiology.

Imaging Modality	AI Application
Intraoral Radiographs	Caries detection
Panoramic Imaging	Tooth numbering and pathology detection
CBCT	Automated segmentation
MRI	TMJ assessment
Ultrasound	Salivary gland evaluation
Optical Imaging	Oral cancer screening

The integration of AI with digital dentistry has created an interconnected ecosystem that enhances diagnosis, treatment planning, and patient care. Digital impressions, intraoral scanners, CAD/CAM systems, virtual surgical planning, and three-dimensional printing technologies allow clinicians to develop highly customized treatment solutions. AI-assisted workflows improve accuracy while reducing procedural errors and treatment time.In oral surgery, AI-driven planning software facilitates implant placement, orthognathic surgery, reconstructive procedures, and guided surgical interventions [20-21]. The incorporation of augmented reality and robotic assistance further enhances surgical precision and patient safety.

AI-Driven Clinical Workflow

Artificial intelligence offers numerous advantages that have the potential to transform Oral Medicine and Oral and Maxillofacial Radiology. One of its most significant benefits is improved diagnostic accuracy, as AI algorithms can analyze complex clinical, radiographic, and histopathological datasets with high precision and consistency, thereby reducing diagnostic errors and inter-observer variability. AI systems also facilitate early disease detection, particularly for oral potentially malignant disorders, oral cancer, periodontal disease, and temporomandibular joint abnormalities, allowing clinicians to intervene at earlier stages when treatment outcomes are more favorable. Furthermore, AI contributes substantially to workflow efficiency by automating repetitive tasks such as image segmentation, lesion detection, tooth numbering, report generation, and radiographic interpretation, enabling clinicians to devote more time to patient management. Another important advantage is its capacity for predictive analytics, whereby machine learning models can forecast disease progression, treatment response, recurrence risk, and long-term outcomes using large clinical datasets. AI additionally supports personalized patient care by integrating imaging findings, clinical parameters, histopathological data and molecular biomarkers to generate individualized diagnostic and therapeutic recommendations. By minimizing subjective interpretation and promoting standardized assessments, AI also helps reduce observer variability, thereby enhancing diagnostic consistency across practitioners and healthcare institutions.

Despite these promising benefits, several important limitations continue to restrict the widespread adoption of AI in clinical practice. A major challenge is data bias, which arises when AI systems are trained on datasets that do not adequately represent diverse populations, potentially resulting in reduced accuracy and inequitable healthcare outcomes. Closely related is the issue of limited and heterogeneous datasets, as many existing studies rely on small sample sizes, retrospective data, or institution-specific

databases, thereby limiting the generalizability of developed models. Another concern is the black-box nature of deep learning algorithms, where the decision-making process remains difficult to interpret, creating challenges in clinician trust, accountability, and explainability [22-24].Ethical considerations also remain prominent, particularly regarding patient privacy, data ownership, informed consent, cybersecurity, and medico-legal responsibility when AI-generated recommendations influence clinical decisions. In addition, the absence of universally accepted regulatory frameworks and validation standards presents significant regulatory barriers to implementation. Finally, the cost of implementation, including investments in digital infrastructure, advanced imaging systems, software platforms, computational resources, and workforce training, may limit accessibility, particularly in resource-constrained healthcare settings. Consequently, while AI demonstrates tremendous potential as a clinical decision-support tool, its successful integration into Oral Medicine and Oral Radiology will require continued efforts toward transparent algorithm development, robust validation, ethical governance, and equitable access to technology.

Limitations and Challenges

Despite significant progress, several limitations continue to impede widespread clinical adoption.Data quality remains a critical concern. AI systems require large, diverse, and accurately labeled datasets to achieve reliable performance. Many existing models are trained on limited populations, raising concerns regarding bias and generalizability. The black-box nature of deep learning algorithms also limits clinician trust and explainability [1,17,21]. Ethical concerns surrounding privacy, data ownership, cybersecurity, and medico-legal accountability require careful consideration.Additionally, implementation costs, infrastructure requirements, and regulatory approval processes remain barriers, particularly in resource-constrained healthcare settings.

Future Perspectives

The future of Oral Medicine will likely be driven by the convergence of AI, molecular diagnostics, biosensor technologies, and precision medicine. Emerging innovations include digital twins, radiomics, wearable biosensors, AI-assisted salivary diagnostics, multi-omics integration, and autonomous diagnostic platforms. These technologies have the potential to continuously monitor oral health, predict disease onset, and provide real-time clinical decision support.AI-powered lab-on-chip systems may facilitate rapid chairside screening of oral potentially malignant disorders and oral cancer, enabling earlier intervention and improved patient outcomes [22-24].

Emerging technologies are expected to redefine the future of Oral Medicine by enabling more precise, predictive, and personalized healthcare. Digital twins will create virtual patient models that simulate disease progression and treatment outcomes before clinical intervention. Radiomics will transform conventional imaging into a source of quantitative biomarkers, facilitating early disease detection and prognostic assessment. The integration of multi-omics data, including genomics, proteomics, transcriptomics, and metabolomics, will support precision diagnostics and individualized treatment strategies. Lab-on-chip devices will enable rapid chairside and point-of-care testing for oral diseases using minimal biological samples. Wearable biosensors will allow continuous monitoring of oral and systemic health parameters, providing real-time clinical information. Furthermore, AI-driven oncology platforms will integrate clinical, radiological, histopathological, and molecular data to support personalized cancer diagnosis, prognostication, and treatment planning, paving the way toward precision oral healthcare [1,13,16,22-24].

Conclusion

Artificial intelligence is fundamentally transforming Oral Medicine and Oral and Maxillofacial Radiology by enhancing diagnostic precision, improving workflow efficiency, enabling predictive analytics, and supporting personalized patient care. Current evidence demonstrates significant potential in the diagnosis and management of oral potentially malignant disorders, oral cancer, salivary gland diseases, temporomandibular disorders, and maxillofacial pathologies. While challenges related to data quality, ethics, transparency, and implementation remain, AI should be viewed as a powerful adjunct to clinical expertise rather than a replacement for professional judgment. The future of oral healthcare lies in the integration of intelligent technologies with precision medicine approaches, creating a proactive and patient-centered model of care capable of improving outcomes across the spectrum of oral diseases.

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