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Artificial Intelligence in Oral Pathology and Oral Medicine: Current Applications, Challenges, and Future Directions

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ABSTRACT

Artificial intelligence (AI) has rapidly expanded its utility within oral pathology and oral medicine, offering promise for diagnostic enhancement, risk stratification, lesion detection, and workflow optimization. Deep learning (DL) models applied to whole-slide imaging have shown potential in grading oral epithelial dysplasia (OED), detecting oral squamous cell carcinoma (OSCC), and identifying features with prognostic significance. Similarly, clinical image-based AI applications in oral medicine are advancing lesion triage and tele-oral healthcare. Despite encouraging results, several translational challenges persist, including dataset scarcity, limited external validation, model explainability, and

regulatory constraints. This review provides a comprehensive synthesis of current evidence, applications, limitations, and future directions for AI integration in oral pathology and oral medicine.

Keywords

Artificial intelligence; oral pathology; oral medicine; oral cancer; deep learning; histopathology; clinical imaging; diagnosis; telemedicine.

1. Introduction

Oral pathology and oral medicine are critical specialties for diagnosing and managing diseases of the oral and maxillofacial region. Conditions such as oral squamous cell carcinoma (OSCC) and oral potentially malignant disorders (OPMDs) require early and accurate detection to improve clinical outcomes. However, subjective interpretation and variability in diagnostic processes limit both clinical and histopathologic evaluation. The integration of AI—especially deep learning (DL) and convolutional neural networks (CNNs)—promises to support clinicians by enhancing consistency and enabling quantitative analyses in both disciplines [1–4].

2. AI Technologies in Oral Pathology and Oral Medicine

2.1 Machine Learning and Deep Learning

Traditional machine learning (ML) models employ engineered features, but have limitations when handling complex visual patterns of oral tissue. DL methods, particularly CNNs, can learn hierarchical features from raw images, offering superior performance in tasks like classification, detection, and segmentation [5–7].

2.2 Whole-Slide Imaging (WSI) and Clinical Image Analysis

WSI enables digital pathology workflows suitable for AI model training, whereas clinical photography supports AI-based lesion recognition in oral medicine. These digital frameworks form the backbone of contemporary AI applications within oral health [8,9].

3. Workflow of AI Integration

A standard AI workflow includes data collection and annotation, preprocessing (e.g., color normalization), model training, validation, performance evaluation, and explainability visualization (e.g., heatmaps). Prospective validation and clinical evaluation are crucial for safe implementation [4,10].

4. AI in Oral Pathology

4.1 AI for Oral Epithelial Dysplasia (OED) and OPMDs

AI systems have been trained to detect and grade dysplasia, reducing subjectivity and variability. Algorithms can quantify nuclear atypia, keratinization, and architectural features associated with malignancy risk [2,5,6].

4.2 AI for OSCC Detection

AI-based models applied to histopathologic images demonstrate high performance in differentiating malignant from benign tissues, offering potential as adjunct diagnostic tools [4,8,11].

4.3 Prognostic and Predictive AI Models

Advanced models now quantify tumor microenvironment features—such as immune cell infiltrate and stromal ratios—that correlate with prognosis. These computational pathology models may enhance personalized risk stratification [12–14].

5. AI in Oral Medicine

5.1 Clinical Lesion Detection

AI models trained on clinical photographs have shown promise for identifying high-risk lesions, enabling

augmented screening in general dental or primary care settings [9,15].

5.2 Risk Stratification and Triage

AI integration with risk factors (e.g., tobacco exposure, lesion morphology) supports triage decisions, prioritizing urgent referrals and optimizing resource allocation [15,16].

5.3 Tele-Oral Healthcare and Community Screening

Telemedicine workflows enhanced by AI can improve access to specialist evaluation, particularly in underserved areas. AI can flag suspicious lesions in remote consultations and improve screening efficiency [9,16].

5.4 Decision Support and Clinical Documentation

Emerging applications include automated documentation, structured reporting, and integration with electronic health records to assist clinical decision making [15,17].

6. Benefits of AI Implementation

AI offers:

- **Improved reproducibility and consistency** in grading and diagnosis;
- **Quantitative metrics** for histologic and clinical features;
- **Workflow efficiency** in pathology and remote triage;
- **Enhanced clinician support** for complex diagnostic decisions [4,8,10,15].

7. Limitations and Challenges

Despite progress, limitations include:

- **Limited external validation** and small dataset sizes;
- **Variability in imaging protocols** (staining and photography);
- **Explainability challenges**, impacting clinical trust;
- **Regulatory and ethical considerations**, including accountability and data privacy [3,7,10,14].

8. Future Directions

Future efforts should emphasize:

- **Multimodal AI models** combining clinical, histologic, radiologic, and molecular data
- **Federated learning** to leverage multi-institutional datasets without compromising patient privacy
- **Prospective clinical trials** to assess real-world impact
- **Explainable AI frameworks** for enhanced clinician trust and regulatory compliance [3,13,14,17].

9. Conclusion

AI applications in oral pathology and oral medicine demonstrate significant promise in improving diagnostic accuracy, standardizing assessments, and enhancing screening pathways. However, widespread clinical adoption will require larger datasets, robust external validation, transparent models, and thoughtful ethical and regulatory frameworks. AI should be viewed as an augmentation tool designed to support expert clinicians rather than replace them.

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