

Review Article

Artificial intelligence in oral pathology: Current applications, challenges, and future prospects

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Abstract

The field of Artificial Intelligence (AI) is revolutionizing the diagnostics industry and oral pathology is no exception. AI has been leveraged for disease diagnosis in the field of diagnostics and deep learning (DL) and machine learning (ML) algorithms have been employed for histopathological analysis, which has been automated. AI has also shown tremendous potential in diagnostics, with a particular emphasis on improving disease diagnosis, as well as in histopathology, where deep learning (DL) and machine learning (ML) algorithms have been utilized to automate the process. AI systems can classify oral lesions and grade dysplasia, analyze cytology slides, and correlate clinical and molecular data for individual patient treatment planning. Nevertheless, there are still hurdles, such as the lack of high-quality data, variability in staining and slide preparation procedures, a lack of interpretability and regulatory and ethics concerns. The aim of this review was to present the present situation of AI in oral pathology, its clinical applications, challenges and limitations, and future directions for research and clinical use.

Keywords: Artificial intelligence, Oral pathology, Deep learning, Machine learning, Histopathology, Oral cancer.

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1. Introduction

Oral pathology is a branch of dentistry that deals with the diagnosis, management and study of diseases of the oral and maxillofacial cavity. The most important pathological conditions that require accurate histopathological assessment for management are oral squamous cell carcinoma (OSCC), oral potentially malignant disorders (OPMDs) and odontogenic tumors.¹ While the use of conventional histopathology is considered as a gold standard, it is time consuming, labor intensive and subject to interobserver variability particularly in defining dysplasia and tumor margins.²

AI has offered a new solution to overcome these challenges. AI is the ability to make computer systems perform tasks that normally require human intelligence, such as pattern recognition, decision making and learning from data.³ In the oral pathology field, AI systems can be used to assist pathologists in the diagnosis, prognosis, and risk stratification of oral diseases, using large databases of digitized histopathological slides and clinical data.

With recent progress in digitizing pathology slides and the availability of large datasets, AI algorithms, in particular deep learning models, have matched the performance of expert pathologists on a number of tasks. These advantages range from AI's capacity to reduce the likelihood of misdiagnosis, to streamlining processes and providing predictions that can guide individual patient treatment.

Machine learning is a part of AI that involves applying statistical techniques to empower computers to learn from data and predict patterns. Commonly used ML algorithms include support vector machine (SVM), random forest (RF) and k-nearest neighbor (k-NN).⁴ In oral pathology, ML has been applied in classification of oral lesions, prediction of malignant transformation of OPMDs and in automation of the detection of OP histological features such as nuclear atypia and keratin pearls.

Images can be used for feature extraction, such as texture, shape and color, which are set manually before training the algorithm in the ML model.⁵

ML is a branch of deep learning, where complex patterns in the raw data are automatically learned by designing multiple layers of artificial neural networks, thereby avoiding feature engineering. For image-based tasks such as histopathological slide analysis, convolutional neural networks (CNNs) proved to be successful.⁶

CNNs have been used to automatically detect the OSCC, categorize the dysplasia and segment the tumor regions in digitized HPE slides. CNN models have been applied to H&E-stained slides for the OSCC detection with a sensitivity of 92% and specificity of 90%.⁵ CNNs are well suited to work with large data sets and learn complex patterns that may not be obvious to human observers, which makes them suitable for high throughput pathology applications.

In recent years, some research had been done on integrating CNNs with recurrent neural networks (RNNs) into hybrid architectures for sequential analysis of image patches and the integration of clinical information to further enhance predictive ability.⁶

NLP is a subset of AI and its focus is to extract valuable insights from unstructured text data. Oral pathology could utilize NLP to analyze pathology reports, clinical notes, and EHR systems to identify patterns, risk factors, and outcomes of oral diseases.⁷

For example, NLP algorithms can be used to classify patients who are at high risk of having OPMDs into clinical

data sets (thereby enabling early patient intervention and reducing manual workload). Multi-modal AI systems can leverage histopathological images along with clinical report texts to create detailed patient profiles when used in conjunction with models such as NLP or DL.

2. Review

2.1. The oral cancer screening and diagnosis includes the following topics

Oral cancers are over 90% OSCCs. The prognosis becomes poor when diagnosed at a late stage therefore early diagnosis is crucial. CNN based AI systems have been found to have a very high sensitivity and specificity in the detection of OSCC from the Digitized slides, sometimes even outperforming the human pathologists.⁸

Another area where AI can assist in the evaluation of oral lesions for the potential of cancerous development is in the assessment of precancerous conditions such as leukoplakia and erythroplakia. In addition, AI can serve as a decision support system for the pathologist, such as by marking up any suspicious areas on the slides and possibly improving the accuracy of diagnosis, and reducing the number of lesions that go undiagnosed.⁹

2.2. Histopathological grading

The classification of the epithelial dysplasia and OSCC has a significant role in the prognosis and treatment planning of OSCC. The traditional histopathology is subjective and interobserver variability exists. With the aid of the AI algorithms, particularly CNNs, the rate of accuracy in the diagnosis of dysplasia and differentiating between low and high-risk lesions has been shown to be high and to be well in agreement with expert pathologists.¹⁰

2.3. Predicting disease prognosis

Histopathology, clinical parameters, and molecular information can all be combined with AI models to forecast disease outcomes. Dixit S et al. developed an ML model based on histopathology and genomic markers with high accuracy to accurately predict OSCC recurrence.¹¹

These prediction models can be used to inform personalized treatment, including those patients who may require more aggressive treatment than those who might be better off on a conservative approach. AI can also have a role to play in survival analysis and risk stratification, which can improve overall care for patients.¹²

2.4. Oral cytology

Brushing cytology is a non-invasive diagnosis technique of oral lesions. Automated classification of cells and detection of abnormal cells with high sensitivity using AI-assisted cytology. Researchers found that ML models performed well in detecting malignant and premalignant cells in cytology specimens, thus minimizing human error and facilitating quick screening in primary care.¹³

AI-based cytology is particularly valuable in regions where there is a scarcity of skilled pathologists, providing a cost-effective screening solution for early cancer detection.

2.5. Telepathology

Telepathology is a style of diagnosis, namely diagnosis from digital slides in a distant place. The use of AI can complement tP by pre-screening slides, identify potential suspicious cases, and make initial evaluations.¹⁴

3. Discussion

The use of AI in oral pathology has great potential, but there are still some challenges that need to be addressed before AI can be widely used in clinical practice. The other primary concern is the scarcity of data, as good data is essential for developing quality AI models. In addition, there are numerous existing studies with small numbers of patients, which are not suitable for extrapolating the results of these studies to other populations or to other clinical scenarios.¹⁵ Standardization is closely related since the staining methods, slide preparation, and imaging equipment can vary considerably and affect the accuracy of AI models at various locations, making it difficult to validate the results across various institutions. Another difficulty is interpretability, as the models used in deep learning are generally a “black box” and it's hard to decipher how certain decisions are taken for a diagnosis.¹⁶ Addressing this, explainable AI (XAI) is crucial to increase transparency, trust, and clinical adoption. Furthermore, regulatory and ethical considerations are of high priority especially when it comes to patient data confidentiality, informed consent and regulatory matters (FDA, CE marking etc.). The other challenges are computational requirements, implementation costs, and seamlessly integrating AI tools into existing laboratory information systems, which may impede their widespread use and integration, especially in resource-limited settings.¹⁷

There are several possible directions that could contribute to overcoming these challenges and further improve the use of AI in oral pathology in the future. Looking ahead, there are several potential future

directions that could further address these challenges and expand the possibilities of AI's role in oral pathology. In the future, there may be several new directions that will continue to mitigate these challenges and extend the applications of AI in oral pathology. Multi-omics (genomics, transcriptomics, proteomics) combined with histopathology may play an important role in the improvement of prediction and precision medicine approaches patient by patient.¹⁸ The development of XAI is also critical, and an interpreted model will allow pathologists to check the results, understand the reasoning and easily incorporate AI recommendations into the diagnosis process. It is important to comprehensively evaluate the performance of AI in clinical practice through well-designed clinical trials and prospective validation studies, and ensure that the technology is safe, reliable, and effective before it is used widely in clinical practice.¹⁹ But the international cooperation around the field has also tremendous potential to help the field, as it would be much easier to advance its research with the creation of common repositories of digitized oral pathology images with standardized annotations. These cooperative arrangements could also help to overcome ethnic and geographic differences in the representation of data. In the realm of dental education, AI has the potential to revolutionize the way dental students, residents, and practicing pathologists learn and practice the field. AI could be used to give instant feedback to the person interpreting the histopathological slides, highlighting the main diagnostic features and giving a structured learning experience.²⁰ With these technological innovations, smart regulation and interprofessional collaboration, AI can revolutionize oral pathology to become more precise, efficient, and accessible. The limitations noted today and the opportunities outlined for the future are key in determining the success of the implementation of AI into routine clinical practice, ensuring that the benefits of AI are felt by clinicians, patients, and in the highest standards of diagnostic quality, ethical responsibility and patient safety in the ever-changing landscape of digital pathology and modern dental healthcare worldwide.²¹

4. Conclusion

The way forward for AI in oral pathology is to enhance the diagnostic accuracy, minimize interobserver variations, and facilitate predictive analytics. They can be used for automated OSCC detection, modelling for prognosis, and telepathology assistance. Although issues of data quality, standardization, interpretation and regulation have arisen, there has been ongoing development in AI algorithms and digital pathology's uptake.

Abbreviations

AI: Artificial Intelligence

CE: Conformité Européenne

CNN: Convolutional Neural Network

DL: Deep Learning

EHR: Electronic Health Record

FDA: Food and Drug Administration

H&E: Hematoxylin and Eosin

HPE: Histopathological Examination

k-NN: k-Nearest Neighbor

ML: Machine Learning

NLP: Natural Language Processing

OPMDs: Oral Potentially Malignant Disorders

OSCC: Oral Squamous Cell Carcinoma

RF: Random Forest

RNN: Recurrent Neural Network

SVM: Support Vector Machine

tP: Telepathology

XAI: Explainable Artificial Intelligence

Author Contributions

Sajda Khan Gajdhar: Conceptualization, literature search, data collection, manuscript drafting, critical revision, and final approval of the manuscript.

Syed Mukith Ur Rahaman: Literature review, data interpretation, manuscript drafting, critical revision, and final approval of the manuscript.

Shaiq Gajdhar: Supervision, manuscript review and editing, critical intellectual input, and final approval of the manuscript.

Ethical Approval

Not applicable.

Declaration of Patient Consent

Not applicable.

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Conflict of Interest

None.

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