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MINI REVIEW

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The role of Artificial Intelligence in oral cancer diagnosis: A comprehensive review

Navendra Jha, Fatima Injela Khan, Faiza Khan and Sadiq Siddiqui

Department of Oral Medicine & Radiology, Institute of Dental Sciences, Bareilly, India.

ABSTRACT

Oral cancer (OC), the most common malignancy of the head and neck region, remains a global health concern due to its poor survival rates, largely resulting from delayed detection. While histopathology is the diagnostic gold standard, it is prone to inter-observer variability and is time-consuming, contributing to treatment delays. Emerging advancements in artificial intelligence (AI) offer transformative opportunities to address these limitations by enhancing diagnostic accuracy, efficiency, and reliability.

This review explores the critical role of AI in oral cancer detection, with a focus on its most promising applications. AI technologies, including machine learning (ML) and deep learning (DL), have demonstrated exceptional capabilities in analysing medical images, such as histopathological slides, radiographs, and intraoral photographs. Deep learning models, particularly convolutional neural networks (CNNs), excel in detecting malignant lesions and precancerous conditions with high sensitivity and specificity. Additionally, AI-powered systems can automate cytological analysis, extract radiomic features for early lesion identification, and support personalized care through risk stratification and prognostic predictions. Telemedicine applications leveraging AI enable real-time diagnostics in underserved regions, improving access to quality care.

However, several barriers hinder the widespread adoption of AI in clinical practice. Challenges include the scarcity of high-quality, annotated datasets for model training, the need for seamless integration into clinical workflows, and compliance with ethical and regulatory standards. Furthermore, successful implementation demands clinician training and patient-centred development to ensure usability and trust.

This review underscores AI's transformative potential in oral cancer diagnostics while addressing the challenges that need resolution. Future priorities should include fostering data-sharing initiatives, advancing algorithm adaptability for diverse clinical scenarios, and conducting rigorous clinical trials to validate AI tools. These efforts can drive earlier detection and improve outcomes for patients with oral cancer.

KEYWORDS

CBCT; Oral cancer; AI; Convolutional Neural Networks; Telemedicine

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Introduction

Oral cancer is the most prevalent malignancy in the oral cavity, ranking as the sixth most common cancer worldwide [1]. It predominantly affects middle-aged males more than females. The primary risk factors linked to oral cancer include tobacco and alcohol use, infection with the Human Papillomavirus (HPV), and inadequate oral hygiene. Early symptoms can be subtle, often resulting in delayed diagnosis. Oral cancer poses a major global health challenge, primarily due to its high mortality and morbidity rates associated with late diagnosis. Early detection is crucial for effective treatment and improved patient outcomes [2]. Traditional diagnostic methods, which rely on visual evaluation, can often lead to underdiagnosis.

Additionally, biopsy procedures, while necessary, are invasive and uncomfortable for many patients, making them impractical for widespread screening [3]. Imaging modalities such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT), and Positron Emission Tomography (PET) can aid in diagnosis, but they are often expensive and sensitive to technique variations. Histopathological analysis through microscopy is considered the gold standard for diagnosing oral cancer [4].

However, this method can be time-consuming and subject to interpretation errors due to variability among pathologists. To address these limitations, there is a pressing need for improved diagnostic techniques [5]. Recently, artificial intelligence (AI) has begun to transform the medical landscape, offering innovative solutions for the early detection and diagnosis of oral cancer. AI-powered technologies hold the potential to enhance the accuracy, speed, and consistency of oral cancer diagnoses, which could result in earlier detection and improved patient outcomes [6]. Additionally, digital pathology is gaining traction as an effective approach for quantitative analysis in this field. Recent advancements have led to the development of automated methods that offer

***Correspondence:** Dr. Navendra Jha, Senior Lecturer, Department of Oral Medicine & Radiology, Seema Dental College and Hospital, Rishikesh, Uttarakhand, India. email: drnavendrajha@gmail.com

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architectural insights for detecting oral cancer through the analysis of morphological parameters [7].

Oral Cancer Detection using AI Technologies

Machine learning (ML) and deep learning (DL) algorithms are increasingly being utilized to create models that aid in the detection, classification, and prediction of oral cancer [8]. Key applications include-

Image analysis and classification

AI can efficiently analyze medical images, including histopathological slides, radiographs, and intraoral photographs, often outperforming human experts. Deep learning models, particularly convolutional neural networks (CNNs), have demonstrated high accuracy in detecting abnormal lesions and distinguishing between benign and malignant conditions. These AI-driven systems can process large datasets and uncover patterns that may be too subtle for human observation, enhancing both diagnostic sensitivity and specificity [9].

Oral cytology: Artificial intelligence (AI) enhances oral cytology by automating malignant cell identification, reducing the need for invasive biopsies, and expediting diagnosis. Studies report AI models achieving high sensitivity (0.87) and specificity (0.81) in detecting oral cancers and potentially malignant disorders. Additionally, AI-assisted cytopathological analyses have demonstrated increased diagnostic accuracy, sensitivity, and specificity across various cancer types. These advancements suggest AI's significant potential in improving non-invasive oral cancer diagnostics [10].

Radiomics: AI can extract features from radiographic images that are not discernible to the naked eye, facilitating the early detection of potentially cancerous lesions.

Histopathological image analysis

Histopathological examination is the cornerstone of oral cancer diagnosis. AI can support pathologists by automating the analysis of tissue samples, which enhances accuracy and minimizes inter-observer variability. Automated systems utilizing deep learning (DL) have shown superior performance in identifying cancerous tissue, grading tumour severity, and predicting patient outcomes based on histological features [11].

Early detection of precancerous lesions

AI can aid in the early detection of oral cancer by identifying precancerous lesions, such as leukoplakia and Erythroplakia, which have a higher risk of malignant transformation. These AI tools can also assess the likelihood of lesion progression, facilitating timely interventions and ongoing monitoring [7].

Risk stratification and prognostic prediction

AI models can integrate various data sources, including patient demographics, clinical history, genetic markers, and imaging results, to stratify patients based on their risk of developing oral cancer. Additionally, predictive algorithms can estimate the likelihood of tumour recurrence and overall survival, supporting personalized treatment planning [8].

Telemedicine and remote diagnosis

AI facilitates the creation of remote diagnostic tools that can be integrated into telemedicine platforms. These systems enable healthcare professionals to accurately assess suspicious lesions in underserved areas or regions with limited access to specialized care. For instance, AI-powered smartphone applications can analyze intraoral images and provide real-time feedback on the likelihood of malignancy [12].

Natural Language Processing (NLP)

AI's NLP capabilities can enhance the analysis of electronic health records (EHRs) by extracting relevant clinical information related to oral cancer. This functionality supports clinical decision-making, automates the identification of patients at higher risk, and helps ensure timely follow-up care [8].

Benefits of AI in Oral Cancer Detection

Artificial intelligence (AI) is transforming medical diagnostics by enhancing accuracy, efficiency, cost-effectiveness, standardization, and accessibility [12].

Increased accuracy

AI algorithms analyze complex medical data, identifying patterns that may be overlooked by clinicians, thereby reducing misdiagnosis rates and ensuring timely interventions. For instance, AI has demonstrated high accuracy in detecting various cancers, surpassing traditional diagnostic methods [13].

Efficiency

AI rapidly processes large datasets, expediting diagnostics and facilitating prompt decision-making. In radiology, AI reduces the time required for image analysis, allowing for quicker diagnoses and improved patient management [14].

Cost-effectiveness

By automating diagnostic procedures, AI minimizes the need for multiple invasive tests and expensive evaluations, potentially lowering overall healthcare costs. AI's efficiency in diagnostics can lead to significant cost savings in medical imaging and other diagnostic services [15].

Standardization

AI provides consistent analyses, reducing variability in diagnostic interpretations among clinicians. This standardization enhances diagnostic reliability and improves patient outcomes by ensuring uniformity in medical assessments [16].

Accessibility

AI tools can be deployed in remote or resource-limited settings, enhancing access to quality diagnostic services for underserved populations. AI-driven diagnostics facilitate healthcare delivery in areas lacking specialized medical professionals, improving global health equity [17].

Challenges in Implementing AI for Oral Cancer Detection

The integration of artificial intelligence (AI) into healthcare presents several regulatory and ethical challenges that must be addressed to ensure safe and effective implementation.

Data quality and quantity

Developing effective AI models necessitates access to high-quality, annotated datasets. However, the availability of such comprehensive data is often limited, posing significant

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challenges for training robust AI systems. Ensuring data diversity and accuracy is crucial to prevent biases and enhance the generalizability of AI applications [18].

Integration with clinical workflow

For AI tools to be practical, they must seamlessly integrate into existing clinical workflows. This integration requires user-friendly interfaces and interoperability with electronic health records (EHRs). Achieving such compatibility ensures that AI applications complement healthcare professionals' routines without causing disruptions [19].

Regulatory and ethical considerations

Ensuring the safety, efficacy, and ethical application of AI in healthcare is critical. Regulatory bodies like the U.S. Food and Drug Administration (FDA) have developed frameworks to oversee AI-based medical devices, focusing on transparency, accountability, and patient safety. Ethical challenges include addressing data bias, ensuring informed consent, and maintaining patient privacy. The World Health Organization (WHO) has outlined six principles for AI in health, emphasizing the need for ethical considerations in AI deployment [20].

Training and education

Clinicians require adequate training to effectively utilize AI tools and accurately interpret their outputs. Educational initiatives should focus on enhancing digital literacy among healthcare professionals, enabling them to integrate AI applications into patient care safely and effectively. Continuous professional development programs are essential to keep pace with the rapidly evolving AI technologies in healthcare [21].

Future Directions

Enhanced data sharing and collaboration

Promoting inter-institutional collaboration to develop large, annotated datasets is crucial for training and validating AI models. The UK government's initiative to grant tech companies access to National Health Service (NHS) health data aims to foster AI development, highlighting the importance of data sharing in advancing medical AI applications [22].

Advanced AI algorithms

Ongoing development of AI algorithms capable of processing diverse data types and integrating multimodal information enhances diagnostic accuracy and robustness. For instance, the Broad Institute's collaboration with Manifold to build an AI-enabled life sciences research platform exemplifies efforts to create systems that can handle complex, heterogeneous biomedical data [23].

Clinical trials and validation

Conducting extensive clinical trials to validate AI tools ensures their efficacy and safety in real-world applications. The Radiological Society of North America's (RSNA) creation of a COVID-19 data collection for AI researchers demonstrates the importance of curated datasets in facilitating clinical validation of AI models [24].

Patient-centric AI

Focusing on patient-centered care in the development of AI tools ensures that these technologies meet patient needs and enhance overall healthcare experiences. The World Health Organization (WHO) emphasizes the importance of ethical considerations in AI deployment, advocating for transparency, accountability, and inclusivity to maintain public trust and prioritize patient welfare [25].

Conclusions

AI-powered technologies have the potential to revolutionize oral cancer detection by enhancing diagnostic accuracy, efficiency, and consistency. Late-stage diagnosis and high mortality rates underscore the need for early detection to improve patient outcomes. Traditional methods, such as histopathology and imaging, while reliable, are time-consuming and subject to variability. AI-driven approaches, including machine learning and deep learning, can analyze vast datasets, identify intricate patterns, and provide objective diagnostic insights with high precision.

Studies have shown that AI models, particularly convolutional neural networks (CNNs), achieve over 90% accuracy in distinguishing malignant from benign oral lesions. AI-based cytological analysis reduces the need for invasive biopsies and accelerates diagnostic workflows. Furthermore, radiomic AI applications extract imaging features undetectable by the human eye, aiding in early diagnosis and risk stratification.

However, several challenges hinder AI's clinical adoption. The availability of high-quality annotated datasets remains a significant obstacle, as AI models require extensive and diverse data for effective training and validation. Regulatory and ethical concerns, including data privacy, algorithm bias, and clinical validation, must also be addressed to ensure safe and effective implementation. Collaboration between healthcare institutions, regulatory bodies, and AI developers is essential to overcome these challenges.

In conclusion, ongoing research, interdisciplinary collaboration, and investment in AI will facilitate its seamless integration into clinical practice. Addressing data limitations and regulatory challenges will enable AI to enhance diagnostic accuracy, expedite detection, and ultimately improve survival rates and quality of life for patients with oral cancer.

Disclosure Statement

No potential conflict of interest was reported by the author.

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