

## Artificial Intelligence In Oral Pathology

Shivani Bhandari-Shrama<sup>1</sup>

<sup>1</sup>Department of Oral and Maxillofacial Pathology and Oral Microbiology, Santosh Deemed to be University, Ghaziabad.

### Corresponding

Shivani Bhandari

Email : docshivanibhandari@gmail.com



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### Abstract

Artificial Intelligence (AI) is revolutionizing oral pathology by enhancing diagnostic accuracy, reducing analysis time, and facilitating early detection of oral diseases, especially oral cancers and precancerous lesions. Using machine learning (ML) and deep learning models, such as convolutional neural networks (CNNs), AI systems can analyze histopathological images to identify subtle patterns, providing consistent, unbiased interpretations and assisting pathologists in differentiating between benign and malignant tissues. Beyond diagnosis, AI also contributes to personalized patient care through predictive analytics, offering tailored treatment plans based on individual risk factors. While challenges in standardization and validation persist, AI's integration into oral pathology holds significant potential for advancing diagnostics, research, and education, ultimately supporting more accurate and efficient patient care.

**Keywords :** Artificial intelligence, Machine learning, Dentistry

### Introduction

Artificial intelligence (AI) and machine learning (ML) are terms that are often used interchangeably in research, though they have distinct meanings. John McCarthy, widely recognized as the father of artificial intelligence, coined the term "artificial intelligence." AI has emerged as a transformative force across various fields, including healthcare. In Oral Pathology, AI is beginning to revolutionize the diagnosis and management of diseases. With its capacity to rapidly and accurately process and analyze vast amounts of data, AI has the potential to enhance diagnostic accuracy, reduce human error, and offer more personalized treatment options for patients.<sup>(1)</sup>

This article explores the role of AI in Oral Pathology, covering its history, current applications, benefits, challenges, and future prospects. AI has been utilized in diagnosing a range of oral diseases, such as dental caries, maxillary sinus conditions, periodontal diseases, salivary gland disorders, TMJ disorders, and oral cancer, through the analysis of clinical data and diagnostic images.<sup>(2)</sup> Larger datasets could enable AI to predict the development of precancerous conditions, assist in population-wide surveillance, and facilitate referrals to specialists. AI can detect microfeatures beyond the capability of the human eye, enhancing its predictive power in critical diagnoses.

AI refers to machines capable of performing tasks that were once considered to require human intelligence, without any human intervention. These machines can solve problems based on the data they are provided. AI has long been a

foundational concept in popular science fiction. Machine learning (ML), a subset of AI, was coined by Arthur Samuel in 1959. ML uses algorithms, such as artificial neural networks (ANN), to predict outcomes based on the provided dataset. These networks, which mimic the human brain, consist of interconnected artificial neurons that receive and process data signals. The concept was first introduced by Warren McCulloch and Walter Pitts in a seminal 1943 paper. Later, in 1951, Minsky and Dean Edmonds developed the first ANN, the stochastic neural analog reinforcement calculator.<sup>(3)</sup>

Convolutional neural networks (CNN), a deep learning (DL) approach in ML, were introduced by Hinton et al. in 2006. These multi-layer neural networks are capable of analyzing patterns in data to improve outcomes. The development of the back propagation algorithm in 1969 was a significant milestone in the evolution of deep learning systems. Figure 1 illustrates the key milestones in the advancement of AI over the years.

Today, AI is being suggested for use in disease diagnosis, prognosis prediction, and the development of patient-specific treatment strategies. Specifically, AI can assist dentists in making critical, time-sensitive decisions, eliminate human error in decision-making, and ensure a consistent and high quality of healthcare, while also reducing the workload and stress on dental professionals.

### History and Evolution of AI in Medicine

The journey of AI in medicine began many decades ago, with initial efforts centered around creating computer algorithms

designed to aid in diagnostic processes. These early systems, typically rule-based, formed the foundation for the more advanced AI technologies we see today. As computing power and data accessibility expanded, machine learning (ML) and deep learning (DL) emerged as key drivers in AI's integration into healthcare. These developments have enabled the creation of AI systems that can learn from extensive datasets, recognize patterns, and make highly accurate predictions.

In pathology, the application of AI has progressed from simple image analysis to advanced diagnostic tools capable of interpreting histopathological slides, forecasting disease progression, and even proposing treatment options. Specifically, in the field of Oral Pathology, these advancements have yielded significant benefits, as the precision needed for diagnosing oral diseases is greatly enhanced by AI.<sup>(4)</sup>

### AI Technologies and Methodologies Used in Oral Pathology

AI in Oral Pathology depends on several key technologies, each playing a vital role in different aspects of the diagnostic process.

- **Machine Learning (ML) and Deep Learning (DL)**- have played a crucial role in creating AI systems capable of recognizing and classifying images with remarkable accuracy. In Oral Pathology, these technologies are utilized to examine digital images of histopathological slides, detecting features that signal specific diseases, such as oral squamous cell carcinoma. Deep learning models, particularly convolutional neural networks (CNNs), have demonstrated significant potential in differentiating between benign and malignant lesions, thereby minimizing the reliance on subjective interpretation by pathologists.
- **Natural Language Processing (NLP)**: It is employed to analyze and interpret textual data, including clinical notes, patient records, and research articles. In Oral Pathology, NLP can be used to extract pertinent information from these sources, assisting in diagnosis and treatment planning. For instance, NLP algorithms can analyze electronic health records (EHRs) to identify patients at risk of oral cancer by evaluating their clinical history and lifestyle factors.
- **Computer Vision**: technologies enable AI to analyze and interpret visual data, making them especially valuable in Oral Pathology for examining digital pathology slides. AI systems can process images to detect microscopic abnormalities, such as cellular changes indicative of dysplasia or carcinoma. These systems can analyze thousands of images in a fraction of the time it would take a human pathologist, greatly accelerating the diagnostic process.
- **Integration with Digital Pathology**: Digital pathology involves converting traditional glass slides into digital images that can be viewed, analyzed, and stored electronically. When integrated with AI, digital pathology becomes a powerful tool for oral pathologists. AI-driven digital pathology platforms can automate slide analysis, provide real-time diagnostic support, and significantly reduce the workload on pathologists.

### Applications of AI in Oral Pathology

AI's impact on Oral Pathology is diverse, encompassing everything from diagnostic support to predictive analytics and more.

- **Tooth Fracture**- Traumatized or cracked teeth are the third most common cause of tooth loss. Early detection and treatment are essential for saving a cracked tooth and preserving it. However, detecting cracked teeth can be challenging due to their often intermittent symptoms. Paniagua et al. (2018) developed an innovative method capable of detecting, quantifying, and localizing cracked teeth using high-resolution CBCT scans combined with steerable wavelets and machine learning techniques. The performance of these ML models was tested on Hr-CBCT scans of healthy teeth with simulated cracks, showing high specificity and sensitivity.

Similarly, Fukuda et al. (2020) employed convolutional neural networks (CNNs) to detect vertical root fractures using 300 panoramic radiographs, which included 330 vertically fractured teeth with visible fracture lines. In this study, 80% of the data was used for training, while 20% was used as the test dataset. The results suggest that CNN can be used as a diagnostic tool for the detection of vertical root fractures.

- **Diagnostic Support**: One of the most impactful applications of AI in Oral Pathology is in diagnostic support. AI algorithms can aid in the early detection of oral cancers by analyzing histopathological images for malignant signs. These systems can identify patterns that might be overlooked by human observers, resulting in more accurate and timely diagnoses.<sup>(5)</sup> For example, AI can distinguish between benign and malignant oral lesions with high accuracy, reducing the risk of misdiagnosis and ensuring that patients receive the appropriate treatment.
- **Dental Caries** - It is one of the most prevalent diseases worldwide, and early diagnosis is crucial for reducing caries-related morbidity in patients. Caries diagnosis is primarily based on visual cues and radiographic data. This visual data can be used as input for machine learning (ML) models. Among the various ML methods studied, the support vector machine (SVM) demonstrated the best performance in identifying root caries. Additionally,

clinical imaging data from various sources have been utilized in AI models for diagnosing dental caries with excellent results, with convolutional neural networks (CNNs) significantly improving the speed and accuracy of caries detection.<sup>(6)</sup>

For instance, Cantu et al. (2020) used bitewing radiographs to evaluate the performance of a deep learning (DL) network in detecting carious lesions. Out of a total of 3,686 radiographs, 3,293 were used for training, while 252 served as test data. The deep neural network showed higher accuracy compared to dentists and proved effective in detecting early carious lesions on bitewing radiographs. Similarly, Park et al. (2021) tested ML prediction models for detecting early childhood caries, finding them more effective than traditional regression models.

- **Predictive Analytics:** AI can also predict the progression of oral diseases. By analyzing patient data, including histopathological findings, genetic information, and clinical history, AI algorithms can create models that estimate the likelihood of disease progression. This information is invaluable for treatment planning, enabling clinicians to tailor interventions based on the anticipated course of the disease.
- **Periodontal Diseases:** Affecting over a billion people worldwide, periodontal diseases destroy alveolar bone and can lead to tooth loss. Early diagnosis of periodontal disease using AI can enhance patient dental health and overall quality of life. Artificial neural networks (ANNs) have been employed to predict the recurrence of aphthous ulcers. Factors such as gender, serum B12 levels, hemoglobin, serum ferritin, folate levels, candida count in saliva, tooth brushing frequency, and daily fruit and vegetable consumption have been associated with the occurrence of these ulcers. Periapical radiographs of single, double, and triple-rooted teeth from 63 patients were utilized in these studies.
- **Histopathological Image Analysis:** AI-powered image analysis tools are transforming the interpretation of slides. These tools can automatically grade and stage tumors, evaluate margins, and even detect specific cellular abnormalities. In Oral Pathology, this capability is especially valuable for analyzing biopsy samples, as AI can swiftly and accurately identify areas of concern, facilitating the diagnosis of conditions such as oral squamous cell carcinoma.
- **Maxillary Sinus Disease-** The maxillary sinuses are frequently examined using extraoral radiographs. Automated identification of these sinuses and the detection of any pathology by AI can significantly reduce the rate of misdiagnoses. AI can serve as a valuable tool for assisting

less experienced dentists. Murata et al. (2018) assessed the performance of a deep learning (DL) system in diagnosing maxillary sinusitis using panoramic radiographs. The AI's diagnostic performance was comparable to that of two radiologists and two residents.

- **AI in Genomic Pathology:** The integration of AI with genomic data is creating new possibilities in personalized medicine. In Oral Pathology, AI can analyze genetic mutations and their pathological implications, assisting in identifying patients who may benefit from targeted therapies. This approach enables more precise treatment planning, leading to improved outcomes for patients with complex oral diseases.
  - **Salivary Gland Diseases -** it presents a diagnostic challenge for inexperienced dentists due to their often confusing and similar morphological features. AI can be a valuable tool in diagnosing these conditions. Deep learning (DL) models can, in some cases, outperform radiologists. In an early Japanese study, researchers employed DL to detect fatty degeneration of the salivary gland parenchyma on CT images, a feature associated with Sjogren's syndrome. The low incidence and overlapping morphological characteristics of salivary gland tumors make them difficult to diagnose. Machine learning (ML) has been used to identify malignant salivary gland tumors based on their cytological appearance. Additionally, AI holds potential for predicting the recurrence of salivary gland malignancies and assessing the risk of facial nerve injury, providing both surgeons and patients with advance knowledge of possible complications.
  - **Telepathology and AI:** The practice of diagnosing diseases remotely using digital images is significantly enhanced by AI. In areas with limited access to specialized oral pathologists, AI can offer crucial diagnostic support, ensuring patients receive timely care. AI-assisted telepathology systems can analyze digital slides, provide diagnostic suggestions, and facilitate consultations between pathologists, helping to bridge gaps in healthcare access.
  - **Temporomandibular Joint Disorders-** Diagnosing TMJ disorders can be particularly challenging for inexperienced dentists. Artificial neural network (ANN) systems can simplify and assist in this process. One study tested an ANN model by identifying non-reducing disks in patients. The study used frontal chewing data from 68 patients, including those with normal disks and unilateral or bilateral non-reducing disks. Half of this data was used to train the ANN system, while the other half was used for testing.
- Orhan et al. (2021) employed magnetic resonance images of TMJs to detect TMJ pathologies, such as condylar

osseous changes and disk derangements, using an AI model. AI models can learn from various types of input data. For example, researchers have used infrared thermography images of patients' masseter and lateral pterygoid muscles to diagnose TMJ disorders with an AI model.

- **Osteoporosis-** It can be detected on panoramic radiographs using various indices, such as the gonion index, mental index, mandibular cortical index, and panoramic mandibular index. AI has the potential to simplify the diagnosis of osteoporosis and support radiologists in their work. Kim et al. (2019) assessed the performance of deep convolutional neural networks (DCNNs) for computer-aided diagnosis (CAD) in identifying osteoporosis from panoramic images, comparing it to the assessments made by radiologists with 10 years of experience.
- **Oral Cancer and Cervical Lymph Node Metastasis-** Oral cancer is the sixth most common malignancy worldwide. Early detection can lead to a better prognosis and a better survival rate. AI can aid in early diagnosis and decrease the mortality and morbidity associated with oral cancer. Nayak et al. (2005) used ANN to discriminate between normal, premalignant, and tissues using laser-induced autofluorescence spectra recordings. Uthoff et al. (2017) used CNN to detect precancerous and cancerous lesions from autofluorescence images and white light images. CNN was more effective than specialists in diagnosing precancerous and cancerous lesions. The performance of the CNN model can improve with larger data sets.

Neural networks and machine learning have proven to be as effective as, or even superior to, trained radiologists and clinicians in detecting caries, sinusitis, periodontal disease, and TMJ disorders. AI models in cancer diagnosis can integrate various data streams to make assessments, evaluate risk, and facilitate referrals to specialists. Research on premalignant lesions, lymph nodes, salivary gland tumors, and squamous cell carcinoma shows promising results for the diagnostic and prognostic value of AI. These advancements have the potential to reduce mortality rates through early detection and effective treatment.<sup>(7)</sup> However, these AI platforms will require large datasets and substantial resources to ensure precise and cost-effective diagnoses. To be securely integrated into daily clinical practice, these models must be refined to achieve the highest levels of accuracy, specificity, and sensitivity. Additionally, regulatory frameworks will be necessary for the deployment of these models in clinical settings.

### Prospects And Challenges

AI in dentistry is still in its early stages and has not yet become a standard part of daily dental practice. Several challenges must be addressed before AI can be seamlessly integrated into diagnostic and healthcare processes. Machine learning relies on large volumes of data, which are often held by private dental practices and institutions. Issues related to data sharing and privacy need to be addressed through federated guidelines and laws to overcome a common limitation noted in many studies: a lack of sufficient datasets. AI can also transform widely heterogeneous data into curated, homogeneous datasets that are easier to use and interpret.<sup>(8)</sup>

Most studies reviewed so far have focused on supervised image-based approaches for identifying structures or associations, providing only partial information for decision-making or treatment. To reduce subjective errors and offer standardized decisions, AI systems capable of unsupervised diagnosis and disease prediction need to be developed. Additionally, a shortage of manpower and resources is a significant issue in rural communities. AI-based healthcare initiatives have the potential to connect remote areas with high-quality care, benefiting local populations. Future prospective randomized control trials and cohort studies are necessary to evaluate the impact of AI on treatment outcomes and cost-effectiveness.

### Conclusion

While studies have highlighted the potential benefits of AI, its integration into routine dentistry remains limited. The field of artificial intelligence (AI) is rapidly advancing and is poised to fill an expanding role in both medicine and dentistry. Most AI research is still in its early stages. Greater availability of patient data could accelerate progress in AI, machine learning, and neural networks. Currently, real-time AI applications are rare in the internal operations of dental clinics. Research indicates that data-driven AI can be reliable, transparent, and, in some cases, outperform human diagnosis. AI has the potential to replicate human functions such as reasoning, planning, and problem-solving, thereby saving time, reducing manpower, and minimizing human errors in diagnosis. The rise of AI in dental care promises to revolutionize the field, offering broader access to dental health services and improved patient outcomes.

AI remains largely in the research phase. The next decade is expected to bring significant advancements in diagnosis and healthcare, driven by ongoing research. This paper reviews various AI applications in dentistry, highlights the challenges

faced in AI research, and suggests strategies for overcoming these obstacles. Addressing these issues will facilitate the seamless integration of AI into dental practice.

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