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The Impact of Artificial Intelligence in Dental Pathologies: A Comprehensive Review

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Abstract

Artificial intelligence (AI) has the potential to completely transform disease detection, diagnosis, and treatment planning in healthcare. Deep learning (DL) and machine learning (ML) improve the accuracy of diagnosing dental caries, periodontal disease, and oral cancer and early detection of OPMDs. AI-powered onco-pathologic histopathology and clinical decision-support systems (CDSS) improve workflows and patient outcomes. To fully integrate AI into clinical practice, many considerations must be addressed, including data privacy, ethical implications, and algorithm transparency. This review investigates AI's role in various dental specialties, focussing on the detection of OPMDs and oral cancer and its benefits, limitations, and future directions in precision diagnostics.

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Keywords
Artificial Intelligence;
Machine learning;
OPMDs;
Oral cancer;
Precision medicine.

Abbreviations

AI	Artificial Intelligence
ML	Machine Learning
ANN	Artificial Neural Network
OPMDs	Oral Potentially Malignant Disorders
OSCC	Oral Squamous Cell Carcinoma
SVM	Support Vector Machines
CNN	Convoluted Neural Networks
CDSS	Clinical Decision Support Systems
KNN:	K-Nearest Neighbours
GA-ANN	Genetic Algorithm with an Artificial Neural Network
ANFIS	Adaptive Neuro-Fuzzy Inference System
TMD	Tempero-Mandibular Disorders
CBCT	Cone-Beam Computed Tomography

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Introduction

The healthcare system, which includes dentistry, is being transformed by AI. Advancements in machine learning, deep learning, and neural networks (ANN and CNN) are enhancing diagnostic methods and treatment strategies. From radiographic image analysis to robotic-assisted surgery, artificial intelligence enhances precision, efficiency, and patient outcomes. Although AI is a relatively new technology, it is increasingly used in various medical specialties to diagnose conditions, interpret results, and assist healthcare providers in achieving successful treatment outcomes.[1] Furthermore, artificial intelligence transforms dental education with simulation-based training and automated assessment systems.

The incorporation of AI in dentistry poses many challenges. Considerations regarding data privacy, ethical implications, and potential biases in AI models necessitate meticulous analysis. Moreover, integrating AI into existing dental practice management systems presents logistical challenges that need resolution.

This paper examines AI's diverse applications in dentistry and explicitly analyzes its role in diagnosing oral pathologies and improving oral cancer diagnoses. This study aims to comprehensively understand AI's impact on modern dentistry by examining its benefits, challenges, and emerging trends.

Core Concepts and Technologies of Ai in Dentistry

In 1956, at Dartmouth College, a professor of mathematics, Prof. John McCarthy, coined the term "Artificial Intelligence" to explain the capacity of machines to carry out tasks that fall under "intelligent activities."[2]

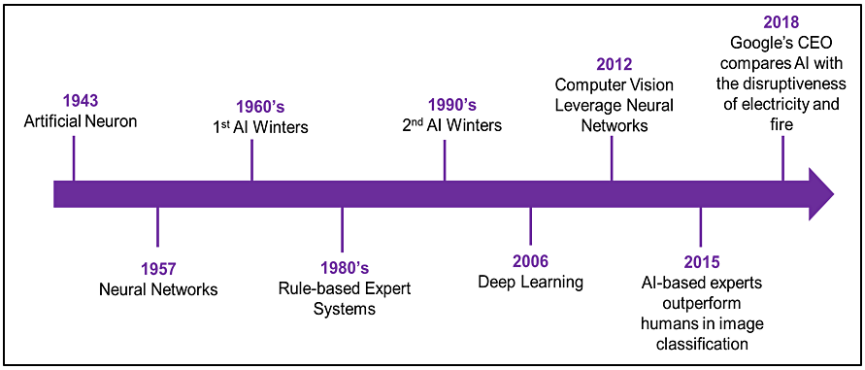

Fig 1: Milestones in the Development of Artificial Intelligence[3]

Table 1: The following list of terms addresses words and phrases indispensable for developing and extending AI knowledge and enhancing the research on solutions.

1.	Artificial Intelligence: The theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages.[6]
2.	Machine Learning: A subset of AI in which statistical classical algorithms and Artificial Neural networks are engaged to perform specific task without previous instruction.[5]
3.	Artificial Neural Network: ANN is a supervised classifier composed of mathematical functions that emulate the structure and functioning of a biological neuron. Designed to recognize patterns from input data.[5]
4.	Convoluted Neural Network: An artificial neural network with an added convolutional layer automatically extracts relevant information from the data.[5]
5.	Support Vector Machines: ML technique where a maximum margin separating hyperplane is built for classification so that the samples of different categories are divided by a clear gap that is as wide as possible.[6]

To understand its applications in various dental specialties, it is essential to comprehend a few key terminologies in artificial intelligence. Throughout the evolution of artificial intelligence, there have been three growth periods and two cooling periods. [Figure 1] Thus, finally, the third-generation AI has found its way into clinical applications in dentistry.

Important subfields in the recent boom include
- Machine Learning (ML)
- Artificial Neural Networks (ANN)
- Convoluted Neural Networks (CNN)
- Computation, Vision, and Robotics
- Natural Language Processing
- Expert Systems[4]

One of the most prevalent types of cancer worldwide is oral squamous cell carcinoma (OSCC). 82% of people who are diagnosed early survive 5 years, but only 27% of people who are diagnosed late do. This shows how important early detection is for improving survival rates. AI models, such as Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Convolutional Neural Networks (CNN), can accurately distinguish between benign and malignant tumors, cysts, and oral cancers. The sensitivity of CNN-based models in detecting oral malignant lesions was 93%, and they were 94% accurate in distinguishing periapical cysts from keratocystic odontogenic tumors.[9,10]

AI-enhanced optical imaging and machine learning-based smartphone applications assist in the real-time detection of oral potentially malignant disorders (OPMDs). Neural network models integrate clinical risk factors (tobacco, alcohol, genetics) to predict individual cancer risk. Several mobile AI Applications (MeMoSA® and other telemedicine tools) provide remote cancer screening, particularly benefiting low-resource settings. Deep CNN models trained on oral cancer images achieve up to 98% accuracy in identifying OSCC vs. benign lesions. AI-driven fluorescence imaging and multispectral analysis improve lesion visibility, enhancing early cancer detection rates.[11,12]

AI offers multiple advantages in early cancer detection by
- Automated Image Analysis
- Early Diagnosis Using Machine Learning (ML)
- Deep Learning & Neural Networks to classify benign and malignant lesions.
- AI-Driven Risk Assessment
- Clinical Decision Support Systems (CDSS)

Diverse AI models were created for cancer diagnosis. IBM Watson for Oncology was initially designed for cancer diagnosis but encountered difficulties in practical medical application. AI-enhanced optical imaging has been evaluated for oral cancer screening, demonstrating encouraging outcomes. Deep learning models have been employed to classify oral lesions and histopathological slides, enhancing diagnostic accuracy.

AI in Oncologic Histopathology

Artificial Intelligence (AI) reshapes histopathologic diagnoses by automating microscopic image analysis. It provides for improved accuracy and efficiency. Enhancing cancer detection and classification through machine learning algorithms and reducing intra- and inter-observer variability among pathologists, speeding up diagnoses and improving patient prognosis through deep learning models. Using histopathological features, SVMs and ANNs improve classification accuracy for oral squamous cell carcinoma (OSCC). 99.3% accuracy, 98.2% sensitivity with 99.5% precision, and 98.35% specificity can be achieved if whole slide imaging fused with CNN Features. This will help in early detection of OSCC along with reduced human error and provide reliable and consistent diagnosis. Machine Learning analyzes large datasets, detecting patterns and anomalies in histopathology images. It improves prognostic prediction for patient survival, recurrence, and treatment response. It helps stratify cancer severity, guiding precision medicine approaches.[10]

AI's applications and current focus among various dental specialties are summarized below. [Figure 2]

AI in Periodontics

AI applications in periodontics primarily focus on diagnosing and predicting periodontal diseases and treatment success. AI models (CNN) achieved an accuracy of up to 82.8% for predicting extractions of compromised teeth. Machine learning models (W-48, ANN, SVM) can predict implant success rates with up to 90.22% accuracy. AI classifiers

(SVM, Decision Trees, ANN) showed 98% precision in diagnosing different periodontal conditions. AI algorithms are capable of examining patient-specific information, including periodontal measurements, genetic indicators, and treatment preferences, to create personalized treatment plans that cater to the unique requirements of each individual.[1]

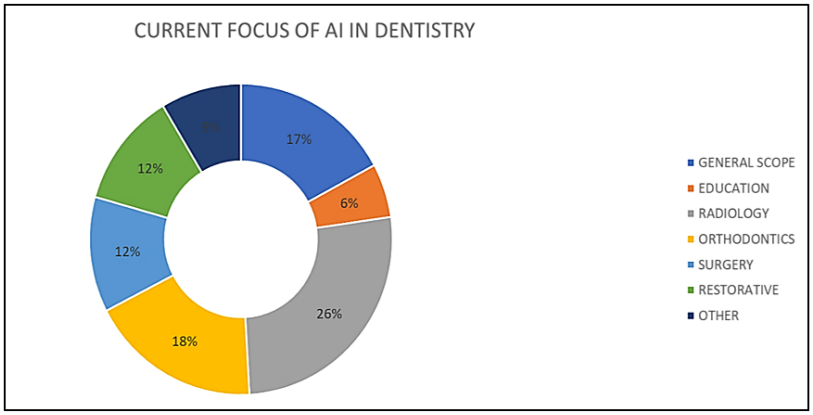

Fig 2: Current Focus of Ai In Dentistry (Illustrated using Pie Chart)[4]

AI in Orthodontics

AI assists in treatment planning, diagnosis, and growth prediction. Several AI models (KNN, ANN) can predict whether teeth extraction is necessary with a success rate of 90.4%-100%. SVM-based models diagnosed skeletal class I, II, and III patients with high sensitivity and specificity. Predicting unerupted tooth sizes and cephalometric analysis with AI models like ANN, GA-ANN, and linear regression outperformed traditional methods. Growth prediction based on cervical vertebrae stages and analysis of facial attractiveness scoring post orthodontic treatment was also possible with ANN. AI can help in dental analysis, facial analysis, skeletal maturation determination, upper airway obstruction assessment with CNN algorithm.[1,2]

AI in Prosthodontics and Restorative Dentistry

AI will give best results if we apply it on digital impressions, radiographs and patient history by machine learning models which can guide clinicians. AI enhances treatment planning, color matching, and longevity prediction of dental restorations. Case-based reasoning systems accurately predicted the longevity of dental restorations. AI (GA-ANN) and Fuzzy Logic can precisely predict shades for aesthetic restorations. It also reduces mismatch and save time with increase patient satisfaction. AI can optimize and automate the restoration design like inlays, onlays, crown with CAD/CAM systems. They help in identifying caries and defect from digital Xray before placement of restoration.[1,2]

AI in Maxillofacial Surgery

AI assists in cancer prognosis and risk assessment. AI models (ANN, SVM, logistic regression, ANFIS) achieved 93.81% accuracy in predicting oral cancer progression. Fuzzy logic models identified high-risk factors in patients with potentially malignant disorders. AI algorithms have been employed to support oral surgeons in diagnosis, treatment decisions, preoperative planning, and the prediction and assessment of outcomes.[1,7]

AI in Oral Medicine and Pathology

AI diagnoses temporomandibular disorders (TMDs), oral malodour, and oral ulcers. Bayesian networks (BN) diagnosed bone changes and disk displacement with 97.6% and 99.6% accuracy.[1,8]

AI in Endodontics

AI helps in working length determination and fracture detection. Apical foramen localization with ANN models correctly identified the apical foramen in 93%-96% of cases, outperforming human endodontists. The detection of vertical root fractures with AI models (ANN) achieved 95.7% accuracy, with 98% sensitivity and 90.5% specificity. AI is also helpful in analysing complex pattern in imaging which is sometimes missed by clinicians. So, it enhanced

accuracy with minimum errors along with more efficiency and less fatigue.[1]

AI in Oral and Maxillofacial Radiology

AI models like CNN have been extensively used for teeth recognition and numbering (95.8% precision), dental caries, and apical lesion detection. CNN-based models achieved high diagnostic accuracy using panoramic radiographs and could detect osteoporosis.[2,8]

AI in Forensic Odontology

AI supports age and gender identification from dental records. ANNs and CNNs estimated age from third molar development using panoramic radiographs with high precision. Similarly, Gender prediction using mandibular features was also done with 75% accuracy.[2,8]

Ethics Principles of Ai In Dentistry

The four fundamental ethical precepts of justice, autonomy, beneficence, and non-maleficence are the foundation on which a biomedical ethical model was proposed thirty years ago to preserve and guide ethical decision-making in dentistry and health care. The eleven ethical pillars by Rokhshad *et al.* (2023) that should be considered while using AI are: [Figure 3][12]

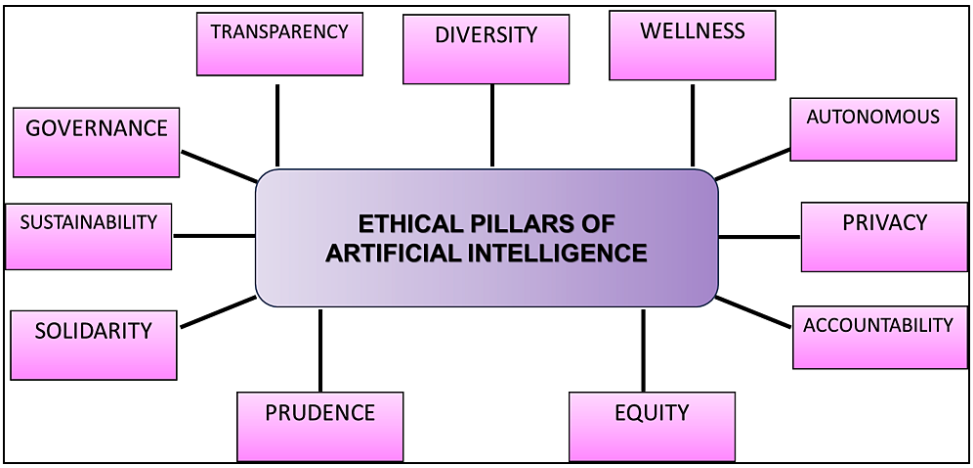

Fig. 3: Ethical Principles of Ai[12]

Future of Ai In Dentistry

AI can analyze dental images to more effectively identify conditions such as caries, periodontal disease, and oral cancers (X-rays, CBCT scans). This reduces diagnostic variability and enhances accuracy. By analyzing historical patient data, AI-driven predictive models can assist in formulating treatment decisions. Dentists can concentrate on patient care by utilizing AI-powered systems to manage administrative tasks such as patient records and billing. Patients may be able to self-monitor their oral health through mobile applications and wearable AI devices. Continuous health monitoring can enable AI to issue early warnings for dental issues. AI is essential for identifying new trends and evaluating the effectiveness of dental treatments, as it facilitates the analysis of substantial volumes of data.

AI can reduce dental care costs by automating diagnostics and enhancing treatment efficiency. It has the potential to alleviate workforce shortages, particularly in underserved regions. Adopting AI is frequently hindered by the fragmented, unstructured, and difficult-to-access dental data resulting from privacy regulations. A comprehensive validation process should be implemented before clinical adoption to guarantee the standardization of the AI models. AI models are often thought of as "black boxes," making it harder to figure out their decision-making process. It is imperative to provide the dental workforce with adequate training in the interpretation of data and the integration of AI to transition from traditional practices.[3,7]

AI will transition from labeled datasets to unsupervised and semi-supervised learning, integrate multimodal data for comprehensive diagnostics, improve real-time diagnosis and treatment recommendations, and enhance dental procedures' precision.

Conclusion

In the future, AI will continue to refine precision dentistry by providing predictive analytics for personalized treatment plans, AI-driven robotics for surgical assistance, and AI-enabled tele-dentistry for remote patient care. A new era of patient-centered, efficient, and accessible dental care will emerge as technology develops, resulting from the synergy between AI and human expertise. Dentistry can leverage the full potential of AI to enhance outcomes, reduce costs, and bridge gaps in healthcare accessibility worldwide by responsibly adopting AI.

Article Highlights

- This article highlights the importance of artificial intelligence across various specialties of dentistry, chiefly focusing on oral cancer screening and diagnoses.
- It focuses on the challenges of artificial intelligence and the biomedical ethical model created to surpass the concerns.

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Informed Consent Statement

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- **Himani Tiwari:** Conceptualization, Analysis, Writing-Review and Editing
- **Aiswarya Asok:** Data collection, Methodology, Writing-Original draft

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