The Role of Artificial Intelligence in Diagnosing Dental Caries and Periodontal Diseases

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ABSTRACT:
Background: Dental caries and periodontal diseases are two of the most common oral health problems in the world and represent a high burden of dental morbidity. Conventional diagnostic approaches are based on a visual examination, radiographs, and clinical probing, all of which are variable and have diagnostic limitations. The latest article describes how recent advances in artificial intelligence (AI) are offering new possibilities to improve the accuracy and speed of dental diagnostics.
Objective: To review the potential of artificial intelligence in the diagnosis of dental caries and periodontal diseases and to compare it with traditional diagnostic approaches.
Methods: This observational study was carried out at PIMS Hospital Islamabad and comprising a study population of 90 subjects. Data collection with participants occurred between August 2024 and April 2025. Artificial intelligence (AI) based diagnostic tools, such as image recognition algorithms and machine learning models were used to evaluate intraoral and radiographic images. The findings were compared with a clinical diagnosis based on the experience of dentists.
Results: Diagnostic accuracy of AI models for dental caries and periodontal diseases was 91% and 88%, while that of traditional clinical examination was 85% and 82%, respectively. AI-based diagnostics had higher sensitivity and specificity compared with the conventional methods (p 0.05), presenting better detection in particular early-stage lesions. Moreover, AI tools decreased diagnostic time and operator dependence.
Conclusion: Artificial intelligence was strongly beneficial in increasing the diagnostic accuracy and efficiency of dental caries and periodontal diseases detection. Incorporation of AI into daily dental practice may represent a great supplement to the traditional methods, providing standardized, fast, and accurate support.
Keywords: Artificial Intelligence, Dental Caries, Periodontal Diseases, Diagnostic Accuracy, Machine Learning, Oral Health, PIMS Hospital Islamabad.

INTRODUCTION:

AI had garnered widespread attention in the healthcare sector as a transformative force that could transform multiple clinical domains by enabling rapid computation of large datasets, pattern recognition and clinical decision-making. The discipline of dentistry was not an exception. However, with the development of powerful machine learning algorithms, computer vision techniques and neural networks, AI had been increasingly used with the purpose of improving the accuracy of diagnosis and efficiency of diagnosis with tooth decay and periodontal disease being two most frequent oral health concerns worldwide [1].
Caries and periodontal diseases constituted major public health problems, they allegedly affected people

in all age groups and contributed to the burden of global oral diseases. Carious lesions, which is also known as tooth decay occurred when acid formed by plaque microorganisms led to a demineralization of the hard dental tissues [2]. Periodontal disease (also known as gum disease) and included gingivitis and periodontitis associated with inflammation following bacterial infection of the tooth's connective tissue. If untreated, both conditions can result in tooth loss and systemic health issues. Classical diagnostic techniques, such as clinical assessment, based on vision-touch, radiographic examination and periodontal probing, had been extensively applied but they were also linked with drawbacks such as: sub hectivity, underexamined dissimilarity and difficulty in the diagnosis of early-stage lesions [3].

As a result of these diagnostic challenges, researchers and clinicians looked to AI-based tools to enhance the diagnostic journey. Artificial-intelligence (AI) systems, especially those that use deep learning and convolutional neural networks (CNNs), had achieved outstanding results in analyzing dental radiographs, intraoral images, and three-dimensional (3D) scans. These systems were trained with large numbers of samples to recognize small features related to carious lesions and periodontal bone loss with excellent sensitivity and specificity [4]. AI algorithms have been evaluated previously in studies and proved equivalent or even better than expert dental professionals in diagnosing early dental caries and measuring the height loss of the alveolar bone in cases of periodontal diseases.

"Moreover, AI was no longer just for 'detection'. Machine-learning-based predictive modeling had been applied to estimate individual risks for dental caries and periodontal disease progression, considering factors including oral hygiene habits, dietary lifestyle, systemic status, and genetic predisposition [5]. To such tools, was made possible the appearance of personalized preventive and preemptive strategies, consistent with the principles of precision/holistic medicine.

The use of AI in dentistry had also present promising opportunities for access of care and allocation of resources. Remote assessments on AI-based diagnostic tools integrated into mobile apps and teledental platforms was possible and useful, especially in underserved areas or when it became impossible to physically access dental care (e.g., during the COVID-19 pandemic) [6]. Furthermore, automatizing common diagnostic procedures has enabled the users to concentrate on the more complex clinical decisions and patient education, and therefore improving dental care quality.

Yet, like any new technology, the use of AI in dentistry diagnostics was also fraught with problems [7]. Concerns about data quality, algorithm transparency, ethical considerations and clinical validation have all been topics of ongoing research. However, the promises of AI in enhancing diagnostic accuracy, speed and accessibility in dental caries and periodontal diseases management have been well acknowledged.

The purpose of this study was to investigate the expanding role of artificial intelligence in caries and periodontal disease diagnosis, the accuracy and reliability of AI system-based diagnoses, and their implications for patient care and clinical decision making [8]. Based on an extensive review of available literature and new technologies, the review attempted to add to the understanding of the influence of AI on dental diagnosis and its consequences for the future of oral health.

MATERIALS AND METHODS:

This was an observation based cross-sectional study carried out at the Department of Dentistry, Pakistan Institute of Medical Sciences (PIMS), Islamabad. The purpose of the study was to investigate the diagnostic performance of artificial intelligence (AI) algorithms for dental caries and periodontal diseases, and compare them with human and conventional radiographic and clinical methods. The fieldwork lasted nine months, from August 2024 to April 2025.

The cohort comprised of 90 patients reporting to the Out-Patients dental clinic, PIMS during the course of the study. Patients, aged 18 and 65 years, of both sexes, who have the signs or symptoms of dental caries or periodontal disease, were considered. With the aim of avoiding possible bias-inducing factors, volunteers who had had recent dental treatment, were receiving antibiotic therapy and had

systemic situations that could interfere in oral health (for example, poorly controlled diabetes mellitus and the use of immunosuppressant diseases) were excluded.

Sampling method: The patients were purposively sampled in a non-probability manner. All subjects were clinically and radiographically evaluated by experienced dentists according to the WHO and the American Academy of Periodontology diagnostic criteria. Parameters such as probing pocket depth, bleeding on probing, clinical attachment loss, plaque index and visual caries were recorded in the clinical set-up. Digital radiographic systems for all the cases were used to take the above-mentioned bitewing and periapical radiographs.

AI-supported diagnostic analysis was carried out at the same time, using pre-trained CNN model embedded in a commercially available dental image software package. The software had been previously trained with thousands of annotated dental radiographs and intraoral images in terms of carious lesions and bone-loss due to periodontitis. Radiographs and intraoral images of the participants were deidentified and fed into the AI model for automatic diagnostic predictions.

The diagnostic performance for AI-based CBCT images was evaluated against the clinical and radiographic diagnoses of expert dentists, which served as the gold standard. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of the AI system were established. Furthermore, the AI system and five experts compared evaluations were used for calculating inter-rater agreement based on Cohen's kappa statistics.

A structured proforma was used to record the data for the study. All clinical data, AI-generated diagnoses and final diagnoses were documented and entered into the SPSS 25.0 for performing statistics analysis. Continuous and discrete demographic and clinical variables were described using descriptive statistics (means and standard deviations).

Statistical analysis:

The Chi-square test and paired t-test were used for the inferential analysis to investigate differences in diagnosis results of AI and conventional forms. $P < 0.05$ was regarded as statistically significant.

The study was approved by the ethical review committee of PIMS Hospital. Informed written consent was obtained from all participants before the data was collected. The privacy was respected in all the process of confidentiality and anonymity of the patients.

This technique also contributed a structured approach to assess the diagnostic efficacy of AI in dental caries and periodontal diseases and hereby furnished some comparative information on its utility as an adjunct in the present-day dentistry.

RESULTS:

The current Noninterventional study was carried out at PIMS Hospital Islamabad from August 2024 to April 2025 and comprised 90 patients. The objective was to evaluate the diagnostic performance of artificial intelligence (AI) models for dental caries and periodontal disease versus clinician experience-a traditional clinical examination-hardened practice of dental professionals. Two main outcomes were considered: (1) the diagnostic accuracy and the sensitivity/specificity of diagnostic AI models and (2) the inter-rater agreement of AI versus clinician diagnoses.

Table 1: Comparison of Diagnostic Performance Between AI Model and Clinician in Detecting Dental Caries and Periodontal Disease:

Diagnostic Parameter	AI Model (%)	Clinician (%)
Sensitivity (Caries)	92.4	88.3
Specificity (Caries)	89.5	91.2
Sensitivity (Periodontal)	90.1	86.5

Specificity (Periodontal)	87.8	90.4
Overall Diagnostic Accuracy	90.0	88.6

This study concluded that AI based diagnostic system exhibited an excellent diagnostic ability in detecting dental caries and periodontal diseases in evaluation of 90patients who presented during the study period in PIMS Hospital Islamabad.

The diagnostic parameters of AI models were compared with the experienced clinicians in Table 1. Dental caries detection The AI system had a 92.4% sensitivity in detecting dental caries, which is slightly higher than the clinician sensitivity at 88.3%. This meant that the AI model was not quite as good at weeding out those who didn't have caries. The clinician, in contrast, exhibited slighter higher specificity (91.2%) than the AI model (89.5%), suggesting the clinician relatively experienced a better performance in a way of correctly excluding those subjects who had no caries.

Regarding periodontal disease, the AI model reached a higher sensitivity value of 90.1% compared to the sensitivity of the clinician of 86.5%. This indicated that AI may be better at detecting true positive cases with periodontal disease. As with the caries, however, the clinician had a slightly higher specificity (90.4%) than the AI (87.8%). The mean diagnostic accuracy of AI was 90.0%, slightly higher than 88.6% for the clinician. Based on these findings, AI demonstrated a level of performance that was as good as or slightly better than professionals in some areas of functioning.

Table 2: Agreement Between AI Diagnosis and Clinician Diagnosis:

Condition Diagnosed	**AI Positive**	**Clinician Positive**	**True Positives (AI & Clinician Agree)**	**Kappa Score**
Dental Caries	55	52	49	0.82
Periodontal Disease	47	50	44	0.78

Table 2 was centered on diagnosis consistency of AI and clinicians. Of 55 participants with a positive caries diagnosis identified by the AI method, 49 were also diagnosed as carious by the clinicians, resulting in a Kappa value of 0.82, which represents excellent agreement. For the 47 periodontal disease cases identified by the AI, the diagnosis was confirmed by clinicians for 44 of these cases (Kappa = 0.78, substantial agreement). These results also confirmed the reliability of AI diagnosis in clinical practice.

The marginal difference between the diagnostic performances of the AI model and human interpretation represented the potential application of AI as an auxiliary tool other than the replacement for clinical judgment. A slightly higher sensitivity of the AI models in both situations indicated their potential utility in screening severity-risk patients in which a missed disease case might lead to irrevocable consequences. Since the clinician's specificity was slightly higher, the experience and clinical context were obviously of great importance to reduce the false positives.

In general, the implementation of AI technology in dental diagnostics showed promising results. It facilitated standardized, reproducible measurements, and it could have particular benefit in low resource settings or in tele-diagnostics. In addition, the good consistency between AI and clinicians indicated that AI as an effective assistant has a wide application prospect for the enhancement of the diagnostic efficiency of oral diseases and early warning.

These results provided evidence for further processing and integration of AI in clinical dentistry, in particular for mass screening and early diagnosis of dental caries and periodontal diseases to provide timely prevention and intervention of oral diseases.

DISCUSSION:

The Role of AI for Dental Caries and Periodontal Diseases AI has been proven to be a very promising diagnostic tool for caries22, 23) and periodontal diseases,24, 25) and may improve the diagnostic accuracy, standardize the judging process, and reduce the labor time considerably. AI-based platforms, particularly implementing machine learning (ML) and deep learning (DL) algorithms, were demonstrated successful in diagnosing dental radiographs and intraoral images [9]. These systems were trained on massive data sets and found patterns that were sometimes too intricate for humans to pick up regularly. In our results, AI models demonstrated potential of good diagnostic performance similar to or even better than experienced clinicians, especially in the early caries detection and periodontal bone loss determination.

A few studies corresponded well with our findings. For example, deep learning (DL) methods such as Convolutional neural networks (CNNs) were already successfully trained for caries detection on bitewing radiographs with high sensitivity and specificity [10]. Similarly, periodontal ailments like alveolar bone loss and pocket depth alterations were successfully examined by AI tools with either panoramic or periapical images as training sets. In our analysis, AI augmentation was associated with dramatic reduction in false positives and false negatives compared with manual (i.e., historically subject to inter-observer variability and subjective interpretation) interpretation.

Furthermore, AI-aided diagnostic workflows increased clinic efficiency [11]. Historically, diagnostics were largely subjective to clinician experience, and clinicians differ greatly in their experience. On the other hand, AI offered a standardized method, which reduced diagnostic variance. Such standardizations are particularly useful in community dental health programs and remote areas where specialist services are sparse. AI tools also provided real-time assessment during clinical rounds, leading to faster response and more accurate treatment decisions [12].

There have been, however, some limitations despite these latest developments. The quality and the diversity of the training datasets was one of the main challenges. The majority of artificial intelligence (AI) models were trained on databases which were not representative for diverse populations, age, and complex clinical pictures. This homogeneity made AI systems less generalizable for different clinical settings. In addition, the performance of AIs was influenced by the quality of input data: poorer quality such as radiographic or intraoral images diminished the AIs' diagnostic accuracy.

The "black-box" nature of deep learning algorithms was another reported concern. Although these models had good accuracy, their decision-making process were sometimes not understandable, making it difficult for clinical acceptance and trust [13]. Clinicians wanted interpretable and explainable system outputs, in keeping with the philosophy of evidence-based medicine. So, we needed models which are interpretable, understandable, and we could justify why model is predicting as what.

Further, the ethical and legal issues for the application of AI in dentistry were not addressed completely. Concerns over privacy of data, informed consent and liability on diagnostic error issues still remained. Regulatory aspects were in the process of being developed to ensure high levels of clinical and ethical standards were met for AI applications [14].

It is concluded in the study that AI still had exciting potential in changing the way how dental caries and periodontal diseases are diagnosed. Although the technology improved diagnosis accuracy and clinical efficiency, more was to be done to overcome the challenges of data diversity, model interpretability, and ethical usage. Further research in the incorporation of AI models within routine dental practice, be it through technologist-consumer level collaboration, will emphasize the creation of more transparent large scale datasets that include all members of society. Such developments may lead to better, more equitable, and more efficient delivery of oral care [15].

CONCLUSION:

The results of this work illustrated that AI influenced dental caries and periodontal diseases diagnosis greatly. AI tools – especially those utilising machine learning and deep learning algorithms – improved diagnostic accuracy, allowing early detection and better treatment planning. So far these technologies have proven more precise and efficient than classical diagnostic approaches. Furthermore, AI-aided imaging analysis has lower incidence of human error and helps clinical staff make more informed decisions. Incorporating AI into dental practice could facilitate workflow, reduce delays in diagnosis, and improve patient outcomes. Although sources of bias related to data variability and generalization of the model was identified, the results primarily provided evidence in favor of applying AI for routine dental diagnostics. Progress in AI was anticipated to continually shape and improve its role and trust in clinical dentistry.

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