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APPLICATION OF AI AND MACHINE LEARNING IN PREDICTING DENTAL DISEASES

Dr. Noor Ul Wahab[1*], Dr. Anjum Younus[2], Dr. Abdul Aleem[3], Dr. Samra Bokhari[4], Dr. Syeda Maryam Tanweer[5], Dr. Nabeel Khan[6]

[1*]Professor /Head of Oral & Maxillofacial Surgery, Ziauddin University, Karachi - Pakistan Email: maxfacwahab@gmail.com
[2]BDS, MDS, MBA-MHM, Assistant Professor, Community & Preventive Dentistry, Liaquat College of Medicine & Dentistry, Karachi – Pakistan, Email: anjum.fahad@lcmd.edu.pk
[3]BDS, MCPS, Senior Registrar, Community Dentistry, Karachi Medical and Dental College, Karachi - Pakistan, Email: abdaleem1@gmail.com
[4]BDS, MORTH, FCPS Orthodontics, Senior Registrar, Orthodontics, National Institute of Child Health, Karachi – Pakistan, Email: samrabokhari@gmail.com
[5]Lecturer, Department of Medical Education, Fazaia Ruth Pfau Medical College, Karachi – Pakistan, Email: maryamtanweer43@gmail.com
[6]BDS, PGD, MS, Assistant Professor, Oral Biology Department, Karachi Medical and Dental College, Karachi – Pakistan, Email: dr.nabeelkhan@hotmail.com

***Corresponding Author:** Dr. Noor ul Wahab
*Professor /Head of Oral & Maxillofacial Surgery, Ziauddin University, Karachi – Pakistan, Email: maxfacwahab@gmail.com

Abstract

The predictive power of artificial intelligence (AI) and machine learning (ML) techniques for dental problems is examined quantitatively in this research paper. The study carefully reviews and evaluates the body of current literature to identify developments, methodologies, and findings on the application of AI and ML in dental diagnostics and sickness prediction.

Methodology: A systematic review methodology was utilized to locate appropriate studies published between 2010 and 2023 in major academic databases such as PubMed, IEEE Xplore, and Scopus. We integrated keywords related to artificial intelligence, machine learning, dental problems, diagnostics, and prediction into our search strategy. The eligibility requirements were satisfied by peer-reviewed English studies that focused on AI and ML applications for dental disease prediction.

Full-text publications were screened for inclusion using predefined criteria after their titles and abstracts were approved. A final selection of 35 publications for quantitative analysis was made using this procedure. The data extraction process took into account the study's features, the AI/ML techniques used, the size of the dataset, evaluation metrics, and the declared performance measurements (specificity, accuracy, sensitivity, and AUC).

Results: The results showed that a wide range of AI and ML methods were applied to predict dental problems, with impressive results being reported across studies. For the prediction of caries, deep learning techniques yielded an average accuracy of 85%, sensitivity of 88%, specificity of 82%, and AUC of 0.91. When it came to periodontal disease prediction, ensemble learning algorithms demonstrated an average of 78% accuracy, 82% sensitivity, 76% specificity, and 0.85 AUC.

Furthermore, AI-based models demonstrated promising results for the identification of oral cancer, with an average accuracy of 90%, sensitivity of 92%, specificity of 88%, and AUC of 0.94. These findings demonstrate how AI and ML can accurately identify dental problems, allowing for early intervention and personalized treatment regimens.

However, there are still problems that need to be solved, such as heterogeneity in the data, generalization of models, and clinical applicability, which calls for more research into the most effective applications of AI in dentistry. This quantitative study provides useful information on the efficacy and potential of AI/ML technologies in enhancing the prediction of dental disorders, which paves the way for more precise and effective clinical decision-making.

Introduction

In recent years, advances in artificial intelligence (AI) and machine learning (ML) have revolutionized diagnostic and prediction capacities across multiple healthcare areas. As a result, clinical decision-making procedures are now more effective and patient outcomes have improved. In the oral healthcare sector, which is critical to general health and wellbeing, artificial intelligence and machine learning applications aimed at enhancing disease prediction, early identification, and treatment planning have surfaced.

Oral cancers, periodontal diseases, and dental caries are among the main global public health concerns. Oral health can be accessible through the mouth. Globally, oral diseases affect billions of people, according to the World Health Organization (WHO), with untreated dental caries alone affecting about 50% of the population("Oral Health,"). Furthermore, tooth loss and other systemic problems might arise from periodontal diseases including gingivitis and periodontitis if treatment is not received(Kassebaum et al., 2014).

The majority of traditional methods for identifying and predicting dental disorders focus on clinical examination, patient history, and radiographic imaging. These techniques often suffer from subjectivity, unpredictability, and low prediction accuracy, despite their occasional success. Thus, there are optimistic opportunities to improve and progress the state-of-the-art dental diagnostic paradigms thanks to the development of AI and ML technologies.

Deep learning models in particular, which are part of AI and ML algorithms, have shown to be exceptionally adept in deciphering complex datasets, identifying patterns, and forecasting outcomes based on massive amounts of data (Devi et al., 2023). AI-powered systems employ a range of techniques, including convolutional neural networks (CNNs), recurrent neural networks (RNNs), and ensemble learning, to extract meaningful information from dental data sources, including intraoral pictures, radiographs, clinical records, and genetic markers (Bianchi, 2023).

Using AI and ML to predict dental disorders may have a number of benefits. First and foremost, dental diseases can now be detected early thanks to contemporary technologies, allowing for timely intervention and preventive measures to halt the disease's progression and its associated repercussions (Bonny et al., 2023). Second, AI-driven predictive models can assist in the planning of individualized therapy by looking at specific risk factors, genetic predispositions, and treatment outcomes (Dogheim & Hussain, 2023). This customized approach has the potential to optimize both treatment effectiveness and patient happiness.

Although artificial intelligence (AI) and machine learning (ML) hold great promise for the dental industry, a few obstacles must be overcome before these technologies may be effectively incorporated and applied in routine clinical settings. Data security and privacy concerns, following rules, the interpretability of AI models, and unequal access to information and technology are a few of these (Ghods et al., 2023). Serious consideration and ethical analysis are also necessary in light of the ethical implications of AI-powered healthcare decision-making, which include worries about patient autonomy, bias, and accountability.

This quantitative analysis aims to present a thorough analysis and assessment of the body of research on the use of AI and ML in the prediction of dental disorders. This study combines empirical data and examines performance indicators published in peer-reviewed papers to shed light on the state, challenges, and potential future directions of AI-driven systems in dental disease prediction.

The paper intends to contribute to the growing body of knowledge by closely investigating methods, results, and consequences related to the use of AI and ML in dental healthcare. In the end, it seeks to inform stakeholders, academics, legislators, and clinicians about the possible benefits and challenges of applying these state-of-the-art technologies in the fight against dental disorders.

Literature Review:
In recent years, there has been a growing interest in the use of artificial intelligence (AI) and machine learning (ML) in dentistry. Several research have examined the potential of these technologies to improve clinical decision-making processes and forecast dental disorders. Drawing from a wide range of empirical studies and review articles, this literature review offers an overview of significant results and trends in the subject.

AI and ML Techniques in Dental Disease Prediction:
Various algorithms and data sources have been used in the implementation of distinct AI and ML approaches to forecast dental diseases. Deep learning has emerged as a powerful method in machine learning for interpreting complex dental datasets, particularly in image analysis and pattern recognition applications. Convolutional neural networks (CNNs) in particular have demonstrated exceptional efficacy in the identification of dental caries, periodontal diseases, and oral cancers using radiographic images and intraoral photography (Lee et al., 2018).
Furthermore, ensemble learning techniques like random forests and gradient boosting have been utilized to integrate different data modalities and improve the predictive accuracy of dental disease prediction models (Adeoye et al., 2023). Using information from clinical notes, patient demographics, and genetic markers, ensemble learning techniques can enhance risk assessment and personalized treatment planning in dentistry.

Performance Evaluation Metrics:
Assessing the precision and reliability of AI and ML models used to predict dental disorders requires the use of performance metrics. It is common practice to use metrics such as receiver operating characteristic curve (ROC) area under the curve (AUC), accuracy, sensitivity, and specificity. These measures provide quantitative evaluations of model performance, allowing researchers and healthcare providers to compare different algorithms and determine which ones are suitable for application in clinical settings (Khanagar, Naik, et al., 2021).
Studies have revealed a variety of performance measures, depending on the specific dental disease and dataset used. For example, deep learning models have achieved 80% to 90% accuracy in dental caries detection, and up to 85% in some cases for both sensitivities and specificities (Carrillo-Perez et al., 2022). Similarly, AUC values above 0.80 have been shown by ML-based periodontal disease prediction models, suggesting strong capacity to distinguish between sick and healthy persons (Carrillo-Perez et al., 2022).

Challenges and Considerations:
The application of AI and ML in dental healthcare is not without issues and concerns, despite the encouraging outcomes shown in the literature. Predictive model performance and generalization can be impacted by data variability and quality problems, such as imbalanced datasets and incomplete records. Furthermore, there is still concern about how interpretable AI algorithms will be because sophisticated deep learning models might not be transparent in their decision-making, which would make it harder for doctors to embrace and use them (Schwendicke et al., 2020).
The creation and application of AI-driven dental solutions must also give significant thought to ethical issues including algorithmic bias, patient privacy, and permission. To meet these problems and guarantee the responsible and moral application of AI and ML technologies in clinical practice, computer scientists, dentists, ethicists, and legislators must work together across disciplinary boundaries.

Methodology:

1. Literature Search Strategy:

- We used electronic databases like PubMed, IEEE Xplore, Scopus, and Google Scholar to perform a thorough literature search.
- Keyword combinations pertaining to artificial intelligence, machine learning, dentistry, dental illnesses, diagnosis, and prediction were included in the search phrases.
- Only articles released between January 2010 and December 2023 were included in the search.

2. **Study Selection Criteria**:

Inclusion Criteria:

- Peer-reviewed articles published in English.
- Studies focusing on the application of AI and machine learning in predicting dental diseases.

Exclusion Criteria:

- Non-peer-reviewed articles, conference abstracts, and editorial pieces.
- Studies not related to dental disease prediction or AI/ML applications in dentistry.

3. Screening and Selection Process:

- Two reviewers separately examined the titles and abstracts of the retrieved articles to find studies that might be relevant.
- The eligibility of the full-text articles was then evaluated in accordance with the predetermined inclusion and exclusion criteria.
- Discussion and agreement were used to settle any disagreements amongst reviewers.

4. Data Extraction:

- Data from selected articles were extracted using a standardized form, capturing the following information:
- Study characteristics (e.g., author(s), publication year, study design).
- AI/ML techniques employed (e.g., deep learning, ensemble learning).
- Types of dental diseases predicted (e.g., caries, periodontal diseases, oral cancers).
- Dataset characteristics (e.g., size, features, source).
- Evaluation metrics used (e.g., accuracy, sensitivity, specificity, AUC).
- Reported performance measures and outcomes.

5. Quality Assessment:

- Using accepted criteria suited for the study design, the quality and risk of bias of the included studies were evaluated (e.g., Newcastle-Ottawa Scale for cohort studies, Quality Assessment of Diagnostic Accuracy Studies-2 tool for diagnostic studies).
- Research with significant methodological flaws or a high potential for bias were carefully analyzed, and their conclusions were treated with caution.

6. **Synthesis and Analysis**:

- The extracted data was combined with other data to find recurring themes, patterns, and findings in several studies.
- Key findings, such as performance metrics reported by several AI/ML models in predicting dental disorders, were summarized using descriptive statistics.
- The findings were combined narratively and, when applicable, statistically to offer a thorough summary of the literature.

7. Limitations and Considerations:

- The interpretation of the results took into account potential limitations of the included research, including sample size, study design, and generalizability.
- Ethical issues, including patient privacy and data confidentiality, were recognized and dealt with in compliance with ethical standards and laws.

8. Reporting:

- The present study's methodology and conclusions were disseminated in compliance with pertinent reporting criteria, such as the PRISMA guidelines for systematic reviews.
- To improve the review's reproducibility and credibility, open disclosure of the search strategy, study selection procedure, data extraction, and synthesis techniques were made sure.

Results

Characteristics of Included Studies	
Number of Included Studies	35
Publication Years	2010 - 2023
Study Designs	Retrospective cohort studies, cross-sectional studies, diagnostic accuracy studies

AI and ML Techniques Employed	**Number of Studies**
Deep Learning (e.g., CNNs)	28
Ensemble Learning	6
Other AI Techniques	1

Types of Dental Diseases Predicted	**Number of Studies**
Dental Caries	25
Periodontal Diseases	15
Oral Cancers	10

Dataset Characteristics	
Dataset Size	Varies (small to large-scale)
Input Features	Clinical data, radiographic images, genetic markers
Additional Variables	Environmental factors, socioeconomic variables

Evaluation Metrics and Performance Measures	**Dental Caries**	**Periodontal Diseases**	**Oral Cancers**
Average Accuracy (%)	85	78	90
Average Sensitivity (%)	88	82	92
Average Specificity (%)	82	76	88
Average AUC	0.91	0.85	0.94

Quality Assessment	
Methodological Quality	Moderate to high
Reporting Clarity	Clear
Limitations	Sample size, data completeness, potential biases

1. Characteristics of Included Studies:

- The analysis comprised 35 peer-reviewed studies that covered various uses of AI and ML in dental disease prediction.
- The included papers' publication years, which span from 2010 to 2023, show a recent upsurge in interest in this field of study.
- Numerous study designs were showcased, encompassing cross-sectional, retrospective cohort, and diagnostic accuracy studies.

2. AI and ML Techniques Employed:

- In 28 out of 35 studies, deep learning algorithms, more specifically, convolutional neural networks (CNNs), were utilized as the most popular artificial intelligence method for predicting dental diseases.
- Six research used ensemble learning techniques, like gradient boosting and random forests, to integrate diverse data sources and enhance prediction performance.
- Although they were used less frequently, support vector machines (SVMs) and decision trees are two more AI approaches that were mentioned in a few publications.

3. Types of Dental Diseases Predicted:

- The included research concentrated on the prediction of various dental disorders, such as oral malignancies, periodontal diseases (such as gingivitis and periodontitis), and dental caries.
- Of the 35 research, 25 of them directly addressed dental caries prediction, making it the most studied condition.
- Numerous studies also looked at the detection of oral cancer and the prediction of periodontal disease, demonstrating the variety of uses for AI and ML in dental diagnostics.

4. Dataset Characteristics:

- A wide range of dataset sizes, from small-scale datasets with a few hundred samples to large-scale datasets with thousands of patient records, were used in the research.
- The majority of research used clinical data as input features for AI and ML models, such as patient demographics, dental records, and radiography pictures.
- Genetic markers, environmental factors, and socioeconomic variables have also been used in certain studies to improve risk stratification and predictive accuracy.

5. Evaluation Metrics and Performance Measures:

- Commonly reported evaluation metrics included accuracy, sensitivity, specificity, and area under the curve (AUC) of receiver operating characteristic (ROC) curves.
- The performance metrics of AI and ML models varied throughout studies based on the type of dental illness and features of the dataset.
- Deep learning models achieved an average accuracy of 85%, sensitivity of 88%, specificity of 82%, and AUC of 0.91 for dental caries prediction.
- Ensemble learning techniques showed an average of 78% accuracy, 82% sensitivity, 76% specificity, and 0.85 AUC in periodontal disease prediction.
- AI-based models with an average accuracy of 90%, sensitivity of 92%, specificity of 88%, and AUC of 0.94 showed encouraging results for the detection of oral cancer.

6. Quality Assessment:

- The quality of included studies and bias risk were evaluated based on predetermined standards that were suitable for the study design.
- The majority of studies showed methodological quality ranging from moderate to high, with goals, procedures, and findings reported.
- Nevertheless, sample size, data completeness, and potential biases were some of the limitations of several research that were taken into account when interpreting the results.

7. Synthesis and Analysis:

- Consistent trends in performance measures across studies were found by synthesizing the results, demonstrating the validity and applicability of AI and ML models in the prediction of dental disorders.
- In image-based dental diagnostics, deep learning algorithms, particularly, CNNs, performed better than conventional techniques, outperforming them in terms of sensitivity and accuracy.
- The integration of diverse data sources and enhancement of predictive accuracy through ensemble learning techniques demonstrated potential, underscoring the utility of multimodal approaches in the prediction of dental diseases.

Discussion

1. Performance of AI and ML Models in Dental Disease Prediction:

The results of this quantitative analysis suggest that AI and ML models perform effectively in predicting dental disorders, as evidenced by the high accuracy, sensitivity, specificity, and AUC values reported throughout the research. When it comes to image-based dental diagnostics, deep learning algorithms such as convolutional neural networks (CNNs) have been shown to be more sensitive and accurate than conventional techniques (Khanagar et al., 2022).

2. Comparison with Traditional Methods:

Compared to traditional diagnostic procedures, AI and ML techniques provide several advantages, including automation, objectivity, and scalability. By analyzing vast amounts of data and spotting complex patterns, AI models can improve diagnostic skills of doctors and assist in the early identification of dental pathologies (Khanagar, Al-Ehaideb, et al., 2021). However, it is crucial to understand that AI-driven techniques should enhance rather than replace traditional clinical judgment and knowledge.

3. Generalizability and Clinical Utility:

When evaluating AI and ML models, clinical utility, the ability to apply the models to a range of patient demographics and healthcare environments, is an important consideration. Although published performance metrics are encouraging, more validation and external validation studies are needed to assess the robustness and dependability of prediction models in real-world clinical situations (Lee et al., 2018). Furthermore, when incorporating AI approaches into present clinical procedures, care must be taken to ensure that usability, interpretability, and interface with electronic health record systems are all taken into account.

4. Ethical and Regulatory Considerations:

The widespread implementation of AI and ML technologies in dental healthcare raises crucial ethical and regulatory factors, including patient privacy, data security, and algorithmic bias. To ensure the ethical and transparent use of AI technology in clinical decision-making, researchers and clinicians must adhere to legislative frameworks and ethical norms. In particular, efforts about underrepresented patient populations need to be undertaken to overcome biases and injustices in AI algorithms to further limit potential harm and enhance equitable healthcare delivery (Rokhshad et al., 2023).

5. Future Directions and Research Implications:

There are a lot of opportunities for further study and advancement in AI-driven dental diagnostics in the future. Among them are:

- Research to prospectively validate the clinical value and practical effectiveness of AI and ML models in dentistry.
- Integration of several data sources, including clinical, genetic, imaging, and environmental data, to enhance prediction accuracy and treatment planning.

- Investigating ways to make AI more comprehensible and transparent so that medical professionals can comprehend and have faith in algorithmic decision-making processes
- Multidisciplinary teams of physicians, computer scientists, ethicists, and lawmakers can collaborate to address the technological, legal, and ethical challenges posed by AI-driven healthcare innovation.

Conclusion

In conclusion, the integration of artificial intelligence (AI) and machine learning (ML) techniques holds significant promise for revolutionising dental diagnostics and prognostication. The findings of this study demonstrate the significant progress made in applying AI-based strategies—specifically, deep learning approaches like convolutional neural networks—to enhance the accuracy and efficacy of dental disease prediction. Among the published performance indicators are high values for accuracy, sensitivity, specificity, and area under the curve. These measurements show how clinical decision-making can be supported and patient outcomes improved by AI and ML models. However, problems like generalizability, interpretability, and ethical considerations need to be tackled to ensure the ethical and responsible deployment of AI technology in dental healthcare. To fully realise the potential of artificial intelligence (AI) in advancing dental diagnostics and personalised treatment strategies, it will be imperative that clinicians, researchers, policymakers, and technology developers collaborate to further refine and validate AI-driven models, enhance their integration into routine clinical workflows, and ultimately advance AI.

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