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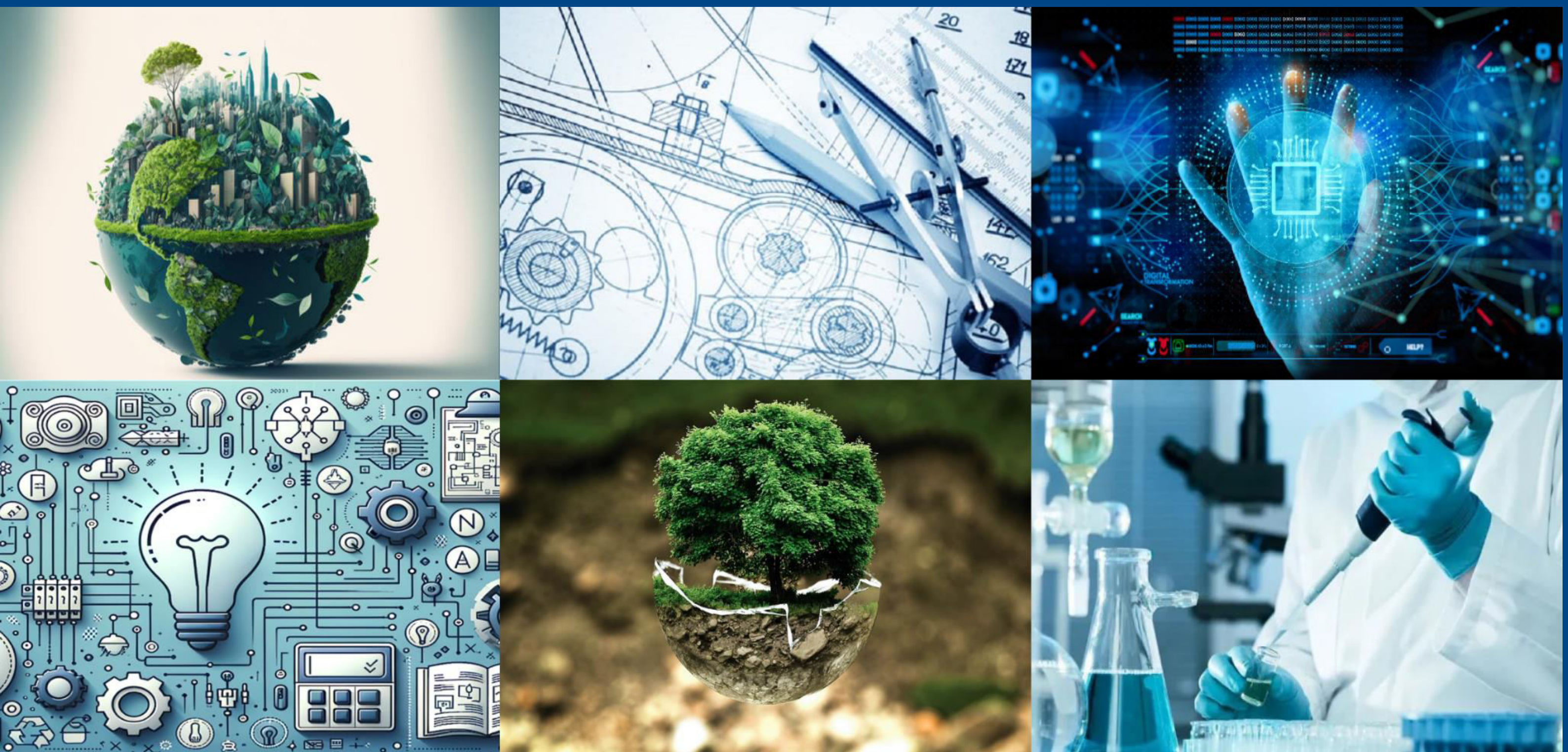

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Self Supervised Masked Deep Embeddings for Dental Caries Detection

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ABSTRACT: AI-supported diagnostic programs offer exciting opportunities to improve dental caries detection using panoramic radiographs. Models such as DLM and Diagnocat demonstrate that, with appropriate design and training, AI can match or even surpass human diagnostic capabilities. Nevertheless, significant challenges remain related to generalizability, interpretability, ethical considerations, and clinical integration. Maximizing the advantages of AI while mitigating its risks will rely on continued research, interdisciplinary collaboration, and implementation strategies. AI is poised to become an indispensable part of dental diagnostics—provided that its deployment remains grounded in a commitment to enhancing, not replacing, clinical expertise and patient-centered care. Several Machine Learning algorithms were applied to this data, and their performances were evaluated using accuracy, F1-score, precision, and recall. Random forest has achieved the highest performance compared to other machine learnings methods, with an accuracy of 92%, F1-score of 90%, precision of 94%, and recall of 87%. The results of the proposed paper show that ML is highly recommended for dental professionals in assisting them in decision making for the early detection and treatment of dental caries.

KEYWORDS: machine learning; dental caries; random forest; logistic regression; gradient boot decision tree; support vector machine;

I. INTRODUCTION

Dental caries can significantly impair an individual's quality of life by causing pain, irritation, sensitivity, tooth loss, and functional impairment. Despite their preventability, carious lesions are the most common health condition in the world, and if left untreated, may progress to disorders that require more extensive and costly interventions compared to the treatment of the original lesion. Consequently, secondary prevention, or the early detection of caries, enables timely intervention to halt disease progression and maintain oral health without residual pathology.

Using a traditional visual-tactile examination may miss hidden or less accessible carious lesions, making radiographic imaging essential for comprehensive detection. Dentists commonly use panoramic, periapical, and bitewing radiographs to augment their clinical assessment for diagnosing caries. Panoramic radiography visualizes the maxillomandibular area on a single film and, since its introduction, has gained popularity and value as a diagnostic tool in general dentistry. Panoramic radiography examines the whole dentition, alveolar bone, temporomandibular joints, and surrounding tissues and since it identifies pathologies not readily apparent during a clinical examination such as subgingival calculus, furcation involvement, and root surface caries, it is used for patient screening at several institutions and private clinics.

While panoramic radiography offers a comprehensive view of the maxillofacial structures, it has notable limitations for detecting dental caries. The major drawback of taking panoramic radiographs is that it requires the digital post-processing of panoramic images to provide the most accurate presentation of caries. As a result, panoramic radiographs have traditionally been considered less reliable for caries detection, especially in the posterior interproximal regions. However, technological advancements have introduced panoramic systems capable of producing bitewing-style images, which have improved diagnostic capability in detecting interproximal caries. Moreover, the visualization of moderate to advanced lesions on panoramic radiographs, particularly in good-quality images, is an area of growing interest to

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supplement intraoral imaging when it is limited or not feasible. This potential was enhanced by the integration of artificial intelligence (AI), which can aid in standardizing lesion detection and potentially compensate for some of PR's limitations. Therefore, while PR may not be the gold standard for caries diagnosis, its evolving role in opportunistic and AI-assisted caries detection warrants systematic evaluation.

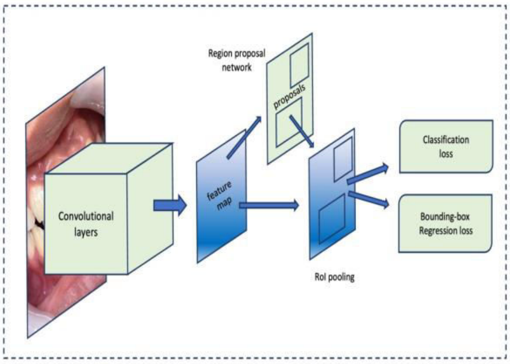

Fig 1: Application in Dental Caries Detection

In recent years, AI—particularly machine learning and deep learning—has emerged as a powerful tool that facilitates the diagnosis of conditions that might be challenging even for experienced dentists. By automating the detection and classification of dental caries, AI has the potential to reduce diagnostic errors, increase consistency among practitioners, and improve the overall efficiency of dental care delivery. AI systems can process large amounts of radiographic data, learning to identify patterns associated with dental caries and other oral conditions with high precision. Clinical studies demonstrate that AI models can achieve diagnostic performance and serve as a dependable second option to experienced clinicians. Additionally, AI performance heavily depends on the quality and diversity of the training dataset, and a limited training dataset may also not account for all anatomical or pathological variations found within a patient population.

The rapid advancements in AI technology and its growing application in dental diagnostics make it important to conduct a comprehensive evaluation of using AI in conjunction with panoramic radiographs for caries diagnosis. Although other reviews examined the use of AI technology and dental imaging in diagnosing caries, this is the first review to explore the application of AI in diagnosing caries on panoramic X-rays. A scoping review is particularly well-suited for this purpose, as it maps the current literature, identifies research gaps, and provides direction for future investigations.

Therefore, the objective of this scoping review was to systematically investigate the current landscape of AI applications designed to detect dental caries using panoramic radiographs. By critically analyzing the reported strengths and limitations of various AI learning models, this review offers a comprehensive overview of their diagnostic capabilities and practical implications. In doing so, it aims to inform clinicians, researchers, and policymakers on how best to integrate AI into dental workflows in a manner that enhances diagnostic accuracy without compromising clinical judgment or patient care. The review placed a special emphasis on evaluating the diagnostic performance of different AI systems, highlighting their potential to significantly improve the early and accurate detection of caries in clinical settings. This review not only maps current advancements but also identifies critical gaps in the literature that warrant future investigation.

II. RELATED WORK

Artificial intelligence (AI) technology can be applied in a variety of ways in the medical field, from early detection of disease, patient condition monitoring using software, clinical decision making using big data, and wearable devices and sensors that use IoT technology to monitor a patient's health status in real time. In addition, ML can improve diagnosis and treatment effectiveness by allowing medical experts to analyze real-time data to identify changes in patients.

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The field of medical image analysis and diagnosis has the highest annual growth rate in the AI-based healthcare industry, and a large amount of medical image data available facilitate the research venture in this field. Based on this paradigm, many AI methods have been introduced in the medical area to alleviate the time-consuming and cost-related aspect of performing some diagnoses. VUNO, a representative case, helps perform bone age assessment using DL by integrating and analyzing medical image information such as X-ray and CT. Lunit improves the early diagnosis rate and reduces the false diagnosis rate by developing an AI-based solution for chest X-rays and mammography images, using DL technology [16]. Consent agreement related to medical data has restricted some research's vulgarization and is currently heavily performed only by medical doctors.

With the entry into an aging society, oral health is one of the essential factors determining the quality of life. Periodontitis is one of the most common diseases afflicted by humankind and is the sixth most prevalent disease globally. Loss of alveolar bone is one of the main symptoms of periodontitis and causes tooth loss, edentulous jaw, and masticatory dysfunction. A classification system for periodontitis was needed to provide a standard for research on the etiology and treatment of periodontitis. Since then, the classification system for periodontitis has been continuously revised according to the newly identified scientific and clinical evidence. In general, clinical attachment loss (CAL) evaluates periodontal health using a periodontal probe. This method has limitations in terms of reliability; thus, a computer-aided diagnosis (CAD) system can help clinicians make decisions by extracting important features from medical images taken in various environments. However, the existing CAD approach has limitations in that feature extraction is not easy and takes much time due to the diversity of disease patterns.

Nevertheless, current methods based on DL, a subset of ML, have the advantage of automatically extracting critical features from images through learning. Convolutional neural network (CNN) is the most used method to segment, classify, and detect organs or related diseases in medical images. In the field of oral and maxillofacial surgery, the CAD approach integrated with CNN has been used to detect landmarks in cephalograms [12], tooth detection and classification, caries diagnosis, and maxillary sinusitis detection. A dentist can provide a more accurate and rapid diagnosis result by adding a second opinion to the results obtained through this method. Recently, studies on RBL detection using CNN in dental panoramic images have also been conducted.

Research on dental caries classification by image interpretation mainly controls the contrast of the X-ray image. The authors of present a novel approach that detects the presence of dental caries-hybridized negative transformation and statistical analysis for the dental image containing dental caries along with cysts. Radon transform and discrete cosine transform were applied to cavities, and some studies diagnose by classification using various classification techniques such as decision tree, random forest, and naïve Bayes. This technique improved the diagnostic accuracy of caries by adjusting the image contrast, but the limitation of the study was revealed due to the generation of image noise. The histogram equalization technique was employed to overcome image noise limitations. The authors of proposed an image enhancement technique using watershed and introduced a kernel-modified SVM to facilitate the initial caries diagnosis at clinics. The authors of [13] proposed a review study for the early detection and diagnosis of dental caries on periapical radiographs using DL CNN algorithms. The authors of presented work on classifying the presence or absence of root caries as a dichotomous variable based on public data from the National Center for Health Statistics in the United States. The top variables influencing dental root caries were extracted using a statistical technique and ranked based on their F1-Score. Various ML techniques were applied, and SVM displayed the highest performance. A case study based on open data in Korea, classifying the presence or absence of dental caries using the decayed–missing–filled teeth (DMFT), was proposed by. This study constructed a multiple linear regression model targeting approximately 20,000 children using the influence of individual oral health management habits, eating habits, dental care products used, and socioeconomic factors as variables in the Oral Health Survey. Using ML, they found feature importance in the order of gender, region, oral health perception status, number of dental treatments, and daily snack intake for one year.

III. METHODS

This scoping review followed the PRISMA guidelines for scoping reviews [14]. The objective was to comprehensively map the existing literature on the advantages and disadvantages of using various AI programs to analyze panoramic radiographs for diagnosing dental caries. This section outlines the procedures used for study identification, including the search strategy, eligibility criteria, study selection process, data extraction, and synthesis.

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The reviewers performed study selection in two stages: (1) title and abstract screening, followed by (2) full-text review. In the first stage, two independent reviewers (D.Y. and M.H.) evaluated and screened the titles and abstracts of all retrieved articles against the eligibility criteria, excluding research papers that did not meet the inclusion criteria. The reviewers resolved discrepancies through discussion. In the second stage, the full texts of potentially eligible studies were independently assessed by D.Y. and M. K. who used a standardized data extraction form that included study characteristics, AI program details, diagnostic outcomes, conclusions regarding the use of AI with panoramic radiographs for diagnosing dental caries and documented reasons for excluding a study. A third reviewer (M.H.) audited the selection process to ensure accuracy and review quality.

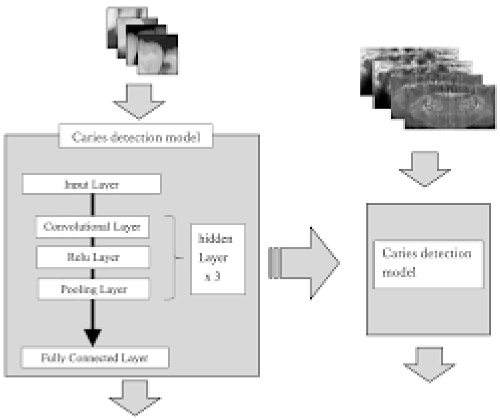

Fig 2: Dental Caries Detection by Deep Neural Network

Data synthesis involved a descriptive-analytical approach to map the existing evidence on the advantages and disadvantages of applying AI to panoramic radiographs for dental caries diagnosis. Where applicable, quantitative data, such as diagnostic accuracy and precision metrics, were summarized using descriptive statistics, as well as accuracy, precision, and F1 scores.

IV. RESULT ANALYSIS

Although bitewing and periapical dental X-rays remain the standard for detecting caries, panoramic radiographs still play an important role in diagnosing and managing caries. They identify larger cavities, especially those between teeth or under existing fillings that might be missed with other types of X-rays, and can help with planning treatment. The findings of this scoping review illustrate the significant advancements and challenges in applying AI to assess panoramic radiographs. These AI models align with practitioners who utilize them to enhance diagnostic workflows, improve detection rates, and assist clinicians in decision-making processes

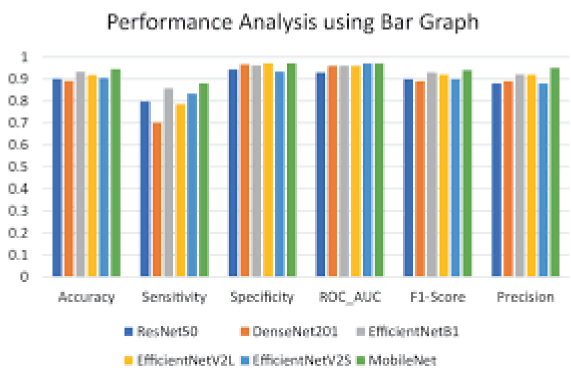

Fig 3: Machine Learning Technique for the Classification of Dental Caries.

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Among the evaluated AI models, DLM, Diagnocat, and TTET demonstrated superior diagnostic capabilities. DLM achieved the highest average overall performance, with specificity, accuracy, and F1 scores all exceeding 0.90, indicating its robustness in correctly identifying both carious and non-carious lesions. However, not all AI programs achieved comparable levels of performance. CranioCatch and CariSeg displayed moderate metrics, and DCDNet lagged significantly behind, highlighting issues related to dataset bias, generalizability, and technical limitations. These disparities underscore the important link between diverse and comprehensive training datasets to generalizability and performance.

While AI holds promise in increasing diagnostic consistency, an overreliance on automated systems may promote an overreliance on AI-related ethical considerations also extending to data privacy and informed consent. The use of patient radiographic data to train, validate, and improve AI models must adhere to strict data governance standards. While de-identified data may mitigate privacy risks, maintaining transparency about data use and identifying any potential commercial interests involved in AI development remain essential to maintaining trust. The European Union's AI Act emphasizes the need for trustworthy AI systems, highlighting the importance of data protection and ethical considerations in AI deployment.

This review has several strengths, including the use of a systematic and comprehensive search strategy, clearly defined inclusion and exclusion criteria, and a focus on peer-reviewed, full-text original research involving human subjects. The use of consistent performance metrics (specificity, accuracy, and F1 scores) across studies enabled meaningful comparisons between AI programs.

However, several limitations should be acknowledged. The inclusion criteria limited the review to articles published in English, possibly excluding relevant studies in other languages. There was also considerable heterogeneity among studies in terms of the specific AI architecture employed, dataset characteristics, and performance evaluation methods. As a result, while this review could identify general patterns, a direct meta-analytical comparison was not feasible. Not all studies included the age ranges for the population x-rayed and might compromise comparisons. Furthermore, the rapid evolution of AI technologies means that studies up to 2024 may not capture the latest innovations.

V. CONCLUSIONS

In this paper, we proposed the DCP model that informs preventive measures or diagnostic solutions for dental caries using data collected from the children's oral health survey conducted in 2018 by the Korean Center for Disease Control and Prevention under the Ministry of Health and Welfare. The data were preprocessed, unnecessary features were removed (using random forest, ANOVA, and mutual information statistic methods) and then balanced using the widely used oversampling technique SMOTE. We conducted a comparative study using three DNN methods (ANN, CNN, and LSTM) and four binary classification ML models (RF, GBDT, SVM, and LR) on the cleaned and balanced dataset.

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