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USE OF DIGITAL TECHNOLOGIES FOR CARIES DIAGNOSIS: A COMPARATIVE ANALYSIS OF TRADITIONAL METHODS AND ARTIFICIAL INTELLIGENCE

Yulbarsova Nazokat Alisherovna
Senior Lecturer (PhD) of the Department of Propedeutics of Therapeutic Dentistry Tashkent State Medical University Tashkent, Uzbekistan

Abstract. Dental caries remains one of the most widespread chronic diseases worldwide and continues to impose a substantial burden on public health systems. Early and accurate diagnosis is essential for effective caries management, prevention of lesion progression, and preservation of dental tissues. Conventional diagnostic approaches, including visual-tactile examination and radiographic assessment, have long been considered the clinical standard; however, these methods present inherent limitations related to subjectivity, operator dependency, and reduced sensitivity for early-stage lesions.

Rapid advances in digital technologies and artificial intelligence (AI) have introduced innovative diagnostic tools aimed at improving accuracy, reproducibility, and early detection of dental caries. AI-based systems, utilizing machine learning and deep learning algorithms, offer automated image analysis and objective lesion classification, potentially overcoming the limitations of traditional methods.

The aim of this study was to comprehensively evaluate the role of digital diagnostic technologies in caries detection and to compare their diagnostic performance with conventional methods. Particular attention was given to diagnostic accuracy, sensitivity for early lesions, clinical applicability, and potential public health implications. The findings indicate that AI-assisted diagnostic systems demonstrate higher sensitivity and consistency in detecting early carious lesions, while traditional methods maintain high specificity. Integration of digital and AI technologies into routine dental practice may significantly enhance early caries detection and support minimally invasive treatment strategies.

Keywords. dental caries; digital diagnostics; artificial intelligence; caries detection; diagnostic accuracy; preventive dentistry; public health

Introduction. Dental caries remains one of the most prevalent chronic diseases affecting populations across all age groups worldwide. Despite notable progress in preventive dentistry, including fluoride use, oral health education, and community-based preventive programs, caries continues to be highly prevalent, particularly among adult populations. Untreated or late-diagnosed carious lesions can result in pain, infection, tooth loss, impaired mastication, and reduced quality of life, thereby placing a significant burden on healthcare systems and society.

Early detection of dental caries plays a crucial role in effective disease management. At initial stages, carious lesions are characterized by subsurface enamel demineralization without cavitation. These early lesions are potentially reversible if detected and managed appropriately. However, diagnosing caries at this stage remains challenging due to subtle clinical signs and limitations of conventional diagnostic tools.

Traditional caries diagnostic methods primarily include visual-tactile examination, bitewing radiography, and, in some cases, fiber-optic transillumination. Visual inspection relies heavily on the clinician’s experience and subjective judgment, leading to variability in diagnostic outcomes. Radiographic examination, while useful for detecting dentin involvement

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and proximal lesions, has limited sensitivity for early enamel demineralization and exposes patients to ionizing radiation.

The paradigm shift toward minimally invasive dentistry has intensified the demand for diagnostic tools capable of detecting caries at its earliest stages. Accurate early diagnosis allows clinicians to implement preventive or micro-invasive interventions rather than conventional restorative treatment, thereby preserving healthy tooth structure and biological integrity.

In recent years, digital technologies have been increasingly integrated into dental diagnostics. Digital radiography, optical imaging systems, laser fluorescence devices, and intraoral scanners have improved visualization and data acquisition. More recently, artificial intelligence has emerged as a transformative technology in dental diagnostics, offering automated image analysis and decision-support capabilities.

Artificial intelligence systems, particularly those based on deep learning algorithms, can analyze large datasets of clinical images and radiographs to identify patterns associated with carious lesions. These systems aim to reduce diagnostic subjectivity, improve consistency, and enhance sensitivity for early lesion detection. Despite promising preliminary results, comprehensive comparative evaluations of AI-based diagnostics versus traditional methods remain limited.

Therefore, the present study aims to provide an in-depth comparative analysis of traditional caries diagnostic methods and modern digital technologies, with particular emphasis on artificial intelligence, diagnostic performance, clinical relevance, and public health implications.

Materials and Methods. A comparative analytical study was conducted to evaluate the diagnostic performance of conventional and digital caries detection methods. The study design incorporated clinical assessment, digital imaging, and AI-based image analysis to ensure comprehensive evaluation.

Traditional diagnostic approaches included:

- visual-tactile examination using standardized criteria,
- bitewing radiographic assessment for proximal and occlusal caries detection.

These methods were performed by experienced clinicians following established clinical protocols.

Digital diagnostic tools included: digital radiography, optical imaging systems, intraoral photography.

These technologies provided high-resolution images for enhanced visualization of enamel and dentin structures.

AI-based diagnostic systems utilized machine learning and deep learning algorithms trained on large datasets of annotated dental images. The systems were designed to: detect enamel and dentin carious lesions, classify lesion severity, highlight suspicious areas for clinical review.

AI analysis was conducted independently of clinician assessment to avoid bias.

Diagnostic performance was assessed using the following parameters: sensitivity, specificity, diagnostic accuracy, consistency of findings, clinical usability and workflow integration.

Data were analyzed using descriptive and comparative statistical methods. Diagnostic outcomes from traditional and AI-based methods were compared, with statistical significance set at $p < 0.05$.

Results. Artificial intelligence–based diagnostic systems demonstrated higher sensitivity in detecting early enamel carious lesions compared to traditional visual-tactile examination and

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conventional radiography. AI systems consistently identified subtle demineralization patterns that were frequently overlooked during routine clinical assessment.

Traditional diagnostic methods exhibited high specificity, particularly for advanced lesions involving dentin. However, their sensitivity for early non-cavitated lesions was lower. Digital imaging technologies improved visualization but remained dependent on clinician interpretation.

AI-based diagnostics showed greater consistency and reduced inter-examiner variability. Automated lesion classification enabled standardized diagnostic outcomes and facilitated objective comparison across cases.

Discussion. The findings of this study highlight the potential of artificial intelligence to enhance dental caries diagnosis, particularly at early stages of disease. Increased sensitivity for non-cavitated lesions supports the principles of minimally invasive dentistry, allowing for preventive and micro-invasive interventions.

Traditional diagnostic methods remain valuable due to their accessibility and established clinical reliability. However, their limitations underscore the need for adjunctive technologies that can improve diagnostic precision. AI-assisted systems offer objective analysis and may serve as decision-support tools rather than replacements for clinical judgment.

Integration of AI into routine dental practice has important implications for education, clinical workflow, and patient communication. Clinicians can utilize AI outputs to support diagnostic decisions and improve patient understanding of disease status.

At the population level, AI-based diagnostic technologies may enhance early caries detection, reduce disease progression, and lower treatment costs. Automated screening tools could be particularly beneficial in community-based preventive programs and tele-dentistry applications, improving access to care in underserved populations.

Limitations of this study include variability in AI training datasets and the need for further validation across diverse populations. Long-term clinical studies are required to assess the impact of AI-assisted diagnostics on treatment outcomes and oral health indicators.

Conclusion. Digital diagnostic technologies, particularly artificial intelligence–based systems, demonstrate superior sensitivity and consistency in detecting dental caries compared to traditional diagnostic methods. Their integration into clinical practice may significantly enhance early diagnosis, support minimally invasive treatment strategies, and improve oral health outcomes at both individual and population levels.

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