Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN (O): 2320-5407
ISSN (P): 3107-4928

Article DOI: 10.21474/IJAR01/22979
DOI URL: http://dx.doi.org/10.21474/IJAR01/22979

RESEARCH ARTICLE

ADVANCES IN DENTAL CARIES DETECTION: CURRENT TECHNOLOGIES AND FUTURE PERSPECTIVES

Kashmala Khalil[1], Kavya Jetani[2], Inderdeep Kaur[3], Shradha Shrivastava[4], Zalak Gohel[5] and Ankita Batra[6]

1. BDS (Pakistan), DA, Marion, Iowa, U.S.A.
2. BDS (India), MPH, CDA, New Jersey, U.S.A.
3. BDS (India), CDA, Vancouver, Canada .
4. BDS (India), RDA, Dublin, California, U.S.A.
5. BDS (India), RDA , Austin, Texas, U.S.A.
6. BDS (India), DA, Dunlap, Illinois, U.S.A.

……………………………………………………………………………………………………....

Manuscript Info

……………………….

Manuscript History
Received: 10 January 2026
Final Accepted: 12 February 2026
Published: March 2026

Key words:-
Dental caries; early detection; optical coherence tomography; fluorescence; salivary biomarkers; artificial intelligence; minimally invasive dentistry; diagnostic technologies; preventive dentistry

Abstract

………………………………………………………………

Dental caries is one of the most prevalent chronic oral diseases worldwide, affecting populations of all ages and posing significant socioeconomic and healthcare challenges. Early detection of carious lesions is critical for implementing preventive strategies and minimally invasive treatment approaches, thereby preserving tooth structure and improving oral health outcomes. Traditional diagnostic methods, including visual-tactile examination and radiography, are limited in their sensitivity for early enamel lesions and are influenced by examiner subjectivity. Over the past decade, significant advancements in diagnostic technologies have emerged, including laser and quantitati ve light induced fluorescence, fiber optic and near infrared transillumin ation, optical coherence tomography (OCT), electrical conductance and impedance methods, photothermal radiometry, salivary biomarker analysis, and artificial intelligence (AI)-assisted detection. OCT allows high-resolution imaging of subsurface enamel and dentin lesions, while salivary biomarkers provide a non-invasive assessment of caries risk and biological activity. AI integration improves diagnostic accuracy and reproducibility while reducing operator dependency. Despite these advancements, barriers such as high costs, lack of standardized protocol s, limited clinical adoption, and ethical considerations remain. This narrative review provides a detailed analysis of current and emerging technologiesfor dental caries detection, critically evaluates their diagnostic performance, and explores future directions emphasizing multimodal and personalized approaches.

"© 2026 by the Author(s). Published by IJAR under CC BY 4.0. Unrestricted use allowed with credit to the author."

……………………………………………………………………………………………………....

Corresponding Author:- Kashmala Khalil
Address:- BDS (Pakistan), DA, Marion, Iowa, U.S.A.

Introduction:-

Dental caries is a dynamic, multifactorial disease characterized by the demineralization of enamel and dentin due to the interaction between cariogenic biofilm, fermentable carbohydrates, and host susceptibility factors.[1,2] Despite advancements in preventive measures, caries remains one of the most common chronic oral diseases globally.[3] Early-stage lesions, particularly subsurface enamel demineralization, are often undetectable by conventional clinical examination, emphasizing the need for advanced diagnostic tools.[3,4]Conventional methods, including visual-tactile assessment and radiography, are limited by subjectivity, poor sensitivity for early lesions, and inadequate lesion depth estimation.[2,5] Operator variability and two-dimensional imaging constraints restrict their efficacy, particularly for proximal and occlusal surfaces.[3] Consequently, the development and clinical integration of more sensitive, objective, and non-invasive diagnostic technologies have become a priority in contemporary dentistry.

Conventional Diagnostic Methods and Limitations:-

Visual-Tactile Examination:-

Visual-tactile examination, often guided by the International Caries Detection and Assessment System (ICDAS), remains the cornerstone of clinical diagnosis. ICDAS improves lesion classification and standardization; however, early enamel lesions are subtle and prone to misclassification.[3,5] The historical use of sharp explorers is discouraged due to the potential to disrupt remineralizable enamel, accelerating lesion progression.[6]

Radiographic Techniques:-

Bitewing radiography is widely used for proximal caries detection but has notable limitations. Detection is typically only possible after substantial mineral loss (~30–40%), and lesion depth is often underestimated.[2,4] Two-dimensional imaging fails to capture the three-dimensional complexity of carious lesions. Digital radiography improves image quality and reduces radiation exposure but does not overcome fundamental sensitivity limitations.[5,7]

Advanced and Emerging Technologies:-

Fluorescence-Based Methods:-

Fluorescence technologies exploit differences in light emission between sound and demineralized enamel or bacterial metabolites.

Laser Fluorescence (LF):-

LF devices such as DIAGNOdent detect fluorescence emitted by bacterial porphyrins within carious lesions.[6,8] These devices offer quantitative readings correlating with lesion severity, enhancing early occlusal lesion detection. However, specificity is reduced by extrinsic stains, plaque, and calculus.[9]

Quantitative Light-Induced Fluorescence (QLF):-

QLF uses blue light to excite enamel, producing green fluorescence in sound tissue and reduced fluorescence in demineralized areas. This allows lesion quantification, monitoring of progression, and assessment of remineralization efficacy.[10] QLF has shown superior sensitivity for early lesions compared to LF, making it valuable for preventive and longitudinal patient management.[11]

Transillumination Techniques:-

Fiber-optic transillumination (FOTI) and near-infrared transillumination (NIRT) exploit differences in light scattering between sound and carious enamel.[12]

- FOTI: Effective for detecting occlusal and proximal lesions, yet qualitative and operator-dependent.
- NIRT: Non-ionizing, improved penetration for proximal lesions, and compatible with digital imaging systems.[12,13]

Despite advantages, both modalities are limited by qualitative output and reduced specificity for deep dentin lesions.[13]

Optical Coherence Tomography (OCT):-

OCT provides high-resolution, cross-sectional imaging using near-infrared light.[14] Key advantages include:

- Non-invasive, radiation-free imaging
- Visualization of subsurface demineralization
- Assessment of lesion depth and structural integrity

OCT demonstrates superior diagnostic performance compared to visual and radiographic methods, with reported sensitivities and specificities exceeding 90%.[14,15] Limitations include high cost, limited clinical accessibility, and the need for standardized interpretation protocols.

Electrical Conductance and Impedance Methods:-
These methods measure changes in enamel porosity and conductivity caused by demineralization. Increased porosity enhances electrical conductivity, enabling early lesion detection.[16] Accuracy is affected by moisture, saliva, and surface conditions, making these techniques highly operator- and environment-dependent.[16,17]

Photothermal Radiometry and Luminescence:-
Photothermal radiometry and modulated luminescence detect thermal and luminescent changes in enamel and dentin caused by caries. This technique shows promise for early lesion detection before cavitation, though clinical validation remains limited.[17]

Salivary Biomarkers:-
Saliva is a rich diagnostic medium reflecting microbial activity, biochemical properties, host immune response, and genetic predisposition.[12,13,18]

- Microbial biomarkers: High levels of Streptococcus mutans and Lactobacillus correlate with caries activity.[12]
- Biochemical markers: Salivary pH, buffering capacity, and mineral content influence demineralization and remineralization.[13]
- Proteomic markers: Immunoglobulins, lactoferrin, and matrix metalloproteinases (MMPs) reflect host defense and tissue breakdown.[18]
- Genetic/molecular markers: MicroRNAs and DNA polymorphisms provide insights into individual susceptibility.[13]

Challenges include variability due to circadian rhythms, diet, and systemic health, as well as a lack of standardized thresholds for clinical use.[13,18]

Artificial Intelligence (AI) in Caries Detection:-
Artificial intelligence (AI) has emerged as a transformative tool in dental diagnostics, particularly for the detection of carious lesions.[14-16] AI algorithms, primarily convolutional neural networks (CNNs), can analyze digital radiographs, intraoral photographs, and 3D imaging data with remarkable accuracy. Unlike conventional methods that rely on clinician experience, AI systems detect subtle structural changes, including early enamel demineralization and microcavitations, which may be overlooked during visual-tactile assessment.[14,15]Recent studies demonstrate that AI-assisted analysis of bitewing radiographs achieves sensitivities of 88–95% and specificities of 85–92%, outperforming traditional radiographic interpretation by general dentists.[15,16] Beyond detection, AI models are being developed for predictive caries risk assessment, integrating patient age, oral hygiene behaviors, dietary patterns, and salivary biomarker profiles.[16,17]

However, challenges remain in clinical implementation. AI models require large, annotated datasets for training, and their performance can be biased if the data lacks diversity (e.g., age, ethnicity, or dental anatomy variations).[14,16] Moreover, the "black-box" nature of deep learning systems raises interpretability concerns, making clinicians cautious about relying solely on AI recommendations.[15,17] Integration into existing dental workflows, standardization of algorithms, and adherence to regulatory guidelines are ongoing areas of research and debate.[17,18]Despite these limitations, AI holds promise as a complementary tool that enhances human judgment, reduces inter-operator variability, and supports early intervention, which is critical for minimally invasive dentistry.[14-16] (Fig.1.)

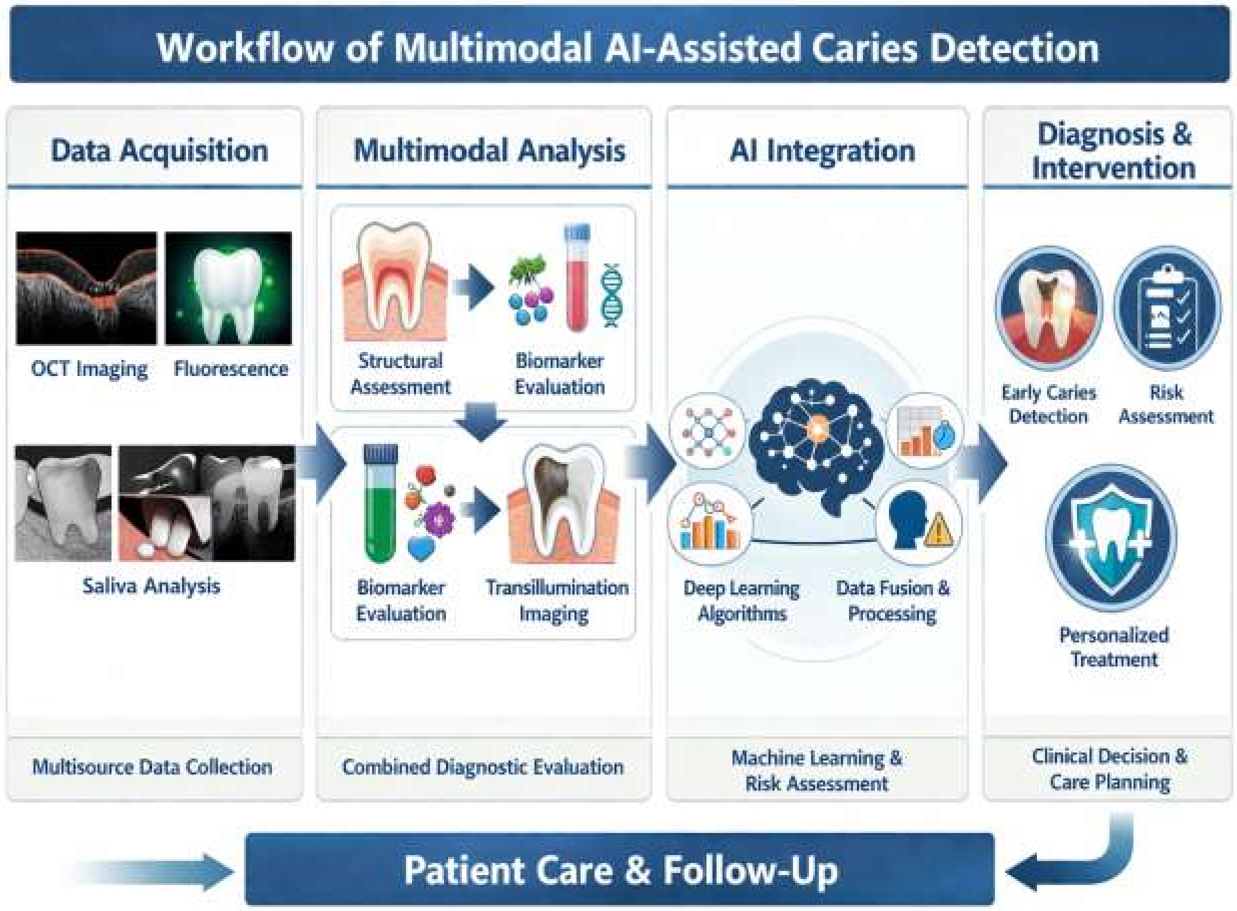

Fig.1 AI-Integrated Multimodal Diagnostic Pathway for Dental Caries Detection

Comparative Analysis of Diagnostic Technologies:-

A detailed comparison of caries detection modalities highlights the trade-offs between sensitivity, specificity, invasiveness, and practicality.

- Visual-tactile examination: Widely used and cost-effective, but highly dependent on clinician experience and unable to detect subsurface lesions reliably.[3,5]
- Radiography: Effective for proximal and advanced lesions but requires substantial mineral loss for detection and involves ionizing radiation exposure.[4,7]
- Fluorescence-based methods: Laser fluorescence (LF) and quantitative light-induced fluorescence (QLF) provide a quantitative assessment of early enamel demineralization. LF devices are limited by plaque, stains, and calculus interference, while QLF offers superior sensitivity and is useful for monitoring remineralization.[6,8,10]
- Transillumination (FOTI/NIRT): Non-invasive and radiation-free, suitable for occlusal and proximal lesion detection. NIRT improves visualization of deeper lesions compared to FOTI but remains qualitative and operator-dependent.[12,13]
- Optical coherence tomography (OCT): Provides high-resolution, subsurface imaging, enabling early detection of enamel and dentin lesions. Sensitivity and specificity exceed 90%, though clinical adoption is limited by cost and interpretative complexity.[14,15]
- Electrical conductance and impedance methods: Sensitive to early porosity changes but affected by moisture and surface conditions.[16]
- Salivary biomarkers: Offer non-invasive biological insights, complementing imaging-based diagnostics, though variability and lack of standardized thresholds limit routine clinical use.[12,13,18]
- Artificial intelligence: Enhances diagnostic performance across imaging modalities, reduces inter-operator variability, and facilitates predictive modeling.[14-16]

A multimodal approach, combining imaging, biochemical assessment, and AI analysis, has emerged as the most promising strategy for personalized caries management, optimizing early detection, treatment planning, and outcome monitoring.[14-18]

Future Perspectives:-

The future of dental caries detection is likely to be shaped by integrated, multimodal, and personalized approaches[16-19]. Key areas include:

1. Multimodal Diagnostics: Combining OCT, fluorescence, transillumination, and salivary biomarker analysis to capture structural, biochemical, and biological data simultaneously, improving diagnostic accuracy and patient-specific risk profiling.[14,16]
2. Point-of-Care Devices: Development of portable, chairside diagnostic tools allows real-time, non-invasive monitoring of caries progression and remineralization, particularly in pediatric and underserved populations.[18]
3. Artificial Intelligence Integration: AI-driven analysis of multimodal datasets can provide predictive insights, highlight early lesions, and propose individualized preventive strategies[15,17].
4. Tele-dentistry and Remote Monitoring: Remote caries screening via digital imaging and AI analysis could improve access to care, reduce disparities, and enable longitudinal monitoring of at-risk populations.[19,20].
5. Personalized Preventive Strategies: Integration of biological markers (saliva, genetics, microbiome) with imaging and AI analytics supports precision dentistry, tailoring preventive and remineralization interventions to individual patient profiles.[13,16,19]

Future research should focus on longitudinal clinical validation, standardization of diagnostic thresholds, cost-effectiveness studies, and ethical considerations related to AI adoption and patient data privacy.[17,19,20]

Challenges and Research Gaps:-

Despite technological advances, several barriers hinder widespread clinical adoption:

- Standardization: There is a lack of universally accepted diagnostic criteria across imaging modalities and biomarker assays.[16,17]
- Clinical Validation: Many novel technologies have been validated in small cohorts or laboratory settings, with limited longitudinal and multicenter studies.[16,19]
- Cost and Accessibility: High acquisition and maintenance costs of OCT and AI-enabled devices restrict use in general dental practice, particularly in low-resource settings.[17,18]
- Salivary Biomarker Variability: Saliva composition is influenced by circadian rhythms, diet, hydration, and systemic health, complicating interpretation and clinical application.[13,18]
- AI and Ethical Considerations: Algorithm transparency, liability, data privacy, and potential bias in AI models are ongoing concerns that require regulatory oversight.[15,20]
- Integration Challenges: Combining multimodal diagnostics into routine workflow requires clinician training, software-hardware interoperability, and streamlined clinical protocols.[17,18]

Addressing these gaps is critical for the translation of research innovations into clinical practice, ensuring that technological advances improve patient outcomes without introducing inequities or unintended harm.

Conclusion:-

Advances in dental caries detection have substantially improved early diagnosis and preventive care. OCT, fluorescence-based systems, salivary biomarkers, and AI represent transformative innovations with the potential to reduce disease progression and enhance patient-centered outcomes[12-20]. Multimodal integration, standardization, and cost-effective implementation will define the next era of precision dentistry, enabling personalized, minimally invasive interventions and improved global oral health.

References:-

1. Kassebaum NJ, Smith AGC, Bernabé E, Fleming TD, Reynolds AE, Vos T, et al. Global burden of untreated caries. J Dent Res. 2017;96(4):380–387.
2. Pitts NB, Zero DT, Marsh PD, Ekstrand K, Weintraub JA, Ramos-Gomez F, et al. Dental caries. Nat Rev Dis Primers. 2017;3:17030.
3. Ismail AI, Sohn W, Tellez M, Amaya A, Sen A, Hasson H, et al. The International Caries Detection and Assessment System (ICDAS). Community Dent Oral Epidemiol. 2007;35(3):170–178.
4. Wenzel A. Bitewing and digital bitewing radiography. J Dent. 2018;75:1–7.

5. Macey R, Walsh T, Riley P, Glenny AM, Worthington HV, Clarkson JE, et al. Fluorescence devices for detection of dental caries. Cochrane Database Syst Rev. 2019;CD013504.
6. Serban C, Lungeanu D, Bota SD, Cotca CC, Negrutiu ML, Duma VF, et al. Emerging technologies for dentin caries detection: a systematic review and meta-analysis. J Clin Med. 2022;11(3):674.
7. Pretty IA. Caries detection and diagnosis: novel technologies. Dent Clin North Am. 2018;62(4):631–642.
8. Shimada Y, Sadr A, Sumi Y, Tagami J. Application of optical coherence tomography in dentistry. Jpn Dent Sci Rev. 2020;56(1):1–9.
9. Zhang CZ, Cheng XQ, Li JY, Zhang P, Yi P, Xu X, et al. Saliva in the diagnosis of diseases. Int J Oral Sci. 2019;11(3):14.
10. Aas JA, Griffen AL, Dardis SR, Lee AM, Olsen I, Dewhirst FE, et al. Bacteria of dental caries. J Clin Microbiol. 2018;56(3):e01604-17.
11. Tjäderhane L. Dentin matrix degradation by host-derived matrix metalloproteinases. J Dent Res. 2019;98(7):725–734.
12. Cuevas-Córdoba B, Santiago-García J. Saliva and omics: a fluid of study for caries diagnostics. OMICS. 2019;23(2):87–97.
13. Javaid MA, Ahmed AS, Durand R, Tran SD. Saliva diagnostics. J Oral Biol Craniofac Res. 2020;10(2):172–177.
14. Schwendicke F, Samek W, Krois J. Artificial intelligence in dentistry: chances and challenges. J Dent Res. 2020;99(7):769–774.
15. Khanagar SB, Al-Ehaideb A, Vishwanathaiah S, Maganur PC, Varadarajan S, Patil S, et al. Scope and performance of artificial intelligence in dentistry: a systematic review. J Clin Med. 2021;10(17):3959.
16. Al-Khalifa KS, Ahmed WM, Azhari AA, Qaw M, Alsheikh R, Alqudaihi F, et al. The use of artificial intelligence in caries detection: a review. Bioengineering. 2024;11(9):936.
17. Head Face Med. Accuracy of artificial intelligence in caries detection. 2025;21:12.
18. Estai M, Kanagasingam Y, Tennant M, Bunt S. Teledentistry applications in caries detection. J Telemed Telecare. 2018;24(3):147–156.
19. Chen H, Zhang K, Lyu P, Li H, Li C, Zhou X, et al. Artificial intelligence in dental imaging. J Dent Res. 2020;99(7):769–774.
20. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. Nat Med. 2019;25(1):44–56.
21. Ekstrand KR, Martignon S, Ricketts D, Qvist V. Detection and diagnosis of caries: criteria and devices. Monogr Oral Sci. 2018;27:33–45.
22. Amaechi BT, Higham SM. Quantitative light-induced fluorescence in caries detection: review and clinical perspective. J Appl Oral Sci. 2019;27:e20180244.
23. Pretty IA, Edgar WM, Smith PW. Novel light-based detection methods for dental caries. Caries Res. 2019;53(1):59–67.
24. Angmar-Månsson B, ten Cate JM. Detection and monitoring of early caries lesions: methods and applications. Adv Dent Res. 2019;30(1):24–30.
25. Fried D, Xie J, Shafi S, Featherstone JD. Infrared and optical imaging for caries detection. Dent Clin North Am. 2018;62(4):615–629.
26. Zakian CM, Stookey GK. Dental caries detection technologies: emerging perspectives. Compend Contin Educ Dent. 2020;41(1):10–18.
27. Diniz MB, Ambrosano GM, Neves FS, Nogueira RP, Filho HG. Diagnostic accuracy of transillumination for proximal caries detection. Oper Dent. 2019;44(2):E85–E92.
28. Sadeghi M, Yazdani J, Jahangiri L, Mortezapour E. Saliva-based biomarker detection in dental caries: recent advances. J Oral Biosci. 2020;62(3):202–210.
29. Abdelaziz MA, El-Monayeri Z, Al-Sayed M. Advances in AI and imaging for early caries detection. Oral Health Prev Dent. 2021;19(1):15–25.
30. Burgersdijk RC, van der Tas JT, Ten Cate JM. Emerging diagnostic methods for caries: a critical review. Caries Res. 2022;56(5):490–507.