

Review Article

Recent Advances in Caries Diagnosis: A Review

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ABSTRACT:

Recent advances in caries diagnosis have significantly transformed the landscape of dental care, enabling earlier detection and management of dental caries. Novel diagnostic technologies, including digital imaging, optical coherence tomography, and artificial intelligence, have enhanced the sensitivity and specificity of caries detection. These innovations allow for a more accurate assessment of carious lesions, facilitating tailored preventive and therapeutic strategies. Additionally, the integration of biomarkers and microbiome analyses provides insights into caries risk assessment and management. This review explores the latest methodologies in caries diagnosis, discusses their implications on clinical practice, and highlights future directions for research to improve patient outcomes and advance dental health.

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INTRODUCTION

Dental caries remains one of the most prevalent chronic diseases worldwide, affecting individuals of all ages and significantly impacting public health. Traditionally characterized by the demineralization of tooth structure due to bacterial activity, the diagnosis of caries has evolved considerably over the years. Early detection is crucial to prevent the progression of carious lesions, thereby reducing the need for more invasive and costly interventions.

Historically, caries diagnosis relied heavily on visual examinations, probing, and radiographic assessments. However, these methods often lack the sensitivity required for detecting incipient lesions, leading to missed opportunities for timely intervention. Recent advances in technology have ushered in a new era of caries diagnosis, integrating state-of-the-art tools and methodologies that enhance the accuracy and efficiency of detection.

Innovative imaging techniques such as digital radiography, fluorescence-based methods, and optical

coherence tomography now allow for a more nuanced analysis of tooth structure, enabling dentists to identify caries at earlier stages. Furthermore, developments in artificial intelligence (AI) and machine learning have transformed diagnostic capabilities by offering predictive analytics and improving the interpretation of complex data sets.

In addition to these technological advancements, a greater understanding of the microbial factors associated with caries has opened new avenues for risk assessment and management. The integration of biomarkers and microbiome analyses aids in identifying individuals at high risk for caries, allowing for personalized preventive strategies.

This review aims to synthesize recent advances in caries diagnosis, emphasizing the implications of these developments on clinical practice and patient outcomes. By exploring the latest methodologies and their applications, we can gain insights into future directions for research and practice that promise to

improve the management of dental caries and enhance overall oral health.

Conventional Diagnostic Methods in Caries Diagnosis

Visual Examination: This is the most fundamental diagnostic method used by dental professionals. It involves inspecting the surfaces of teeth for color changes, surface irregularities, and signs of decay. Dentists look for cavitations (visible holes), discoloration, and texture changes in enamel. This method relies heavily on the clinician's experience and visual acuity, making it essential for routine checks but limited in detecting early-stage caries.¹

Visual-Tactile Assessment: This method combines visual examination with tactile feedback. Dentists use an explorer or probe to gently touch the tooth surfaces, providing additional information about the texture and hardness of enamel and dentin. This approach can help identify softer, compromised areas indicative of early carious lesions. However, careful technique is needed to avoid damaging healthy tooth structure, and this method is subjective and operator-dependent.¹

Radiographic Techniques: X-rays are invaluable in identifying interproximal caries (cavities between teeth) and assessing the depth and extent of carious lesions. Bitewing radiographs are commonly used for caries detection, providing a clear view of both upper and lower dental arches. Radiographs can reveal changes in bone density and the presence of restorations, aiding in comprehensive assessments. However, they involve radiation exposure and may not detect early demineralization effectively.³

Recent Advances in Caries Diagnosis

Cone Beam Computed Tomography: Cone Beam Computed Tomography (CBCT) is a dental imaging technique that uses a cone-shaped X-ray beam and flat panel detectors to create high-resolution, three-dimensional images of teeth, allowing for views in frontal, sagittal, and axial planes. This capability enables the detection of caries at all sites of a tooth, overcoming the limitations of traditional two-dimensional imaging. However, CBCT has drawbacks, including higher radiation exposure, increased costs, and potential imaging artifacts. Studies on its accuracy in detecting dental caries show considerable variability, with several in vitro analyses indicating that CBCT does not provide superior diagnostic accuracy for enamel and dentin caries compared to bitewing radiography.⁴

Digital Transillumination: Transillumination is a technique that uses light transmission through dental tissues to assess their density and composition. Carious tissue, being more porous, absorbs more light and appears darker. Traditional fiber-optic

transillumination provides instant results but does not create images. Digital transillumination improves this by using near-infrared light (700-1500 nm), which penetrates deeper into tissues, offering better contrast between healthy and carious tissues. This enhanced light intensity contrast aids clinicians in diagnosing dental caries more effectively.⁵

Light-Induced Fluorescence: Various wavelengths of light, including ultraviolet (100–400 nm), green-yellow (370 nm), blue-violet (400–450 nm), and near-infrared (750–10,000 nm), can induce fluorescence in carious lesions. Fluorescence is the emission of longer-wavelength light after a substance absorbs shorter wavelengths. This technique detects caries by highlighting the altered fluorescence properties of carious lesions compared to healthy dental tissues. When a carious area absorbs short-wavelength light, it re-emits longer wavelengths, causing a color change. This light-induced fluorescence can be applied to multiple surfaces of a tooth, including occlusal, buccal/lingual, or proximal surfaces.⁶

Electrical Conductance Measurement: Electricity for caries detection was first proposed by Emile Magitot in 1878. These devices exploit the high electrical resistivity of hydroxyapatite in dental enamel. When caries develop, the increased porosity allows more electrically conductive fluids to fill the spaces, reducing electrical resistance and increasing conductance. Electric-based detection methods include electrical conductance measurement and alternating current impedance spectroscopy. The conductance measurement uses a fixed-frequency alternating current to assess the electrical conductance of carious teeth.

The electrical conductance measurement device uses a single, fixed-frequency alternating current to measure the electrical conductance of a carious tooth. The measuring electrode is designed to fit into deep pits and fissures to be in contact with a minuscule amount of dentinal fluid to complete the circuit. If no carious lesions are present on a tooth and have intact enamel, a circuit of the current flow cannot be completed, making the reading on the device zero. If a lesion is present, a current flow would present and the circuit would be closed, which provides a reading on the device.⁷

Ultrasonic Caries Detector: The ultrasonic caries detector features a probe that can be angled to effectively identify carious lesions, especially approximal ones. This technology is relatively straightforward, as the amplified ultrasonic waves significantly exceed background noise, facilitating easier interpretation of wave profiles. The probe does not need to be in direct contact with the lesions, enhancing its clinical utility for hard-to-assess areas. Its advantages include good directionality, deep penetration, and non-toxicity, making it a promising diagnostic tool for caries. However, in the medical

field, ultrasound is known for its low spatial resolution, which makes it less competitive. Additionally, it cannot accurately measure the depth of carious lesions, posing a limitation for digital detection.⁷

Optical Coherence Tomography: Optical coherence tomography (OCT) generates two or three-dimensional images by utilizing the optical absorption and scattering properties of tissues. This imaging technique is based on interferometry, where emitted light interacts with backscattered light from a sample, creating interference patterns. These patterns are then compared to a reference light pattern to generate a micro-structural profile of biological tissues. Swept-source (SS-)OCT is particularly effective for caries detection, offering enhanced image resolution, faster imaging speeds, and greater sensitivity compared to traditional OCT systems. Typically, a near-infrared laser with a central wavelength of approximately 1310 nm serves as the light source. In SS-OCT images for caries detection, demineralized enamel or dentin appears as a bright zone due to the heightened backscatter signal from the carious tooth structure, enabling detailed assessment.⁷

Laser-Induced Thermal Imaging: Laser-induced thermal imaging relies on the principle that the porosity of a carious lesion influences the amount of water stored in a tooth, which in turn affects its thermal profile. This temporal profile is associated with the ongoing evaporation of water from the porous dental tissues, causing thermodynamic changes on the tooth's surface until a new equilibrium is reached when the tooth dries. The technology operates by either capturing the chronological evaporation profile of a carious tooth surface as it dries or by measuring the tooth's thermal response immediately after being exposed to a heat pulse.⁸

Soprolife: Soprolife is a dual-function device that combines a caries detection system with a high-magnification intraoral camera. This light-emitting diode fluorescence device is software independent, making it compatible with most imaging and practice management software. During the excavation process, it allows for clear differentiation between infected and affected dentin: the infected dentin appears bright red and is easily removed, while the affected dentin shows up in orange and can be preserved to support the tooth's recovery. A significant advantage of using SOPROLIFE is its capability to display carious lesions on a computer monitor, which aids in follow-up procedures and boosts patient motivation.⁹

Soprocure Camera: The Soprocure camera serves three distinct clinical applications: daylight, caries, and periodontal modes. The caries mode focuses on identifying enamel and dentin caries, while the periodontal mode is tailored for recognizing and

assessing periodontal inflammation. When used for examinations, the Soprocure camera exhibits relatively lower sensitivity but higher specificity in detecting ICDAS code 1 and 2 lesions. Additionally, teledentistry consultations can provide satisfactory diagnostic performance for detecting dental caries. Overall, the Soprocure camera enables timely and effective detection of carious lesions.⁹

Pearl®: Pearl® is an innovative AI-powered tool designed to interpret dental radiographs, transforming the landscape of dental diagnostics. By enhancing precision and consistency, Pearl improves diagnostic accuracy and standardization within dental practices. At its core, the tool employs a sophisticated deep learning model trained on a wide range of dental radiographs. It can identify and annotate various dental pathologies, including dental caries, periodontal bone loss, and periapical lesions. By recognizing these common conditions, Pearl serves as an invaluable second set of eyes for dentists, helping to ensure that no detail is missed. However, while Pearl is a valuable aid in diagnosis, it is not intended to replace a dentist's clinical judgment. Instead, it should be viewed as a supportive tool for dental professionals, rather than a standalone diagnostic system.¹⁰

Denti. AI: Denti. AI is a state-of-the-art tool specifically designed to revolutionize how dental professionals diagnose and manage dental caries, one of the most prevalent oral health issues worldwide. By leveraging advanced AI algorithms and machine learning models, Denti. AI enhances the accuracy and efficiency of dental caries detection and treatment planning. Traditionally, diagnosing dental caries relied heavily on a dentist's expertise, experience, and the quality of dental radiographs. While this method is generally effective, it can be somewhat subjective and susceptible to variability and human error. Denti. AI mitigates these challenges by offering a more objective and standardized analysis of dental radiographs.¹⁰

Biomarkers and Salivary Analysis: Advances in microbiome research have highlighted the role of specific bacteria in caries development. Utilizing salivary biomarkers, practitioners can assess caries risk and tailor preventive measures to individual patients, allowing for personalized treatment strategies.¹¹

Risk Assessment Models: Recent advances have also focused on developing comprehensive caries risk assessment models that integrate clinical, behavioral, microbiological, and environmental factors to predict an individual's susceptibility to caries.¹² These advances in caries diagnosis not only promote early detection but also allow for more conservative management of dental caries, ultimately improving

dental health and reducing the burden of disease. The ongoing research and development in this field promise to further enhance the effectiveness and precision of dental diagnostics in the future

CONCLUSION

The recent advances in caries diagnosis mark a significant leap forward in the field of dentistry, combining technology and innovation to enhance early detection and management of dental caries. Digital imaging, fluorescence techniques, and AI-driven analysis have transformed traditional diagnostic practices, allowing for a more nuanced understanding of carious lesions. These advancements not only increase the accuracy of diagnoses but also promote conservative treatment approaches that can preserve tooth structure and maintain optimal oral health.

The integration of biomarkers and personalized risk assessments further empowers dental professionals to tailor preventive strategies, ultimately leading to improved patient outcomes. As the research continues to evolve, we anticipate the development of even more sophisticated diagnostic tools and methodologies that will redefine caries management.

In conclusion, embracing these advancements is essential for modern dental practice. By leveraging cutting-edge technologies and insights from ongoing research, dental professionals will be better equipped to combat the prevalence of caries, ensuring that patients receive the highest standard of care in their oral health journey. As we move forward, continued collaboration and innovation will play crucial roles in shaping the future of caries diagnosis and prevention.

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