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Contemporary Methods for Diagnosing Early Occlusal Carious Lesions

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Abstract

Early diagnosis of occlusal carious lesions is crucial for preventive and minimally invasive dental care. Accurate diagnosis requires not only recognition of the lesion itself but also contextual evaluation of biological and behavioral determinants influencing the disease process.

The visual-tactile method remains the most widely used technique in caries lesion diagnosis. Various contemporary methods enhance the detection, assessment, and monitoring of these lesions beyond traditional examination. The use of adjunctive tools such as fiber-optic transillumination, laser fluorescence (DIAGNOdent), and fluorescence-based camera systems (quantitative laser fluorescence, Canary, VistaCam, Soprolife) offer unique advantages and limitations in assessing lesion presence, depth, and activity in order to enable preventive and minimally invasive clinical decisions without radiation exposure. The purpose of this review is to explore contemporary methods for diagnosing early carious lesions and their significance for preventive and minimally invasive interventions, while also evaluating the effectiveness and limitations of both traditional and modern diagnostic techniques.

Keywords: diagnosing methods, occlusal carious lesions, prevention

Background

Dental caries remains one of the most prevalent oral diseases in childhood. Despite the implementation of primary preventive measures and the availability of established guidelines for caries prevention, it continues to represent a major cause of tooth loss worldwide. This condition adversely affects children's quality of life, both physically and psychologically, and constitutes a significant global public health issue (1, 2). The study of a given lesion requires a clear distinction between the terms caries lesion diagnosis and caries lesion detection. Detection refers to the process of identifying changes in enamel, dentin, or cementum, as well as differentiating between a sound tooth surface and one affected to varying degrees by the disease process. This is achieved through optical or physical means. The contemporary approach to caries management emphasizes the importance of detecting the earliest enamel changes (3, 4).

For each carious lesion, three diagnostic requirements must be met: lesion detection, assessment of the extent of tissue involvement, and evaluation of lesion activity—criteria essential for clinical

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decision-making. At present, the visual-tactile method remains the most widely applied technique, fulfilling all of these requirements (5).

Numerous adjunctive diagnostic tools have been developed to assess the depth of carious lesions, which cannot be determined by visual inspection alone. These are aimed at lesion detection, meaning the differentiation between sound and diseased tissue (6, 7). However, lesion detection does not establish whether a lesion is active or arrested, and unlike diagnosis, it does not take into account patient-specific environmental factors such as tooth position, lesion location, saliva characteristics, microbiome composition, oral hygiene practices, use of fluoride agents, diet, and others (7, 8, 9). Building on the need for more objective and reproducible methods, fiber-optic transillumination has emerged as a valuable electronic adjunct in overcoming the limitations of traditional techniques.

Fiber-Optic Transillumination

The limitations of traditional methods, such as poor reproducibility, the requirement for clinical experience, and the risk of subjectivity, can be overcome by the additional use of electronic methods. These enable quantitative characterization and longitudinal monitoring of the progression of carious lesions (1). Many of these systems were introduced during the last decade; however, further studies are still required, as the sensitivity of the techniques and the correct interpretation of the data may negatively influence the results (1).

In enamel, fluorescence is associated with the presence of fluorescent residues originating from food, bacteria, or as a result of the carious process itself. Dentin possesses the property of autofluorescence. Several hypotheses attempt to explain this phenomenon: modification of collagen fibers with fluorescent properties, accumulation of secondary metabolic products, and bacterial biofilm formation with specific endogenous porphyrins (11, 12). The best-studied byproducts of the carious process are those produced by the so-called Maillard reaction. This is a non-enzymatic glycation of carbohydrates and proteins, leading to the formation of a brownish polymer of cross-linked proteins and advanced glycation end-products (13). Dentin collagen fibers bind to glycation products, rendering the matrix more resistant to degradation. Studies focus on porphyrin and its derivatives in an attempt to establish a link between the autofluorescent signal of enamel and dentin carious lesions and porphyrin deposits (14). In primary teeth, light scattering is more pronounced compared to permanent teeth, giving them a whiter or bluish appearance depending on the wavelength used (14).

Fiber-optic transillumination (FOTI) employs the principle of light scattering to enhance the contrast between sound and carious enamel. Since the structure affected by caries is more porous than healthy tissue, it absorbs significantly more light. Thus, due to the scattering of visible light, it appears darker. Proposed as an alternative to bitewing radiographs, this method can be applied to any tooth surface, with particular value in the detection of interproximal lesions in anterior teeth, as their buccolingual enamel thickness is lower compared to posterior teeth (15). Light is directed toward the tooth via optical fibers and must have sufficient intensity to penetrate the dental structure and reach areas that are difficult to visualize clinically (16, 17, 18). The tooth is transilluminated bilaterally using a handpiece. In advanced lesions, affected dentin appears as an

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orange, brown, or gray area beneath the enamel, thereby assisting in differentiating enamel from dentin caries (16, 19).

This method was subsequently improved by the addition of a small digital camera within the handpiece—digital fiber-optic transillumination (DIFOTI). The device allows in vivo image capture and database storage of digital images when the transmitted light passing through the tooth is converted into a signal that can be processed by a computer. Combining laser transillumination and computer analysis enables the reproduction of high-quality images, which can be instantly visualized on a screen (20 - 22). To this end, DIFOTI is equipped with a handpiece, control panel, dedicated software, personalized image recording system, foot pedal, and interchangeable tips for examining specific surfaces (occlusal or approximal) (15).

DIFOTI differentiates esthetic restorations from dental structures easily and allows diagnosis of macro- and microfractures (23). Large composite or amalgam restorations may hinder light penetration and impede the detection of secondary caries. High-quality DIFOTI images clearly reveal the depth of carious lesions, which assists clinicians in deciding between non-invasive or invasive treatment approaches (24). This may reduce unnecessary operative interventions and facilitate the successful implementation of preventive measures. Since images obtained by this method visualize a single tooth, they provide more detailed information compared to bitewing radiographs. Moreover, easy image storage enables longitudinal monitoring of lesion progression and the outcomes of preventive interventions (23, 24).

During the past two decades, the growing interest in transillumination as a diagnostic tool for carious lesions led KaVo (KaVo, Biberach, Germany) to introduce, in 2012, a device known as DiagnoCam, as a further development of DIFOTI (25). This device is based on transillumination with near-infrared light transillumination (NILT), employing invisible light with wavelengths ranging from 700 to 1500 nm. This characteristic represents the major distinction from FOTI and DIFOTI (25). Altering the wavelength enhances the early detection of carious lesions, since light in this range is less scattered and thus penetrates deeper into the dental structure. This method provides good contrast between carious and adjacent sound tissues, thereby facilitating lesion detection (15). A new version of KaVo's DIAGNOcam Vision Full HD (a single-shot device that captures transillumination, fluorescence, and HD intraoral images) is available. Preliminary data report rapid multimodality acquisition and potential workflow advantages, but peer-reviewed in-vivo studies directly evaluating the diagnostic accuracy of the combined 3-in-1 modality are still limited and require prospective clinical validation (26, 27).

The most significant advantage of this method is that it does not expose the patient to additional radiation. Therefore, it is a safe modality that may be used even when radiographs are contraindicated (21, 25). Furthermore, it has been shown to detect more incipient and advanced carious lesions compared to visual or radiographic diagnosis (28). In some cases, the device causes less patient discomfort than bitewing radiographs, as certain individuals experience difficulty tolerating the intraoral sensor (24). Real-time imaging is beneficial not only for clinicians but also for patient education, illustrating the condition of the dentition and each tooth individually. This makes the device a simple and effective tool for motivating patients toward improved oral hygiene practices (23).

Nevertheless, scanning with the device may be challenging, requiring appropriate and thorough training. Additional errors may arise during image acquisition and analysis (23). Another

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disadvantage is the variability of image quality among different clinicians (28). Proper transillumination requires positioning the handpiece tip parallel to the tooth axis and deep enough to cover the gingival margin. Incorrect positioning reduces image quality, producing blurred, grainy, over- or underexposed images. Accurate positioning is particularly difficult in posterior regions due to limited space. Moreover, to improve image quality and reproducibility, standardized procedures are needed, which currently exist for bitewing radiographs but are lacking for this method (23, 28).

Laser Fluorescence

DIAGNOdent is a commercially available device for laser fluorescence. It is equipped with tips of different designs and a pen-like form, which facilitate the examination of various tooth surfaces, including those that are difficult to access (29). Fluorescence is the phenomenon of photon emission from a substance that has absorbed light or other electromagnetic radiation (17, 30 - 32). The device can be used to quantitatively assess the activity of carious lesions, as more advanced lesions fluoresce more intensely. DIAGNOdent can also be applied for differentiating between inactive and active lesions on root surfaces (33). It serves as an adjunct to visual inspection in the diagnosis of occlusal carious lesions.

Its principle of action is based on the fact that when a diode laser with a wavelength of 655 nm irradiates the tooth surface, it is absorbed by metabolic products of microorganisms within the carious lesion, and these metabolites emit light in the red spectrum. The fiber-optic bundle captures the emitted light and transfers it through the optical fiber to the tip of the handpiece. Reflected and emitted photons pass back through the same tip but via different fibers. The intensity of the fluorescent light is indicative of the size and depth of the lesion, with values ranging from 0 to 99 (17, 30 - 32). This provides a quantitative measurement of caries development, since affected tissues fluoresce more strongly than sound tissues (30, 34). The threshold separating enamel from dentin lesions is 18 under moist conditions and 21 after drying. In addition to the numerical display, the results are accompanied by an acoustic signal. Thus, laser fluorescence offers a quantitative and non-invasive method for diagnosing carious lesions (30, 35).

The occlusal surface is a caries-prone site, and lesion detection in this area remains challenging (36). Laser fluorescence has advantages over other diagnostic methods, the most important being its ability for early detection. This allows the preservation of more sound tooth structure and enables the use of minimally invasive treatments. The method is characterized by high sensitivity and low specificity. Because of the high likelihood of false-positive diagnoses, its use is recommended in combination with other techniques (36). Some studies were performed in vitro and are not directly applicable to clinical practice due to the absence of influencing factors such as plaque, calculus, remnants of prophylactic paste following professional oral hygiene, tooth type (primary or permanent), storage conditions of extracted teeth, operator skill level, and different analysis methods. Therefore, to compensate for its low specificity, this method is recommended as an adjunct to visual inspection when diagnosing the occlusal surface (37 - 39).

Despite published reports on high sensitivity of DIAGNOdent, a study by Fung et al. comparing visual methods and DIAGNOdent across three different groups demonstrated low sensitivity for DIAGNOdent. Furthermore, poor correlation was found between histological findings and results obtained with laser fluorescence (38). In clinical practice, DIAGNOdent frequently leads to over-diagnosis. The main drawback is the frequency of false-positive signals (37). Two main reasons have been identified: first, the presence of biofilm or debris in the deepest portions of pits and fissures; second, the size of the device tip, which is larger than the fissure entrance. The requirement for frequent recalibration is another limitation. The higher rate of false-positive diagnoses suggests that this device should not be used as a primary diagnostic method (37).

Detection of lesions beneath restorations or sealants is difficult. Some studies indicate that DIAGNOdent may be used in such cases (38). Laser radiation has the potential to penetrate composite materials and identify underlying lesions; however, multiple factors may compromise the reliability of the data. For example, polishing of restorations prior to measurement is recommended, since surface deposits can result in false positive results (39). In deep dentin lesions, the method cannot be used to evaluate residual dentin near the pulp because of pulpal fluorescence (40). In pediatric patients, DIAGNOdent is a user-friendly device as the examination takes only a few seconds, and the data obtained allow immediate assessment of the carious lesion (37). Moreover, repeated use of this device poses no harm to the patient.

Camera–Fluorescence Systems

Quantitative Laser Fluorescence (QLF)

Enamel and dentin possess natural fluorescence, or autofluorescence. Carious lesions, dental plaque, and microorganisms also contain fluorescent substances. The difference between the fluorescence of sound tooth structure and that of carious lesions can be visualized using quantitative laser fluorescence (QLF) (32).

Irradiation of dentin with blue light (wavelength 290–450 nm) induces fluorescence in the yellow-green spectrum. Initial enamel lesions become visible due to light scattering relative to the surrounding sound enamel. Consequently, less excitation light reaches the dentin, resulting in reduced fluorescence (32 - 45). The lesion appears as a dark spot against a light green background, while fluorescence from bacterial porphyrins is observed in red (32). With the aid of a computer algorithm, it has been established that this method allows quantification of enamel demineralization (46). It has also been demonstrated that the technique is suitable for evaluating lesions on smooth surfaces, but less effective for approximal lesions. The number of lesions detected on the vestibular surfaces of patients following orthodontic treatment with QLF far exceeds those identified visually after debonding of fixed orthodontic appliances (47).

Canary

Canary (Quantum Dental Technologies Inc., Ontario, Canada) is a laser-based device that utilizes a camera and a combination of heat and light (48). Its diagnostic scale ranges from 0 to 100:

- 0–20: sound structure,
- 21–70: early lesion,
- 71–100: advanced lesion.

By altering the laser pulse, a depth profile of the tooth can be generated, allowing detection of lesions up to 4–5 mm beneath the enamel surface and with a diameter as small as 50 µm. Simultaneous measurement of reflected light and heat provides information about the presence and size of lesions before they become visible radiographically. The device enables early detection of small lesions on occlusal, smooth, and approximal surfaces, which is advantageous compared to traditional methods for diagnosing incipient lesions (49). It is also claimed to detect secondary caries lesions around visible margins of composite restorations (49).

VistaCam

VistaCam is an intraoral camera that illuminates teeth with violet light (405 nm) and captures the reflected light as a digital image. A filter blocks reflected light below 495 nm, allowing passage of green-yellow fluorescence of sound teeth (peak at 510 nm) and red fluorescence of bacterial metabolites (peak at 680 nm). The accompanying software quantitatively evaluates the green and red components of reflected light on a scale from 0 to 3, expressed as a red-to-green ratio, highlighting areas with abnormally high ratios (50). The device has demonstrated good diagnostic efficacy in detecting occlusal carious lesions at different stages of progression (51).

Soprolife Camera

Soprolife is an intraoral QLF camera that enables visualization of images on an LCD screen and recording on a computer using dedicated software (Sopro Imaging Software Life Mode) (32). The images allow qualitative differentiation between the autofluorescence of sound hard dental tissues and bacterial fluorescence, forming the basis for a clinically relevant classification system. The correlation between histological lesion depth and various diagnostic methods is presented in Table 1 (32, 43).

Table 1. Correlation of diagnostic results using ICDAS II, DIAGNOdent, and Soprolife (values of each system corresponding to the histological classification of carious lesions).

Histological diagnosis	ICDAS II	DIAGNOdent	Soprolife	Fluorescence appearance
Sound surface	0	0–13	0	Green, blue coloration
Outer half of enamel	1	14–20	1, 2	Blue, white coloration
Inner half of enamel	2	21–29	3	White coloration
Dentin carious lesion	3–6	≥30	4, 5, 6	Red, black coloration

The system offers two operating modes: “day light” for observation under white light and “blue light,” based on autofluorescence (32, 45). The scientific literature contains a limited number of studies reporting results with newer diagnostic tools such as Soprolife for early detection of enamel carious lesions (52, 53). This camera allows diagnosis of initial caries, monitoring during cavity preparation, and recording of high-quality images (44, 52). Several studies suggest that the use of Soprolife may prevent unnecessary operative interventions (52, 53).
Disadvantages associated with Soprolife include higher cost and the requirement for additional equipment. From the patient’s perspective, cooperation is needed to keep the tooth surface dry

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during the examination; furthermore, the camera head may cause discomfort, especially in children, due to the need for specific angulation and multiple measurements on different points of the occlusal surface (44, 52). The system aims to guide clinicians toward preventive and minimally invasive therapeutic approaches, with the possibility of monitoring lesion progression or arrest over time (52, 53).

Similar to radiography, fluorescence-based methods provide information on the presence of cavitation. However, their major drawback is the increased risk of false-positive results, attributable to autofluorescence from the dental biofilm, certain prophylactic agents (toothpastes), and restorative materials. Therefore, these techniques are more appropriate for adjunctive diagnosis of primary carious lesions (53). Their application requires prior professional oral hygiene and drying of the tooth. Therapeutic decisions should not be based solely on this type of diagnostic information (35, 53).

Conclusion

While advanced diagnostic tools such as Soprolife and fluorescence-based methods offer promising results for the early detection and monitoring of carious lesions, their integration into clinical practice requires careful consideration. These technologies enhance diagnostic accuracy and support minimally invasive treatment approaches, yet their limitations—including high cost, the need for specialized equipment, and potential for false-positive results—underscore the importance of comprehensive clinical assessment. Ultimately, adjunctive use of these methods, combined with traditional diagnostic techniques and sound clinical judgment, will best serve patient care and preventive dentistry.

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