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Caries risk assessment: methods available to clinicians for caries detection

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Abstract – It is hypothesized that occlusal lesions are initiated on the fissure walls and can therefore be obscured by sound superficial tissue. Additionally, there is evidence that one effect of regular use of fluorides is greater opacity of enamel, which may obscure underlying lesions in dentin, the so-called 'hidden lesions'. Dental radiographs are inadequate for detecting decay in the occlusal surfaces until the lesion is well advanced through the enamel and into the dentin. The clinician relies on visual observation of texture and discoloration, clinical judgment based upon experience, and on tactile sense by probing with an explorer. An objective detection method to complement the traditional visual assessment is used by the clinician for arriving at clinical decisions on the management of the carious lesion: whether invasive therapy or a more conservative, noninvasive approach. Objective and reliable longitudinal monitoring of the lesion's response to preventive measures allow the selection of an appropriate therapy before the lesion progresses to the stage where invasive treatment is required. This paper discusses the problem of the lack of appropriate clinical methods for the detection and quantification of carious lesions. A few commercially available methods are described (the quantitative light-induced fluorescence method, the DIAGNOdent device, and electrical caries monitor) and some new techniques mentioned.

Key words: caries; caries risk; quantification

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Modern management of dental caries has three major components: prevention, control, and treatment, and is based on appropriate diagnosis of the disease and detection of pathological changes, i.e. lesion formation in its earliest stages. In Scandinavian dental schools, preventive and restorative dentistry have, for many years, been integrated in the undergraduate curriculum as one subject, 'Cariology', and this is reflected in the textbooks of the 1960s, 1970s, and 1980s (1, 2). In North American textbooks of operative dentistry, however, this concept has only recently been introduced (3). The importance of chairside application of basic theoretical concepts has been emphasized in a textbook for dental practitioners (4).

Current treatment strategy in Scandinavia is based on diagnosis of caries activity, identification of the main causal and predisposing factors in the individual case, and assessment of the actual caries risk (5). Diagnosis of dental caries is often regarded as synonymous with detection of the clinical signs of tissue damage caused by the disease, i.e. carious lesions and cavities. For practical clinical purposes, the diagnosis should express the individual patient's caries activity, which is a compound diagnosis derived from immediate past experience, lesion progression, and the clinical appearance of the lesions or cavities. Caries activity is evaluated on the basis of data obtained from clinical examination and assessment of factors associated with the pathogenesis of the disease. The most important clinical parameters are the lesion sites, typical or atypical, and the appearance of individual lesions, and

whether the disease process at these sites is active or arrested.

In recent years, there has been a pronounced change in the epidemiology and disease pattern of dental caries (6–8). However, despite the dramatic decline of caries incidence, particularly in children and young adults, the disease is far from eradicated. The following major changes have occurred in the pattern of the disease. Progression of enamel caries is now slower, and allows preventive intervention before the stage of irreversible destruction of the tooth is reached. There is also a pronounced reduction in lesion development on smooth surfaces accessible to fluoride (9–12). Much of the decay for which clinical intervention is required occurs around existing restorations and/or in the occlusal surfaces of the teeth, particularly the complicated fissure systems of the molar teeth. The occlusal fissures of the first permanent molars are generally the first sites in the permanent dentition to develop caries (13).

As the prevalence of dental caries in high-income countries has decreased, lesion detection has become more difficult. Dental radiographs are inadequate for detecting decay in the occlusal surfaces until the lesion has advanced through the enamel and into the dentin (14). The clinician relies on visual observation of discoloration, clinical judgment based upon experience, and on tactile sense by probing with an explorer.

It is hypothesized that the occlusal lesion is initiated on the fissure walls and is therefore obscured by superimposed sound tissue. Additionally, there is evidence that an effect of regular use of fluorides is greater opacity of enamel, which may obscure underlying lesions in dentin, the so-called 'hidden lesions' (15). More research is clearly needed on 'hidden caries', especially longitudinal clinical studies in which the long-term fate of these lesions can be documented (16).

Variation in caries diagnosis and treatment decisions is a well-recognized phenomenon (17–20). For the clinician, a major shortcoming in caries management strategies based on risk assessment is the lack of methods which can reliably establish the extent of the subsurface decay (14, 21–25).

With modern methods, lesion detection is possible at a stage long before frank cavitation, and is very important for carrying out timely and appropriate preventive measures. In view of these changes, caries diagnosis has a critical impact on treatment decisions: incorrect diagnosis may easily result in incorrect treatment decisions, particularly with respect to operative intervention. With respect to dentinal caries, the diagnosis of the disease and the detection of early lesions should be regarded as cornerstones of cost-effective dental health care delivery and quality of care (26).

Despite the decline of caries incidence in children over the past 20 years (6, 27), there remains a proportion of the population which is susceptible to caries. These individuals require intensive preventive measures. In Scandinavia, the measures most commonly applied in the clinical setting comprise a prophylaxis (professional tooth cleaning) followed by an application of fluoride varnish (28). The outcome, however, is often difficult to evaluate with conventional clinical methods. In clinical practice, objective, reliable quantitative data on the outcome of efforts to arrest disease activity, e.g. longitudinal monitoring of lesion response to preventive measures, would allow flexibility in selecting intervention appropriate to the individual patient before lesions progress to a stage requiring expensive invasive therapy.

Carious lesions occur in a variety of anatomic locations and have unique aspects of configuration and rate of spread. These differences make it unlikely that a single diagnostic method will have the adequate sensitivity and specificity to detect caries at all sites. Multiple diagnostic tests would increase the overall efficacy and precision of caries diagnosis, and some new techniques for caries detection and quantification have been developed and evaluated (23, 26, 29–31). Some are now commercially available.

Conventional caries detection methods

Traditional diagnostic methods, such as visual inspection, appear to have very low sensitivity and high specificity in diagnosing occlusal caries (13, 32, 33). Attempts to improve the sensitivity have been made. In a study by Ekstrand et al. (34), sensitivity and specificity for detection of dentinal lesions ranged between 0.92 and 0.97, and 0.85 and 0.93, respectively. The criteria that were used for visual inspection are presented in Table 1. One conclusion from the study was that although good results were obtained regarding sensitivity and specificity as well as operator agreement, it takes more time to learn the method. Although improvements in visual inspection with new scoring

Table 1. The detailed criteria for visual inspection of occlusal surfaces introduced by Ekstrand et al. (34)

Classification	Visual inspection
0	No or slight change in enamel translucency after prolonged air drying (>5 s)
1	Opacity or discoloration hardly visible on wet surface, but distinctly visible after air drying
2	Opacity or discoloration distinctly visible without air drying
3	Localized enamel breakdown in opaque or discoloured enamel and/or greyish discoloration from the underlying dentin
4	Cavitation in opaque or discoloured enamel exposing the dentin

systems seem promising (34–36), further clinical validation is still necessary.

For detection of occlusal dentinal lesions, the sensitivity of the explorer is reported to be only about 0.5–0.6 (9). A number of reports have demonstrated that probing with a sharp explorer may cause damage to newly erupted teeth or create a cavity at the site of a superficial carious lesion, and its use has been questioned by several authors (9, 37, 38). Loesche et al. (39), in a study on intra-oral transmission of pathogenic microorganisms, showed that sterile fissures might be inoculated by probing after previous contact with an infected fissure.

Fiber-optic transillumination (FOTI), is a qualitative method that has been used since the 1970s. In FOTI, white light from a cold-light source is passed through a fiber to an intra-oral fiber-optic light probe that is placed on the buccal or lingual side of the tooth. The surface is examined using the transmitted light, seen from the occlusal view. Demineralized areas appear darker compared with the surrounding sound tissue. The contrast between sound and carious tissue is then used for detection of lesions. Figure 1 shows an example of FOTI in clinical use. FOTI has been evaluated in a number of studies for detection of posterior approximal carious lesions (40–43), and has shown low-to-good sensitivity and good specificity. Côrtes et al. (44) showed, in an *in vitro* study, that a combination of FOTI and visual inspection was useful for determination of occlusal lesion depth.

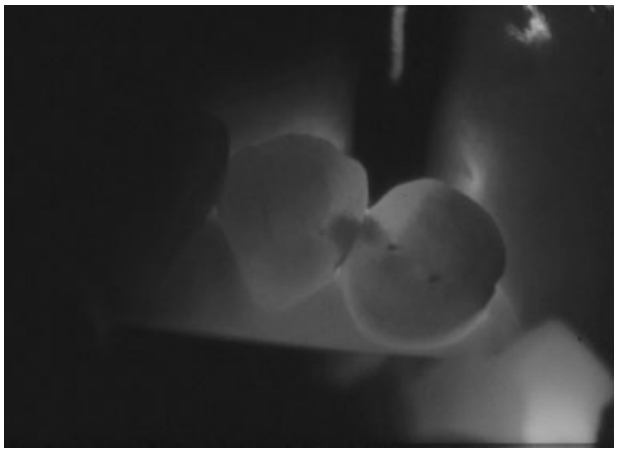

Fig. 1. FOTI – clinical use (Photo by Dag Wallerstedt, Karolinska Institutet).

Using the digital image of a tooth (seen from the occlusal view during transillumination) through computer image analysis, researchers have attempted to improve the performance of FOTI (45–47). This quantitative method, digitized fiber optic transillumination, DI-FOTI, has been evaluated in a few studies, and the initial results indicate that both the sensitivity and specificity are very high. However, this method needs to be developed further before it can be applied in clinical situations.

The use of film radiograph for caries detection has a long history, and is still the most widely used diagnostic technique. Bitewing radiography has been found to be useful for dentinal caries detection on both occlusal and approximal surfaces. However, it has no value for occlusal enamel caries detection and only a limited value for approximal enamel caries detection. One drawback of bitewing radiography is that it is associated with the unavoidable hazards of ionizing radiation, although this may be ameliorated by the introduction of a digital technique.

This paper does not aim to list all existing new methods for caries detection and quantification. A few more-or-less commercially available devices will instead be discussed: quantitative light-induced fluorescence (QLF), DIAGNOdent, and electronic caries monitor (ECM). New radiographic techniques will not be discussed.

New caries detection methods – optically based

Light interacts with the dental hard tissues in different ways. It can be reflected, scattered, transmitted or absorbed. Figure 2 shows (a) a photon that is reflected by the material, (b) a photon that is scattered several times in the medium, (c) a photon

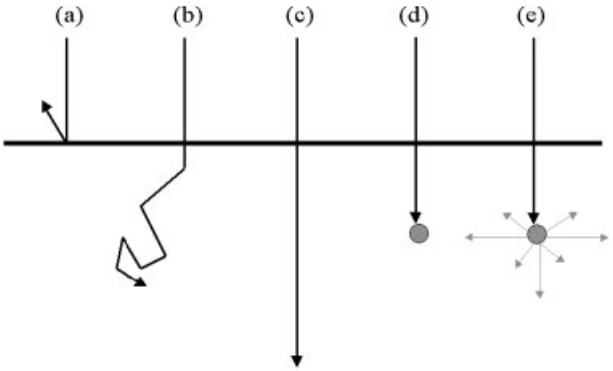

Fig. 2. Light interaction with the dental hard tissue. (a) a photon that is reflected by the material; (b) a photon that is scattered several times in the medium; (c) a photon that is transmitted right through the material; (d) a photon that is absorbed; (e) a possible consequence of absorption: fluorescence.

that is transmitted right through the material, and (d) a photon that is absorbed and then transformed into heat. The different phenomena can occur alone or in combination.

A possible consequence of absorption is fluorescence (Fig. 2e), in which electrons of a lower energy status are moved to a higher status. When they fall back to the original level, energy is emitted in the form of light, called fluorescence. In other words, fluorescence occurs as a result of the interaction of electromagnetic radiation with molecules in the tissue.

The cause of enamel fluorescence is still unclear. Most of the fluorescence is induced by organic components, proteinic chromophores, but some is probably attributable to apatite (48). It has been proposed that fluorescence in dentin is caused by inorganic complexes, as well as some organic components (49). In sound enamel, the path lengths are long with a high probability that the photons will hit a chromophore. Thus, fluorescence is relatively intense.

Demineralization of dental hard tissue, enamel or dentin results in the loss of autofluorescence, the natural fluorescence. Several factors may contribute to the decreased fluorescence of incipient caries lesions. Four possible mechanisms have been proposed (50):

- The light scattering in the lesion causes the light path to be much shorter than in sound enamel: the light absorption per volume is much smaller in the lesion and the fluorescence is weaker.
- The light scattering in the lesion acts as a barrier for the excitation light to reach the underlying fluorescing dentin, and a barrier for fluorescent light from dentin to reach the surface.
- Fluorescence is quenched by a change in the molecular environment of the chromophores.
- Proteinic chromophores are removed by the caries process.

The QLF method – yellow/orange fluorescence

In the quantitative light-induced fluorescence (QLF) method, yellow fluorescence is induced by irradiating the tooth by visible light in the blue-green region. Early last century, this phenomenon had already been proposed as a useful tool for diagnosing dental caries (51). More recently, laser light was used to induce fluorescence of enamel in a sensitive, nondestructive method for detection of enamel demineralization and dental caries (52, 53).

The tooth is illuminated by a broad beam of blue-green light from an argon$^+$ ion laser, producing diffuse monochromatic light with a wavelength (λ) of 488 nm, or by blue light from a 50-W xenon microdischarge arc lamp equipped with an optical bandpass filter with a peak intensity of 370 nm (full-width half-measure of 80 nm). The fluorescence of the enamel occurring in the yellow region is observed through a yellow high-pass filter ($\lambda \geq 540$ nm for the laser and $\lambda \geq 520$ nm for the xenon lamp), which filters out all reflected and back-scattered light. The light illuminating the tooth is transported through a liquid-filled light guide. The fluorescent filtered images are captured using a colour CCD video camera and a frame-grabber. Data are collected, stored and analyzed by a custom-made software (Inspektor Research Systems BV, Amsterdam, The Netherlands).

Demineralized areas appear as dark spots. The fluorescent radiance of a carious lesion viewed by QLF is lower than that of sound enamel. To enable calculation of loss of fluorescence in the carious lesion, the fluorescent radiance of sound tissue at the lesion site is reconstructed by interpolation from the radiance of the sound tissue surrounding the lesion. The difference between the measured values and the reconstructed values gives the resulting fluorescence loss in the lesion. Three quantities are obtained: lesion area (mm^2), ΔF (average change in fluorescence, in %), and ΔQ (area $\cdot$ ΔF).

The QLF method has been tested in several *in vitro* (54–56), *in situ* (57) and *in vivo* studies (58–62) for smooth-surface caries lesions. The possibility of adapting the QLF method for occlusal caries diagnosis (63–65) as well as modification for detection and quantification of secondary caries is under investigation (66–68), but has yet to be tested clinically.

It has been shown that the QLF method is a sensitive, reproducible method for quantification of enamel lesions on smooth surfaces. However, it seems to be limited to a lesion depth of about 400 μm.

Examples of factors that may influence the outcome of the measurements in different ways include presence of plaque, calculus and/or staining on the tooth surface (69), ambient light, daylight or office light, and the degree of dehydration of tooth tissue (70). Certain errors in the capturing stage of the method, such as differences in *x*- or *y*-axis, or rotation of the image, may be adjusted during the analytical stage of the method.

The DIAGNOdent device – near-infrared fluorescence

In 1985, Sundström et al. (71) conducted a comparative study on the fluorescence of sound tooth substance for various excitation wavelengths and reported no fluorescence within the visible range for illumination by red (633 nm) light. Recent studies by Hibst and Gall (72) showed that red light (638–655 nm)-induced fluorescence could differentiate between sound and carious tooth tissue.

KaVo DIAGNOdent (KaVo, Biberach, Germany), based on studies by Hibst and Gall (72), is a recently introduced laser-based instrument, developed for detection and quantification of dental caries on smooth and occlusal surfaces. It operates with light from a diode laser with a wavelength of $\lambda = 655$ nm and 1 mW peak power (72). The light is transmitted through a descendent optic fiber to a hand-held probe with a bevelled tip with a fiber-optic eye.

Both organic and inorganic molecules in the tooth substance absorb the light, and fluorescence within the infrared spectra occurs. The emitted fluorescence, as well as back-scattered ambient light, is collected through the tip, and passed in ascending fibers to a photo-diode detector. The back-scattered excitation and short-wavelength ambient light is absorbed by a bandpass filter in front of the photo-diode detector. To discriminate the fluorescence from the ambient light, the laser diode is modulated. By amplifying only the modulated portion of the signal, the ambient light is suppressed (73). The signal is finally processed and presented on the display as an integer between 0 and 99.

In order to collect fluorescence from the maximum extension of carious lesions on occlusal surfaces, the instrument has to be tilted around the measuring site. This ensures that the tip picks up fluorescence from the slopes of the fissure walls where the carious process is believed to originate. Variations in the laser diode output power should regularly be compensated by calibration of the instrument against a fluorescence standard, in accordance with the manufacturer's instructions.

In the presence of carious tooth substance, fluorescence increases. The origin of the fluorescence is still the subject of debate, but proto- and meso-porphyrins, bacterial metabolites from the mitochondria respiratory chain, probably play a major role (74, 75).

The DIAGNOdent device has been evaluated in several *in vitro* studies (76–83), and some *in vivo* studies (84–87). In a study by Lussi et al. (88) comparing traditional examination and treatment and the concurrent use of the DIAGNOdent device, good to excellent sensitivity and excellent reproducibility were reported.

Factors that may influence the outcome of the measurements in different ways are e.g. presence of plaque, calculus and/or staining on the tooth surface (44, 76), the degree of dehydration of tooth tissue (79). For measurements on occlusal surfaces, it is also of great importance that the tip is tilted forwards and back in the fissure for all surfaces to be scanned.

New caries detection methods – electrical impedance based

This technique is based on the theory that sound dental hard tissue, especially enamel, shows very high electrical resistance. Demineralized enamel becomes porous, and the pores are filled with saliva. The liquid content makes the tissue conductance higher. The more demineralized the tissue the lower the resistance becomes. The devices based on this theory have the same function: a circuit of a very weak alternating current is closed through the patient. From the device, a cord leads to a probe, which is placed on the site that is to be measured. The patient holds an earth-unit in the hand, and from the earth-unit, a cord leads back to the device. Compressed air through the probe isolates the measuring site from the surrounding saliva.

Measurements can be performed either as site-specific (a small area is covered by the probe tip) or as surface-specific (the surface is covered with an electrolyte in which the probe tip is placed). In the

latter case, a much larger area will be covered in one measurement.

Electronic caries monitor

The ECM device, as well as its predecessor the Vanguard instrument (Massachusetts Manufacturing Company, Cambridge, MA, USA), was designed for measurements of carious lesions on occlusal surfaces. Site-specific electrical conductance measurement in caries diagnosis has been evaluated in a number of *in vitro* (81, 89–92) and *in vivo* studies (93, 94). The reported sensitivity for ECM in diagnosing dentinal carious lesions of permanent premolar and molar teeth ranges from 0.67 to 0.96, and the specificity ranges from 0.71 to 0.98, which could be regarded as acceptable. One reason for the variation in results regarding sensitivity and specificity has been suggested to be differences in the handling of the technique, e.g. airflow (95, 96).

The validity of surface-specific electrical conductance measurements has been investigated under *in vitro* conditions (31). This mode of application is somewhat sensitive to the area of the electrode (conductive medium) but its reproducibility was good. Sensitivity and specificity, however, were moderate.

The principle of electrical impedance has been applied by researchers to detect caries lesions at approximal sites of teeth (97, 98). Although the results from these *in vitro* studies were very promising, there is a need of more research in this area.

Examples of factors that may influence the outcome of the measurements in various ways include the degree of dehydration of tooth tissue (99), the degree of maturation of the enamel (100), and temperature variations (101).

Miscellaneous

As mentioned in the introductory paragraphs, only a few commercially available methods and devices have been discussed in this paper. Attempts to develop different systems for detection and quantification of carious lesions have been ongoing for many years at a number of universities and commercial companies. However, developing and testing a new medical technical device is a long-term commitment and it often takes 10–20 years to advance from the initial idea to a commercially available device.

Some of the methods and devices, based on various physical theories, that might appear in the market in the future are ultrasonic technique, multi-photon imaging, frequency-domain infrared photothermal radiometry, modulated laser luminescence, polarization sensitive optical coherence tomography, infrared thermographic imaging, fiber optic confocal microscopy, fluorescence spectroscopy, and alternated current impedance spectroscopy.

Conclusions

Although these new technologies hold significant promise, there is not enough evidence for any of the reviewed diagnostic systems to be recommended as a substitute for traditional techniques. However, as adjuncts to visual inspection and bitewing radiography, longitudinal application of any of these new methods may provide additional quantitative information on mineral changes as a basis for the evaluation of caries activity and risk assessment. In doing so, the dentist should always remain responsible for the interpretation of the information, and the quantitative measurements should always be weighed against other relevant information.

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