Supplementary Methods for Detection and Quantification of Dental Caries

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SYNOPSIS

This article reviews the modes of action and clinical application of novel caries detection methods including digital imaging fiber-optic transillumination, laser fluorescence, quantitative light-induced laser fluorescence, and alternating current impedance spectroscopy.

ABSTRACT

There is a need for objective instrumental caries detection methods to supplement traditional visual assessment by the clinician. These methods should be used as supplements to aid in making appropriate decisions about the clinical management of the individual lesion, such as whether to use invasive therapy or a more conservative, noninvasive approach. Objective, reliable, quantitative measures for longitudinal monitoring of lesion response to preventive measures would allow flexibility in selecting intervention appropriate to the individual patient, before lesion progression reaches a stage requiring invasive therapy. This paper reviews some novel and commercially available caries detection methods: Fiber-Optic Transillumination, Digital Imaging Fiber-Optic Transillumination, Laser Fluorescence, Quantitative Light-induced Fluorescence, and Electronic Caries Measurement.

INTRODUCTION

Our efforts to make the concept of caries prevention popular, and to preserve the dentition into old age are continuously successful.1-5 However, despite the dramatic decline in dental caries, particularly in industrialized countries and among children and young adults, the disease persists, albeit with highly skewed distribution.6-7 The following major changes have occurred in the pattern of the disease: progression of enamel caries is now slower, and allows preventive intervention before irreversible destruction of tooth substance. There is also a pronounced reduction in lesion development on the smooth surfaces, which are readily accessible to fluoride.8-11 Diagnostic techniques to support appropriate clinical decisions about management of the individual lesion, whether invasive therapy or a more conservative, noninvasive approach is indicated,12 are predominantly based on subjective interpretation of visual information: visual inspection, bitewing radiography, and the use of a dental explorer. Longitudinal monitoring of lesions has been hampered by the lack of appropriate diagnostic techniques, i.e., techniques of high sensitivity and specificity that reflect the slow lesion progression. The aim is to arrest or reverse the disease process, and to intervene before operative restorative dentistry is needed.

Objective, reliable quantitative data on the outcome of this strategy, i.e., lesion response to preventive measures, would allow flexibility in selecting intervention appropriate for the individual patient, before lesion progression to a stage requiring expensive invasive therapy. Optimal dental care and treatment will increasingly involve a shift of emphasis and a change of the education and training of oral health personnel, and dental providers need to keep abreast of new approaches and technological advances for diagnoses and therapies of dental caries. In this context, there is a need for complementary methods for detection and quantification of dental caries. There are certain requirements that should be met by the methods; they have to meet all safety regulations; detect early, shallow lesions; differentiate between shallow and deep lesions; give a low proportion of false positive readings; present data in a quantitative form so that activity can be monitored; be precise so that measurements can be repeated by several operators; be cost-effective and user-friendly. Clinically applicable methods for detection of a very early phase of mineral loss and quantification of caries lesions have emerged. In this paper, some novel and commercially available supporting caries detection methods will be summarized: Fiber-Optic Transillumination, Digital Imaging Fiber-Optic Transillumination, Laser Fluorescence, Quantitative Light-Induced Fluorescence, and Electronic Caries Measurement.
THE METHODS
Fiber-Optic Transillumination (FOTI)
FOTI is a technique that uses light transmission through the tooth and has been available on the market for more than 40 years, in contrast to the other more novel methods described below that have only recently been developed. FOTI is based on the theory that demineralized dental hard tissues scatter and absorb light more than sound tissue. White, cold light is transmitted from a light source through an optical fiber to a hand-piece with a thin probe that is applied to the tooth surface. Figure 1 shows the clinical FOTI setup. It detects and visualizes the caries lesions, so demineralized regions appear darker compared to the surrounding sound tissue, and the contrast between sound and carious tissue is then used for detection of lesions on occlusal, approximal, and smooth surfaces, on enamel as well as dentin. This technique relies on the human eye as the detector and is not quantitative. The majority of the FOTI studies show the same tendency as the well-performed in vitro study on occlusal surfaces by Grossman et al., which showed low sensitivity (0.39) and high specificity (0.92), i.e., the risk for false positive observations was low, and the risk for missed carious lesions was high. There is a need for training and calibration of operators, but few clinical factors influence the readings.

Clinical perspective: FOTI is essentially a refinement of traditional visual observation that can enhance caries detection by a trained and experienced clinician, but is not quantitative and has the same limitations as traditional visual methods for assessing lesion extent and following lesions over time.

Digital Imaging Fiber-Optic Transillumination (DIFOTI)
A recently marketed method based upon the same principles as FOTI is the digitized DIFOTI method. In this method the white light is delivered through an optical fiber via a specially designed handpiece that has a mirror on the opposite side of the tooth, thereby channeling the image back to a digital camera and visualizing the image on a monitor via a computer system. An ordinary computer setup with specially designed software creates a real-time image of the illuminated tooth on the computer screen. The images can be stored for later retrieval and comparative examination. Two disposable mouthpieces are available, one for proximal and one for occlusal surfaces, in an adult as well as a pediatric size. The DIFOTI method is still qualitative. Figure 2 shows a DIFOTI image of a molar occlusal surface. As can be seen tooth defects are readily visualized, such as the unusual morphology in this image. As with regular FOTI, the user’s level of experience is essential. Only limited research has so far been performed.

Clinical perspective: The DIFOTI technique essentially picks up surface scattering of the visualizing light and readily indicates the presence of very early carious lesions, cracks, or imperfections in the tooth surface. From a clinical perspective, however, this information is very limited in its usefulness. The method gives no indication of lesion depth, severity, or progress over time, and cannot be used in the determination of how deep the lesion is and whether surgical intervention is necessary. This problem was highlighted in the recent study by Young and Featherstone.

Laser Fluorescence (LF)
When a caries lesion in enamel and dentin is illuminated with red laser light (\( \lambda = 655 \text{ nm} \)), organic molecules that have penetrated porous regions of the tooth, especially metabolites from oral bacteria, will create an infrared (IR) fluorescence. The enamel is essentially transparent to red light. The IR fluorescence is believed to originate from porphyrins and related compounds from oral bacteria. These molecules are chiefly responsible for the absorption of red light. The laser instrument, DIAGNOdent® (DD) (KaVo Dental GmbH, Biberach, Germany), is based on research by Hibst and Gall, was introduced in the late 1990s, and is today marketed in two versions. Apart from smooth and occlusal surfaces, the latest version,
the DD-pen, also aims to readily access approximal surfaces. There is as yet limited information on the usefulness of the latter device.

As described in a recent review by Hibst, red light from a 655-nm diode is transmitted through an optical fiber to a hand probe. This light beam is used to irradiate the tooth, with the red light transmitting readily through sound enamel. When the light reaches a carious lesion and interacts with appropriate organic molecules that have been absorbed into the porous structure, the light is re-emitted as invisible fluorescence in the near-infrared region. The emitted light is channelled through the handpiece to a detector and presented to the operator as a digital number on a display (0-99). A higher number indicates more fluorescence and by inference a more extensive lesion below the surface.

The first version of the LF device has shown good performance and reproducibility for detection and quantification of occlusal and smooth surface carious lesions in *in vitro* studies, but with somewhat more contradictory results *in vivo*, both in the primary and permanent dentition. It has also been tried for longitudinal monitoring of the caries process, and for assessing the outcome of preventive interventions. The DD-pen (Figure 3) might be a useful additional tool in detecting approximal caries, but has so far only been evaluated in three *in vitro* studies. Factors that may influence the outcome of the measurements in different ways are: presence of plaque, calculus and/or staining on the tooth surface, and the degree of dehydration of tooth tissue. The system detects fluorescent organic molecules that can be present in any surface deposits, thereby readily producing false positives. For measurements on occlusal surfaces, it is also of great importance that the tip is tilted over a range of several different angles to access all relevant subsurface regions.

**Clinical perspective:** The LF device is a useful adjunct to traditional visual examination, especially in occlusal surfaces, for the detection of hidden lesions below the surface. However, the device detects organic molecules that have penetrated into surface deposits or subsurface porosities, such as carious lesions. It does not directly detect demineralization. Results must be interpreted with caution by understanding how the device works and how false positive readings can be misleading. The digital number displayed indicates the amount of fluorescence, which is not necessarily a measure of lesion size or depth.

**Quantitative Light-Induced Fluorescence (QLF)**

The phenomenon of tooth autofluorescence has long since been suggested to be useful as a tool for the detection of dental caries. Fluorescence is a property of some man-made and natural materials that absorb energy at certain light wavelengths and emit light at longer wavelengths. An increased porosity due to a subsurface enamel lesion, occupied by water, scatters the light either as it enters the tooth or as the fluorescence is emitted, resulting in a loss of its natural fluorescence. Consequently the demineralized area appears opaque. The strong light scattering in the lesion leads to shorter light path than in sound enamel, and the fluorescence becomes weaker. Bjelkhagen and Sundström and later de Josselin de Jong *et al.* developed a technique based on this optical phenomenon, making the difference in fluorescence radiance between the carious and sound tooth structure quantitative. This has been termed quantitative light-induced fluorescence (QLF).

The QLF method can readily detect lesions to a depth of approximately 500 µm on smooth and occlusal enamel surfaces. In the currently marketed systems (Inspector™ Pro, Inspektor Dental Care, Amsterdam, The Netherlands) the illumination system consists of a 50-Watt microdischarge arc lamp equipped with an optical bandpass filter with a peak intensity of 370 nm, transmitted through an optical fiber from the light source to a handpiece with a micro CCD video camera. A high-pass filter in front of the camera blocks the excitation light together with the ambient light, so

![Figure 3: Approximal measurement with the DIAGNOdent pen. The red laser light can be seen through the dental hard tissue.](image-url)

![Figure 4: Principal setup of the Quantitative Light-Induced Fluorescence method.](image-url)
that only wavelengths above 520 nm are transmitted to the detector. Figure 4 shows the principal setup for the QLF-technique.

The preferred image is captured and saved by the operator by pressing a foot switch, and is later processed. Details about the tooth and the surface examined are set in the program, and the position and orientation of the processed image is thereafter automatically stored in a preset pattern so that when the patient comes back on recall, a contour guides the operator to the right position again. The program offers an automatic repositioning facility, which can be set at any level, and when correlation between the reference image and the real-time image is satisfactory, it can be saved automatically. The fluorescence image is first converted into a black-and-white image so that thereafter the lesion site can be reconstructed by interpolating the grey level values in the sound enamel around the lesion. The difference between measured and reconstructed values gives three quantities: $\Delta F$ (average change in fluorescence, %), lesion area (mm$^2$), and $\Delta Q$ (area x $\Delta F$), the latter giving a measure of the extent and severity of the lesion. Figure 5 shows the analytical part of the QLF method, as calculated by the specially designed software.

The QLF method has been tested in several in vitro, in situ, and in vivo studies for smooth surface caries lesions. The possibility of adapting the QLF method for occlusal caries diagnosis is under investigation as well as modification for detection and quantification of secondary caries but has yet to be tested clinically. Application for quantification of dental fluorosis has also been investigated.

Higham et al. concluded “QLF has the potential to detect, diagnose, and longitudinally monitor occlusal caries and provide useful information to the clinician with regard to the severity of the lesion and likely treatment.” Eggertsson et al. reported good reproducibility of QLF methods clinically with inter- and intra-examiner reliability greater than 0.95 after training.

Factors that may influence the outcome of the measurements are: presence of plaque, calculus and/or staining, ambient light, daylight or office light, and the degree of dehydration of tooth tissue. The newly designed handpieces on the commercially available devices have largely overcome the ambient light problems. 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 QLF method can also measure and quantify the red fluorescence (RF) from microorganisms in plaque. The RF observed in plaque can be of use when monitoring oral hygiene; removing infected dentin; detecting a leaking sealant or caries at the margin of a restoration. Two quantities are obtained, AR (average change in red fluorescence, %), and area (mm$^2$). So far there are a very limited number of studies performed with this feature.

**Clinical perspective:** The QLF system that has recently come on the market (Inspektor™ Pro) in several countries can be used as a quantitative measure of enamel lesions in smooth surfaces. It is likely that is will also be useful for occlusal surfaces but this has yet to be proven. The sophisticated computer-driven repositioning feature enables lesion progression or arrestment to be followed over time. This system appears to be a useful adjunct to traditional visual examination.

**Electronic Caries Measurement (ECM) and Alternating Current Impedance Spectroscopy**

The ECM technique is based on the theory that sound dental hard tissue, especially the enamel, shows very high electrical resistance or impedance. Demineralized enamel becomes porous, and the pores fill with saliva, water, microorganisms, etc. The more demineralized the tissue, the lower the resistance becomes. In the impedance measurement system a circuit of a very weak alternating current is closed through the patient. From the device, a fiber leads to a probe, which is placed on the site that is to be measured.

Figure 5: The analytical interface of the QLF method. The lesion is color-coded so that the operator can get a quick impression of the area and the depth.

Figure 6: Clinical use of Electronic Caries Measurement (ECM).
Figure 6 shows clinical use of an Electronic Caries Measurement device. The patient holds a ground-unit in the hand, and from the ground-unit, a fiber leads back to the device. Compressed air that is led through the probe isolates the measuring site from the surrounding saliva. The result of the measurement is presented on a display as a number between 1 and 13, and the higher the number, the deeper the lesion.

Site-specific measurements have been evaluated in a number of in vitro studies and in vivo studies. The reported sensitivity for ECM in detecting dental caries lesions of permanent premolar and molar teeth ranges from 0.93 to 0.95, and the specificity ranges from 0.53 to 0.70, in clinical studies, which gives a moderate risk for false positive readings, and a low risk of missed carious lesions. Surface-specific electrical conductance measurements have been investigated under in vitro conditions, which showed moderate sensitivity and specificity. Factors that may influence the outcome of the measurements are the degree of dehydration of tooth tissue, the degree of maturation of the enamel, and temperature variations.

Another impedance/conductance-based method is Alternating Current Impedance Spectroscopy (ACIST). It is based on the same assumptions about electrical circuits and dental hard tissues as the ECM instrument. Apart from the forward conductance (resistance values, representing continuous conduction/diffusion pathways) it also measures transverse conductance (capacitive conductance pathways). This could give more information than the ECM. A commercially manufactured impedance measurement device has recently come on the market in the United Kingdom (CarieScan™, IDMoS PLC, Dundee, United Kingdom) and is likely to reach the United States in the near future.

**Clinical perspective:** The electrical conductance or impedance measurement devices have had limited success in the past. The new ACIST system shows considerable promise as a method with good ability to detect lesions with a low level of false positives. However, the device gives a lesion/no lesion answer rather than an image, extent of the lesion, position of the lesion measure. This technique is likely to be a useful adjunct to traditional examination provided the clinician uses the information wisely in combination with other observations to determine an intervention or restorative treatment plan.

**DISCUSSION**

Quantitative dental caries detection methods may take subjective interpretations of visual, tactile, and radiographic methods to evidence-based clinical practice. A shift from traditional diagnostic methods to advanced and more sensitive methods will improve caries diagnostic routines and hence the dental care and treatment for our patients’ benefit: minimize the use of unavoidable hazards of ionizing radiation, detect caries in an early stage, obtain a more precise estimation of lesion depth and severity, reveal a carious lesion obscured by superimposed sound tissue, monitoring de-or remineralization, evaluate the outcome of different preventive strategies, and detect and quantify bacterial activity.

The caries detection methods reviewed in this article meet general clinical needs and although significant promise is seen in these techniques, there is not enough evidence currently available to recommend any one of them as a substitute for conventional methods. However, each of them can be valuable in its own way, as summarized above as a supplement to traditional methods. Each of the new methods reviewed brings additional information about lesions in a manner specific to the technology used.

Nevertheless, traditional methods of caries assessment, which discriminate lesions at the cavitation stage, are not always clinically appropriate, and are obsolete for clinical research requiring detection of a very early phase of mineral loss, which allow a reduction in the duration of experimental periods and the number of subjects required, saving both time and money. To develop and test a new medical technical device is a long-term commitment; it takes time, scientific research, and evidence from the time of the “first idea” to a validated commercially available device, and even though laboratory findings show strong results, caution is indicated when extrapolating these into clinical conditions.

The QLF method is today the most promising technology of those currently on the market, due to its close correlation to the enamel mineral content, but with limitations such as the inability to detect approximal (and occlusal) caries lesions, and dentinal caries. One of the upcoming methods and devices, based on different physical theories that is expected to appear on the market in the future is Optical Coherence Tomography (OCT) which can produce two- or three-dimensional images of demineralized regions in dental enamel. When a tooth with a carious lesion is illuminated with infrared light at 1310 nm, OCT technology can produce a quantitative image of the subsurface lesion to the full depth of the enamel.

The OCT method is, however, still yet far from a marketed device for everyday use in the dental office.

All improvements require change, but not all change is improvement. Evidence-based care
is by definition “the conscientious, explicit, and judicious use of the current best evidence in making decisions about the care of individual patients, which includes integrating individual clinical expertise with the best available external clinical evidence.” It is therefore important to emphasize the need for clinical trials to support critical appraisal and decision making in using these techniques, by theory and empirical evidence.

In summary, there are several devices currently on the market and more to come that can be used by the clinician as valuable supplements to the traditional caries detection and assessment methods. All of the new methods require a basic understanding of how they work so that the results can be correctly interpreted for the benefit of the patient, especially to aid in the decision as to how to treatment plan, which lesions can be reversed, which chemical therapy should be used, how to assess success or not, and when to intervene with restorative work.

**AUTHOR BIOGRAPHIES**

Lena Karlsson is a registered dental hygienist and a PhD student at Karolinska Institute, Sweden. She works as a lecturer at the Institute of Odontology, unit of Cariology and Endodontics, and is involved in the dental hygienist and the dental student educational programs. In the late 1990s she began to undertake research in the field of diagnosis, prevention, and management of dental caries with a focus on the interaction between laser light and dental hard tissues, supervised by Professor Birgit Angmar-Månsson. Today she is one of Dr. Sofia Tranæus’s doctoral students and her thesis work involves studies of different methods for detection and quantification of carious lesions at their earliest stages. She may be contacted by e-mail at lena.karlsson@ki.se.

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Dr. Sofia Tranæus is a senior lecturer in the Department of Odontology at the Karolinska Institute in Stockholm, Sweden. She has spent the past 10 years developing and testing new techniques for detection and quantification of dental caries. Dr. Tranæus completed her PhD in 2002 at the Karolinska Institute, with her thesis entitled “Clinical application of QLF and DIAGNodent – Two new methods for quantification of dental caries.” Currently, she is on a temporary 2-year assignment at SBU – The Swedish Council on Technology Assessment in Health Care. Dr. Tranæus may be contacted by e-mail at softe.trananeus@ofa.ki.se.

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