A Closer Look at Diagnosis in Clinical Dental Practice: Part 5. Emerging Technologies for Caries Detection and Diagnosis

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Abstract

Parts 5 and 6 of this series examine innovations in diagnostic and management procedures and assess their potential to become everyday tools of the dental clinician. This paper examines some of the diagnostic tools supporting a philosophical shift in mainstream dental practice from concern with extensively decayed teeth to a focus on detecting incipient demineralized tissues. With the latter approach, the incipient carious process can be reversed by promoting enamel remineralization and thus eliminating the need for restorative intervention. Numerous methods and devices have been developed to detect, diagnose and monitor such lesions, and several have been produced in versions that may appeal to dental practitioners. This paper considers 3 of these methods and devices: the DIAGNODent laser device, quantitative light-induced fluorescence and the Digital Imaging Fiber-Optic Transillumination device. Each technique is illustrated, the research on its effectiveness is assessed to determine usefulness to the practitioner, and the comparative advantages of the 3 adjunct tools are discussed.

MeSH Key Words: decision support techniques; dental caries/diagnosis; predictive value of tests; risk assessment methods

Despite a significant reduction in the prevalence of caries within some population subgroups in the Western world, this problem remains significant at the clinical and public health levels. Diagnostic devices have been developed with claims of detecting the earliest signs of enamel demineralization and thus affording the opportunity to intervene with aggressive therapies (mainly fluorides) at an incipient stage, arrest the lesion, encourage remineralization and avoid the need for restorative intervention. The extent of the epidemiological problem, along with this battery of new diagnostic tools, poses a challenge for the dental practitioner attempting to address the former while maximizing the scope for using the latter. An examination of the applications of these tools, and of the information they reveal, is in order.

In this paper, we examine techniques for detecting caries that are intended for, or currently available to, general dental practitioners. This information is presented in the context of the larger framework of diagnostic tests and management strategies discussed in the current series of articles.¹⁻⁴ Before the techniques are discussed in detail, however, we should define the clinical context into which they have been introduced. Table 1 summarizes the evidence for the more conventional methods of detecting caries: visual, visual and tactile, and radiographic. This summary is based on 2 highly recommended reviews of the subject by Bader and others.⁵,⁶ Although they are commonly used in dental practice and are reasonably reliable by today’s standards, these conventional techniques leave room for improvement. This paper assesses whether any of the new systems fill that need.

A glossary, with concise definitions of terms, is available for the entire series (see Appendix 1, Glossary of epidemiology terms, at http://www.cda-adc.ca/jcda/vol-70/issue-4/251.html).

DIAGNODent Laser Device

The DIAGNODent laser device (KaVo, Lake Zurich, Ill.) uses laser fluorescence to detect incipient caries. The exact mechanism of detection has not been fully articulated,
Table 1 Effectiveness of common diagnostic tests for detection of caries

<table>
<thead>
<tr>
<th>Method, surface and extent</th>
<th>No. of studies</th>
<th>No. of examiners</th>
<th>Prevalence of lesions (%)</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Median</td>
<td>Mean</td>
<td>Median</td>
<td>Mean</td>
</tr>
<tr>
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<td>63</td>
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<tr>
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<td>9</td>
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<tr>
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<td>2</td>
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</tr>
<tr>
<td>Any</td>
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<td>7</td>
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<td>59</td>
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<tr>
<td><strong>Visual-Tactile</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Occlusal surfaces</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Dentinal</td>
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<td>12</td>
<td>6</td>
<td>29</td>
<td>19</td>
</tr>
<tr>
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<td>2</td>
<td>4</td>
<td>4</td>
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<td>39</td>
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<td><strong>Radiographic</strong></td>
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<td></td>
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<td>Occlusal surfaces</td>
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<td>4</td>
<td>3</td>
<td>54</td>
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<td>2</td>
<td>18</td>
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<td>5</td>
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<td>Proximal surfaces</td>
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<td></td>
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<tr>
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<td>13</td>
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<td>11</td>
<td>6</td>
<td>3</td>
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<td>50</td>
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</table>

*Modified from Bader and others5,6*

Figure 1a: The DIAGNODent device showing the 2 light-emitting diode readouts.

Figure 1b: The B version of the DIAGNODent handpiece is used for occlusal pits and fissures. The broader, flatter version A (not shown) is used for smooth surfaces.

but the device appears to measure the fluorescence of bacterial products within carious lesions — namely, porphyrins — rather than crystalline disintegration.7 This theory is supported by the fact that the DIAGNODent device does not detect lesions produced in the laboratory by means of acidic buffers, which produce no microbiological activity.8 The device generates a laser beam that is absorbed by materials within the tooth and is subsequently re-emitted as infrared fluorescence.

The DIAGNODent device (Fig. 1a) is compact, portable and fully compliant with cross-infection control directives. It consists of a control unit and a hand-held probe. The probe comes with 2 attachments, one with a small tip, for examining fissure caries, and the other with a larger, broader tip, for examining smooth surfaces (Fig. 1b).

**Technique**

After calibration, the appropriate probe is selected. For smooth surfaces, the probe is gently run over the surface of the tooth. For occlusal examinations, the probe should be moved (e.g., mesially to distally) and swayed bucolingually to ensure that all fissures are examined.
The device displays the results in real time. The unit presents current and peak values from the time when the unit was last reset. Therefore, the unit should be reset between teeth, so that the peak value for each tooth can be recorded, along with notes as to the location on the tooth where the reading was taken. Further readings at recall appointments can be used to determine if the DIAGNODent value has increased, decreased or stabilized. Recent research has proposed indices for the interpretation of DIAGNODent values in relation to occlusal decay.8,9

Evidence
This device has generated a great deal of research interest.10 Attrill and Ashley11 compared it with clinical–visual and radiographic examinations of primary occlusal surfaces in vitro. Echoing previous findings, they discovered that radiography performed poorly, whereas the DIAGNODent device performed effectively, although not significantly better than the visual scale. Despite little statistical separation between the device and a clinical (visual) scale, the ability to quantify the result may be of great value for monitoring teeth longitudinally. Studies on occlusal surfaces in adults have shown that, for certain lesions, the DIAGNODent device offers significant advantages over conventional techniques.12,13 With a sensitivity of 0.72 and a specificity of 0.73, the device might also be used for smooth-surface caries.14 Table 2 provides details of other studies that have assessed the sensitivity and specificity of the DIAGNODent device. The device may be used to detect demineralization that is developing beneath fissure sealants, although its diagnostic performance appears to depend to some degree on sealant colour.20

Summary
The DIAGNODent is probably a valuable device for the dental practitioner. It is relatively inexpensive and, when combined with a visual exam, improves the clinician’s ability to detect demineralization, as well as to longitudinally monitor suspect lesions to determine the success of remineralization interventions. Its capacity to ascertain demineralization under sealants may be of particular appeal to pediatric dentists. The unit has been designed with general dental practice in mind, and its physical appearance, ease of use, compliance with cross-infection stipulations and capability for longitudinal recording of values are suitable for this setting.

Digital Imaging Fiber-Optic Transillumination Device
Illuminating teeth to determine the presence of demineralization is far from a novel approach to caries detection. However, the Digital Imaging Fiber-Optic Transillumination (DIFOTI) system (Electro-Optical Sciences, Irvington, NY; www.difoti.com), which allows images from all tooth surfaces to be digitally captured and stored, has made this technology accessible for practitioners and sophisticated enough for longitudinal evaluation of individual caries lesions. The principle behind transilluminating teeth is that demineralized areas of enamel or dentine scatter light (in this case a high-intensity white light) more than sound areas. Incipient caries appear as darker areas in the resultant images. The user-friendly DIFOTI system consists of 2 handpieces (one for occlusal surfaces and one for smooth and interproximal areas), a disposable mouthpiece, a foot pedal for selecting the image of interest from the live pictures, and a computer system to capture and store the resulting image (Fig. 2). Examples of the images obtained are shown in Fig. 3 (sound teeth), Fig. 4 (early demineralization) and Fig. 5 (larger lesions).
Technique

The appropriate handpiece is selected and placed over the tooth, and a live image appears on the screen. The software detects when the image is focused, and the operator selects images to be captured. The software automatically moves through the dental arch, and an entire mouth series can be captured in 10–15 minutes; the operator simply moves the handpiece over each tooth in sequence. DIFOTI is not a quantitative technique, and the software does not perform any analysis. Instead, the images must be analyzed by the clinician in the same way as radiographs (i.e., visual assessment of the light scattering relating to mineral loss).

Evidence

Table 3 summarizes the one research employing FOTI and DIFOTI methods. These results suggest that the technique is highly specific and sensitive, especially in the diagnosis of occlusal caries. The current clinical environment is influenced by the inherent difficulties of diagnosing mineral loss in occlusal caries; therefore, the observation in one study of an area under the curve of 0.85 in a receiver operating characteristics (ROC) analysis of DIFOTI suggests that there is a basis for using this device in diagnostic dentistry.

Summary

The DIFOTI system has been developed with the dental practitioner in mind. It is simple to use, and the instantly available images are easily interpreted. It can also be used as a patient education tool, since the images can be readily understood by the layperson. The ability to combine an image from, for example, an intraoral camera with the DIFOTI image can help patients target their oral hygiene to at-risk areas.

Quantitative Light-induced Fluorescence

Quantitative light-induced fluorescence (QLF) is the newest technology in the field. The theory behind QLF has been amply discussed in recent publications, and is briefly summarized here. Under certain conditions, human enamel autofluoresces. Bjelkhagen and others were the first to describe the reduction of fluorescence seen in demineralized enamel, and Angmar-Månsson and ten Bosch suggested that the increased porosity of carious lesions leads to a decrease in the refractive index. Use of this theory to develop a viable technique was followed by the capture of images on charge coupled device (CCD) cameras, which enabled longitudinal monitoring of individual carious lesions. An existing method for quantifying mineral loss from lesions was improved by substituting the cumbersome laser-based system with a portable arc-lamp unit. A commercial device and software (including an image subtraction system...
for in vivo longitudinal assessment) are now available (QLFPatient, Inspektor Research Systems BV, Amsterdam, The Netherlands); the system includes cameras suitable for intraoral use and a repositioning system to ensure that images are correctly aligned.42 With the addition of a fluorescent dye, QLF can be used to detect early demineralization in dentine.39,43–45 In addition to its use in detecting incipient caries in permanent teeth, adjacent to restorations and orthodontic brackets, in primary teeth and in clinical trials of dentifrice products,34,41,43,46–50 QLF can be used to detect failing fissure sealants, to measure planimetric plaque41,48,51 and to monitor enamel erosion in vitro.52

Table 3 Summary of studies assessing FOTI/DiFOTI devices

<table>
<thead>
<tr>
<th>Subject</th>
<th>Study</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occlusal caries</td>
<td>Cortes and others²¹</td>
<td>Receiver operating characteristic 0.85, kappa statistic 0.87</td>
</tr>
<tr>
<td>FOTI in general practice</td>
<td>Davies and others²²</td>
<td>Practitioners reported enhanced detection with FOTI</td>
</tr>
<tr>
<td>Inter-observer agreement</td>
<td>Cleaton-Jones and others²³</td>
<td>Excellent agreement between observers (&gt;90%)</td>
</tr>
<tr>
<td>Occlusal caries</td>
<td>Fennis-le and others²⁴</td>
<td>Inter-observer reproducibility 0.79</td>
</tr>
<tr>
<td>Occlusal and approximal surfaces</td>
<td>Schneiderman and others²⁵</td>
<td>Sensitivity 0.67 for occlusal surfaces and 0.56 for approximal surfaces; radiography had sensitivity of 0.18 and 0.21 respectively</td>
</tr>
<tr>
<td>In vitro use</td>
<td>Peers and others²⁶</td>
<td>Sensitivity 0.67, specificity 0.97</td>
</tr>
<tr>
<td>Occlusal caries</td>
<td>Mitropoulos²⁷</td>
<td>Sensitivity 0.85, specificity 1.00</td>
</tr>
<tr>
<td>Buccal surfaces</td>
<td>Sidi and Naylor²⁸</td>
<td>Sensitivity 0.74, specificity 0.99</td>
</tr>
</tbody>
</table>

Technique

The QLF device consists of the light source and the intraoral camera (Fig. 6 illustrates how the system works, and clinical examples are shown in Figs. 7 and 8). The QLF technique is a 2-stage process. First, an image of the tooth must be acquired with the intraoral camera held in the hand. Then, both qualitative and quantitative assessments of mineral loss are obtained. The enhanced contrast (more than 20 times that which can be detected clinically) between sound and demineralized enamel enables the clinician to identify areas of concern. Longitudinal monitoring of lesions with the QLF analysis software can be used to quantitatively measure mineral loss (Fig. 9).
Evidence

Table 4 summarizes the evidence supporting the use of QLF to detect caries, both the initial validation studies and more recent work to ascertain sensitivity and specificity. Table 5 outlines how QLF compares with other systems for detection of occlusal caries. Table 6 summarizes predictive values for detecting caries on occlusal and smooth surfaces, caries adjacent to a variety of restorative materials (secondary caries), root caries and demineralization adjacent to orthodontic brackets and bands, giving examples for both high-and low-risk populations.

Summary

QLF is a more versatile system than either DIAGNODent or DIFOTI and can measure absolute mineral loss along with a number of other applications. Research suggests that the correlation between QLF and absolute mineral loss (as measured by a radiographic gold standard) may be as high as $r = 0.92$.63 The ability to visualize bacterial products, which appear as red fluorescence, may be used to determine the activity of lesions.64 QLF can be considered a diagnostic system, rather than simply a detection device. The feasibility of using QLF to detect root caries45 and early orthodontic demineralization65 will be of interest to specialists treating patients with these kinds of lesions. It is likely that, within the next few years, general practitioners will become more familiar with how QLF applies to their clinical work, and the unit will become more affordable for general clinical use.

Discussion

Because this is a narrative rather than a systematic review, we cannot say unequivocally that these devices offer clear improvements over the more traditional systems. They do, however, offer distinct advantages. For example, QLF and DIFOTI images can be stored and viewed at a later date. The DIAGNODent device generates a simple numeric index of demineralization that can be entered into the patient’s notes and monitored over time. Ultimately, however, the plethora of methods, validating systems and (often) arbitrary gold standards makes comparisons difficult and poses a challenge for the dental practitioner who is trying to stay abreast of technological developments.

Appropriate assessment of the many studies in the literature and the barrage of marketing messages from the industry is of critical importance. It is also worthwhile to examine motivations for supplementing, or even replacing, well-established diagnostic methods in dental practice. A new approach or technique must perform substantially better in diagnosing the status of carious lesions if it is to be adopted.

One of the components of diagnostic thinking is information, which is also the basis of the Bader and Shugars66 model of decision making in dental practice. These authors focused on creating a system composed of many pieces of information and proposed that clinicians resort to inventories, or “caries scripts,” to match each clinical case with profiles. Clinical and nonclinical items are used to modify the profiles; in particular, patient factors may include relatively abstract concepts within the consultation environment (such as treatment preferences) or highly specific, tangible information (such as changes in tooth colour that indicate decay). The highly specific pieces of information that connote dental caries were considered as patient factors at the tooth or mouth level in the Bader and Shugars66 model.
Table 5  Effectiveness measures for a variety of diagnostic methods applied in the detection of occlusal caries

<table>
<thead>
<tr>
<th>Diagnostic system</th>
<th>Study</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Youden's J</th>
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</thead>
<tbody>
<tr>
<td>Electronic caries monitor</td>
<td>Ashley and others</td>
<td>0.65</td>
<td>0.73</td>
<td>0.38</td>
</tr>
<tr>
<td>Visual</td>
<td>Ashley and others</td>
<td>0.60</td>
<td>0.73</td>
<td>0.33</td>
</tr>
<tr>
<td>Fibreoptic transillumination</td>
<td>Ashley and others</td>
<td>0.21</td>
<td>0.88</td>
<td>0.09</td>
</tr>
<tr>
<td>Bitewing radiographs</td>
<td>Ashley and others</td>
<td>0.19</td>
<td>0.80</td>
<td>0.01</td>
</tr>
<tr>
<td>Quantitative light-induced fluorescence</td>
<td>Pretty and others</td>
<td>0.68</td>
<td>0.70</td>
<td>0.38</td>
</tr>
<tr>
<td>Visual</td>
<td>Alwas-Danowska and others</td>
<td>0.50(a)</td>
<td>0.91(a)</td>
<td>0.41(a)</td>
</tr>
<tr>
<td>DIAGNODent</td>
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<td>0.94(a)</td>
<td>0.52(a)</td>
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<td>1</td>
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<tr>
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<td>Bamzahim and others</td>
<td>0.75</td>
<td>0.88</td>
<td>0.63</td>
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</table>

\(a\)Calculated from reference.

Figure 8: a) Clinical example of a lesion on the mesial surface of the canine associated with partial denture wear. b) The QLF image showing enhanced contrast between sound and demineralized enamel; note the lack of reflections. c) An example of an in vitro artificial lesion imaged by QLF. d) An example of secondary caries imaged by QLF; note the failing composite. e) Further example of secondary caries. f) Plaque imaged by QLF.

Figure 9: Example of QLF image analysis.
Examen approfondi du diagnostic en pratique clinique dentaire : Partie 5. Nouvelles technologies pour la détection et le diagnostic de la carie

### Table 6  Positive and negative predictive values of QLF on various surfaces

<table>
<thead>
<tr>
<th>Surface</th>
<th>High risk population (0.8)*</th>
<th>Low risk population (0.1)*</th>
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</thead>
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<tr>
<td></td>
<td>PPV</td>
<td>NPV</td>
</tr>
<tr>
<td>Smooth</td>
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</tr>
<tr>
<td>Occlusal</td>
<td>0.90</td>
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<tr>
<td>Secondary caries</td>
<td>0.96</td>
<td>0.70</td>
</tr>
<tr>
<td>Orthodontic</td>
<td>0.98</td>
<td>0.62</td>
</tr>
<tr>
<td>Root caries</td>
<td>0.97</td>
<td>0.74</td>
</tr>
</tbody>
</table>

*Prevalence of the disease within the population.

model. It is in this domain of information that new devices such as the DIAGNOdent can help to improve diagnostic performance: the pieces of information they can provide (in this case, quantifiable records depicting caries status, which are amenable to comparison with observations made during subsequent periodic recall appointments) become valuable building blocks in better performance. But these pieces of information are just that: building blocks that ought to be interpreted by the clinician in the context of a core set of themes employed in the appraisal of restorative needs. A clinician cannot rely totally on one diagnostic system or another, but must assimilate all the information available, modify it in light of the patient's particular situation, then formulate a treatment plan. The way information is assimilated by clinicians is likely to be quite diverse and will depend on various settings and levels of clinical expertise. Kay and Nuttall showed that neither clinicians’ stated therapeutic criteria, nor their stated therapeutic attitudes, corresponded to their clinical decisions.

In conclusion, the DIAGNOdent, DIFOTI and QLF devices may improve decision making by affording more sophisticated diagnostic and management capabilities (through more detailed information) and by providing a clearly stated measure of longitudinal lesion activity that can be incorporated into a diagnostic heuristic (thus making consultation patterns closely relevant to the natural history of dental caries). However, responsibility for making the “right” decision (i.e., correctly combining the various pieces of information into a treatment plan that satisfies the patient’s personal preferences, attends to sociobehavioural aspects and takes care of the patient’s biomedic needs) will continue to rest with the clinician.

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