

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

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A b s t r a c t

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

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This article has been peer reviewed.

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^a

Method, surface and extent	No. of studies	No. of examiners		Prevalence of lesions (%)		Sensitivity (%)		Specificity (%)	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
Visual									
<i>Occlusal surfaces</i>									
Cavitated	4	1	1	56	51	63	51	89	89
Dental	10	9	4	50	44	37	25	87	91
Enamel	2	2	2	21	21	66	66	69	69
Any	4	12	7	78	75	59	62	72	74
Visual-Tactile									
<i>Occlusal surfaces</i>									
Dental	2	12	6	29	29	19	19	97	97
Any	2	4	4	40	40	39	39	94	94
<i>Proximal surfaces</i>									
Cavitated	3	3	3	5	6	52	32	98	99
Radiographic									
<i>Occlusal surfaces</i>									
Dental	26	4	3	54	55	53	54	83	85
Enamel	4	2	2	18	18	30	28	76	76
Any	7	5	4	82	84	39	27	91	95
<i>Proximal surfaces</i>									
Cavitated	7	3	3	13	9	66	66	95	97
Dental	8	39	5	27	27	38	40	95	96
Enamel	2	10	10	25	25	41	41	78	78
Any	11	6	3	62	66	50	49	87	88

^aModified from Bader and others^{5,6}**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.

Table 2 Summary of studies assessing the DIAGNODent device

Subject	Study	Main Findings
Root caries	Wicht and others ¹⁵	Correlation of 0.45 with lesion depth
Active vs. arrested lesions	Pinelli and others ¹⁴	Kappa statistic for agreement of operators 0.77, sensitivity 0.72, specificity 0.73
Clinical occlusal lesions	Sheehy and others ¹⁶	Reported a tendency for device to overscore occlusal lesions and effect of stain
Smooth-surface lesions	Shi and others ¹⁷	Good correlation with lesion depth (0.83); inter-observer agreement substantial (0.94)
Occlusal caries in primary teeth	Attrill and Ashley ¹¹	DIAGNODent device had highest sensitivity (0.78), but lowest specificity (0.83) relative to other devices tested
Validation of detection	Shi and others ¹⁷	Strong correlation with total mineral loss (0.89)
Validation in occlusal surfaces	Lussi and others ¹²	Sensitivity 0.96 (better than achieved with bitewing radiographs), specificity 0.86
Approximal caries	Shi and others ¹⁸	Sensitivity 0.75, specificity 0.96
Occlusal caries	Shi and others ¹⁹	Receiver operating characteristics analysis used; DIAGNODent device significantly better than radiography

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 hand-pieces (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).

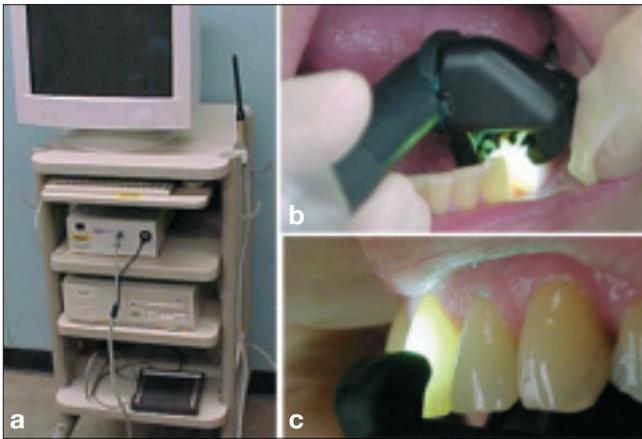


Figure 2: a) The DIFOTI set up, including light box, computer and foot pedal. b) The occlusal handpiece, with illumination from the buccal and lingual aspects, imaged from above. c) The smooth surface handpiece, illuminated from the palatal aspect and imaged from the buccal surface.

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;²⁹ therefore, the observation in one study of an area under the curve of 0.85 in a receiver operating characteristics (ROC) analysis of DIFOTI²⁴ 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.³⁰ 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.³⁰

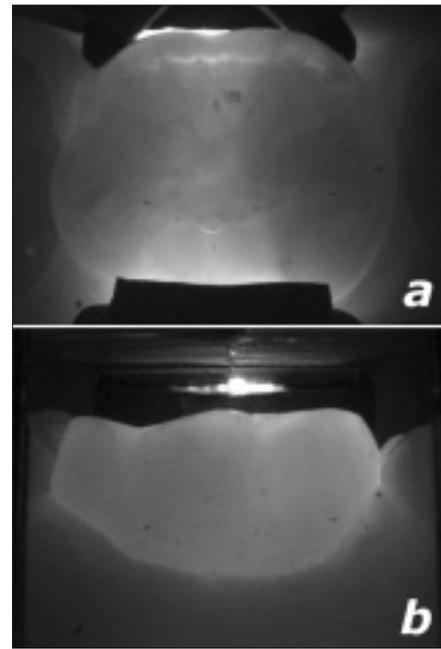


Figure 3: a) Sound occlusal surface as seen with the occlusal handpiece of the DIFOTI. b) Buccal view of the same tooth demonstrating lack of demineralization.

One potential problem with DIFOTI relates to image interpretation. Because the results are not directly quantified, the clinician must perform the analysis, with all the advantages and disadvantages that such analyses entail.²⁸ Furthermore, the content of the images should not be considered equivalent to what appears in radiographs. Specifically, areas of radiotranslucency appearing in radiographs should generally be restored. However, areas detected with the DIFOTI system are generally incipient lesions that are amenable to remineralization therapies.

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,^{31–34} and is briefly summarized here. Under certain conditions, human enamel autofluoresces. Bjelkhagen and others³⁵ were the first to describe the reduction of fluorescence seen in demineralized enamel, and Angmar-Månsson and ten Bosch³⁶ suggested that the increased porosity of carious lesions leads to a decrease in the refractive index.

Use of this theory to develop a viable technique³⁷ was followed by the capture of images on charge coupled device (CCD) cameras, which enabled longitudinal monitoring of individual carious lesions.³⁸ An existing method for quantifying mineral loss from lesions³⁹ was improved by substituting the cumbersome laser-based system with a portable arc-lamp unit.^{40,41} A commercial device and software (including an image subtraction system

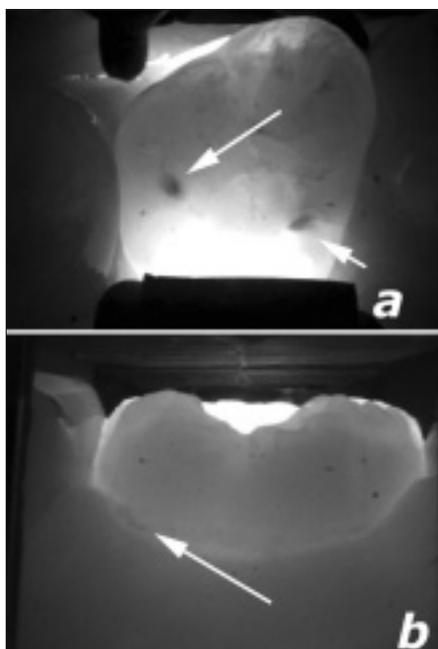


Figure 4: a) Arrows point to areas of light scattering, which indicates mineral loss on the (a) occlusal and (b) buccal surfaces. These are both early lesions that may respond to a fluoride remineralization therapy.

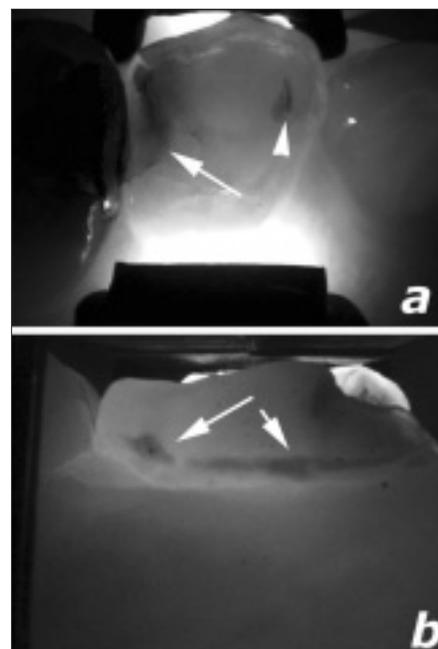


Figure 5: Arrows indicate more severe scattering and hence greater mineral loss on the occlusal (a) and buccal (b) surfaces. Such lesions may require minimal restorative intervention (i.e., enamel biopsy).

Table 3 Summary of studies assessing FOTI/DiFOTI devices

Subject	Study	Main findings
Occlusal caries	Cortes and others ²¹	Receiver operating characteristic 0.85, kappa statistic 0.87
FOTI in general practice	Davies and others ²²	Practitioners reported enhanced detection with FOTI
Inter-observer agreement	Cleaton-Jones and others ²³	Excellent agreement between observers (>90%)
Occlusal caries	Fennis-le and others ²⁴	Inter-observer reproducibility 0.79
Occlusal and approximal surfaces	Schneiderman and others ²⁵	Sensitivity 0.67 for occlusal surfaces and 0.56 for approximal surfaces; radiography had sensitivity of 0.18 and 0.21 respectively
In vitro use	Peers and others ²⁶	Sensitivity 0.67, specificity 0.97
Occlusal caries	Mitropoulos ²⁷	Sensitivity 0.85, specificity 1.00
Buccal surfaces	Sidi and Naylor ²⁸	Sensitivity 0.74, specificity 0.99

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 plaque^{41,48,51} and to monitor enamel erosion in vitro.⁵²

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).

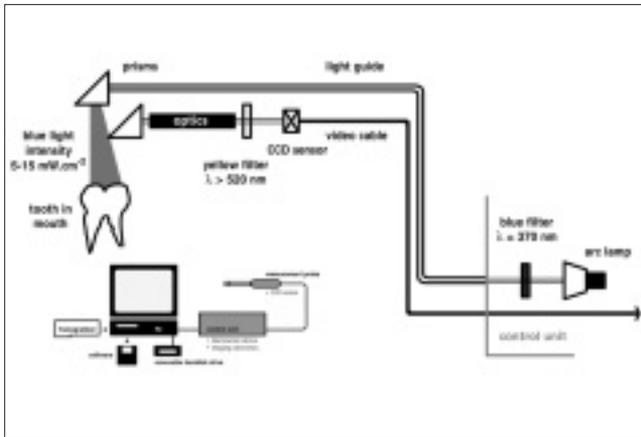


Figure 6: Diagrammatic representation of the QLF system.

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

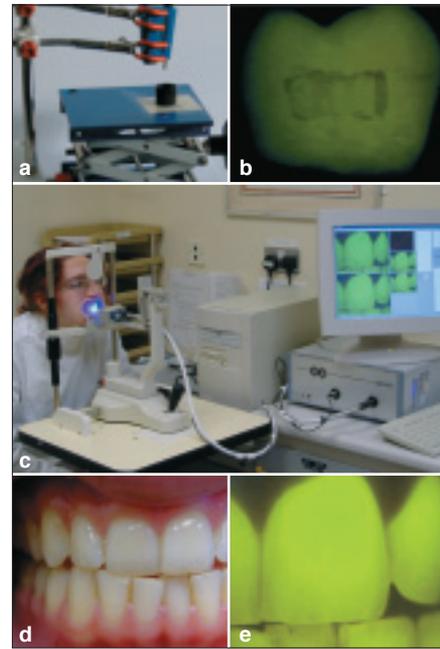


Figure 7: a) Quantitative light-induced fluorescence (QLF) camera in an in vitro set-up. b) An image captured in vitro. c) The VidRep system used with the QLF handpiece held on a headrest. d) White light image. e) The QLF image taken using this system.

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

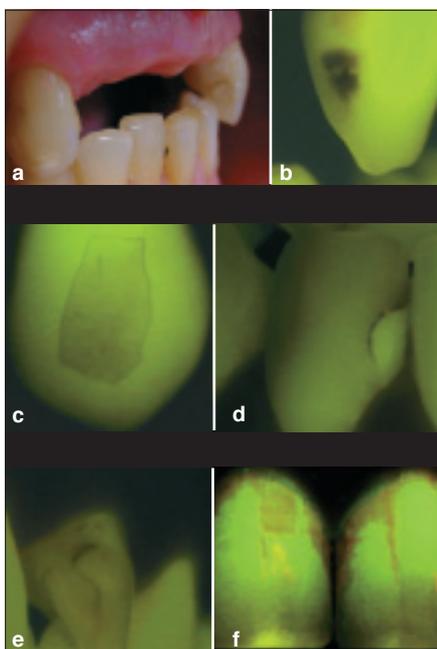


Figure 8: a) Clinical example of a lesion on the mesial surface of the canine associated with partial denture wear. b) The QLF image showing enhanced contrast between sound and demineralized enamel; note the lack of reflections. c) An example of an in vitro artificial lesion imaged by QLF. d) An example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

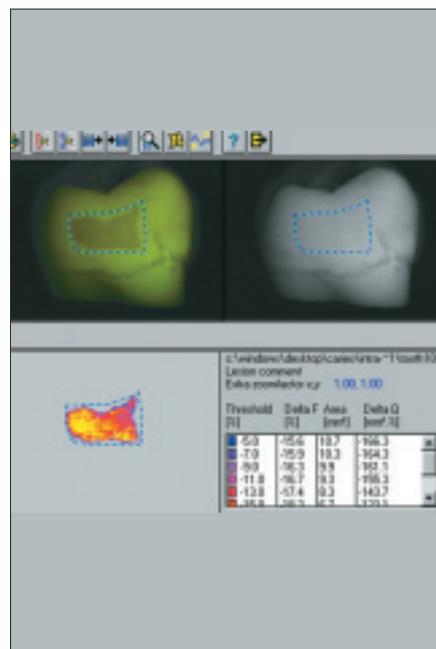


Figure 9: Example of QLF image analysis.

Table 4 Summary of studies assessing quantitative light-induced fluorescence device

Subject	Study	Main findings
Occlusal caries	Pretty and others ⁸ Ando and others ⁵³ ten Cate and others ⁵⁴	Strong correlation with histologic findings (0.82) Sensitivity 0.76 with plaque-covered surface Sensitivity 0.77, specificity 0.71
Reliability	Tranaeus and others ⁵⁵	Intra-observer agreement 0.96, inter-observer agreement 0.97
Secondary caries	DeSchepper and others ⁵⁶ Benedict and others ⁵⁷	Sensitivity 0.88, specificity 0.85 Sensitivity 0.95, specificity 0.85
Root caries	Pretty and others ⁴⁵ Gonzalez-Cabezas and others ⁵⁸	Correlation with gold standard 0.89 Receiver operating characteristic value of 0.78
Smooth surface caries	Hall and others ⁵⁹ Shi and others ¹⁸	Sensitivity 0.75, specificity 0.90 Sensitivity 0.76, specificity 0.92

Table 5 Effectiveness measures for a variety of diagnostic methods applied in the detection of occlusal caries

Diagnostic system	Study	Sensitivity	Specificity	Youden's J
Electronic caries monitor	Ashley and others ⁶⁰	0.65	0.73	0.38
Visual	Ashley and others ⁶⁰	0.60	0.73	0.33
Fibreoptic transillumination	Ashley and others ⁶⁰	0.21	0.88	0.09
Bitewing radiographs	Ashley and others ⁶⁰	0.19	0.80	0.01
Quantitative light-induced fluorescence	Pretty and others ⁸	0.68	0.70	0.38
Visual	Alwas-Danowska and others ⁶¹	0.50 ^a	0.91 ^a	0.41 ^a
DIAGNODent	Alwas-Danowska and others ⁶¹	0.94 ^a	0.52 ^a	0.46 ^a
	Bamzahim and others ⁶²	0.8	1	0.80
Electronic caries monitor	Bamzahim and others ⁶²	0.75	0.88	0.63

^aCalculated from reference.

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

Surface	High risk population (0.8) ^a		Low risk population (0.1) ^a	
	PPV	NPV	PPV	NPV
Smooth	0.95	0.43	0.36	0.96
Occlusal	0.90	0.35	0.20	0.95
Secondary caries	0.96	0.70	0.40	0.98
Orthodontic	0.98	0.62	0.65	0.98
Root caries	0.97	0.74	0.64	0.99

^aPrevalence 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.^{67–69} 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.^{67,70} 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 Nuttall⁷¹ 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 biomedical needs) will continue to rest with the clinician. ♦

Acknowledgements: The authors would like to thank Prof. G. Stookey and Dr. M. Ando from the University of Indiana for permission to use Figures 2 to 5.



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The authors have no declared financial interests in any company manufacturing the types of products mentioned in this article.

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