Diagnodent® and the caveats of caries diagnosis by laser fluorescence

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Introduction

The Diagnodent device is based on principles of caries detection by laser fluorescence which were developed in Sweden in the mid-1980s. Since that time, several lasers have been employed for caries detection (such as the argon, carbon dioxide, and excimer lasers). These systems are however more complex to use and more expensive than the visible red diode laser system upon which Diagnodent® is based, and for this reason they have not been used in clinical practice to any significant extent.

Conventional means for detecting caries on fissured surfaces of teeth (such as visual examination, probing and X-rays) have limitations and can easily overlook small lesions. The fluorescence diagnosis method has a very high specificity (almost no false positive responses), although the sensitivity (ability to detect true positive lesions) is not as high. Both sensitivity and specificity with laser fluorescence are substantially better than current clinical techniques or other approaches such as electrical resistance. This conclusion is based primarily on laboratory studies undertaken of the various techniques using extracted teeth, in which the teeth were finally sectioned to determine the presence and extent of caries histologically (the gold standard). While unavoidable for studies of this type, using extracted teeth poses concerns that the teeth may have different levels of hydration (water), and solutions used for storage (such as formalin) may cause fluorescence which then affects the readings obtained.

Detection of mineral loss from caries (or dental erosion) at a very early stage of formation may permit more efficient reversal of the caries process than when lesions are detected at a more advanced stage. Early intervention will reduce the need for irreversible restorative procedures. This is an essential part of the modern philosophy of minimal intervention dentistry. Laser fluorescence uses low power non-ionizing radiation, and can be used with safety at high frequency, unlike dental X-rays. It can be used in situations where radiographs are contra-indicated, such as with pregnant women.

The current clinical use of laser fluorescence methods lacks a proper appreciation of the technical limitations of this technique, which arise from the underlying physics and optics. These are outlined further below.

Exploration of key issues

Dental caries is the most common dental disease in Australia and the Western world and is responsible for the majority of tooth loss in the population. Direct health costs for restorative dental care are a significant component of total health expenditure. Modern dental practice emphasises early detection of lesions so that chemically based preventive agents (such as fluoride therapies) can be applied to the lesion to promote remineralization.[1]

With an overall decline in caries prevalence in the Western world over the past two decades, there has also been a change in focus from diagnosing and treating frank carious lesions to having to evaluate more truly caries-free tooth surfaces. The clinician is now faced with more small or early lesions and fewer advanced lesions with cavitation. In spite of the fact that cervical and occlusal surfaces are directly visible clinically, early lesions are often difficult to diagnose by simple visual examination as optical changes are limited either by overlying fluid or by the anatomy of the fissure space.
No single diagnostic method has gained universal acceptance for the diagnosis of early dental caries. Current methods used for the detection of dental caries are based on visual, mechanical and radiographic methods. Visual methods are favoured because they are non-destructive, compared with mechanical methods such as probing which can damage tooth structure, and X-rays, which are ionizing radiation and are hazardous to the patient. There are many studies which indicate that the reliability of conventional diagnostic methods for examining teeth for dental caries and other defects is poor.[1] There is a substantial literature which documents the problems of visual inspection, when compared with the “gold standard” of histological examination. While there is a range of results in the literature, even with ideal visual examining conditions, visual examination will detect only a minority of lesions which have reached the dentine (between 20 and 48 per cent).

In recent years, there has been increasing interest in diagnostic methods which will provide greater specificity and sensitivity. Numerous studies have shown that coherent light (from lasers) can elicit fluorescence in tooth structure, and this has been applied both for analysis of the mineral composition of dentine and enamel [2] as well as for the clinical diagnosis of incipient lesions of dental caries in fissures and proximal tooth surfaces [3]. The original concept of caries detection by laser fluorescence was developed in Sweden by Angmar-Mansson at the Karolinska Institute, who employed visible blue light (488 nm wavelength) generated using an argon ion laser [4]. At this wavelength, yellow fluorescence occurs in the apatite, and this fluorescence signal is reduced in areas of demineralisation, which have increased levels of water. As argon lasers are complex and expensive instruments, there have been moves to adapt the principles of laser fluorescence to wavelengths which could be generated using diode lasers, which are simpler and cheaper. The first commercial product of this type, the Diagnodent®, uses an In:Ga:As:P diode laser (wavelength 655 nm), and was released by KaVo in early 1999.

The Diagnodent® has obtained EEC, US FDA and Australian TGA approval. It has been used in Europe and Australia since February 1999, and was introduced to the US market in February 2000. The laser output power of the Diagnodent unit is less than 1 mW, and the visible wavelength of 655 nm affords protection from the blink reflex. Accordingly, the device is designated a Class 2 laser device under international (ISO) standards and the relevant Australian Standard (AS2211:1997).

There is limited clinical information on the usefulness of laser fluorescence, and the literature fails to identify a range of user, equipment and optical factors which can potentially affect the reliability and performance of this technique over time. In addition there is the possibility that extrinsic or intrinsic stains can alter the signal to noise ratio, and indeed it may be possible to enhance the detection of lesions using dyes in combination with laser fluorescence. [3] This has the additional value that some dyes when photo-activated can exert anti-microbial effects on the microorganisms which cause dental caries initiation and progression. [5]

For fluorescence diagnosis of caries, the underlying phenomenon is that the fluorescence properties of enamel and dentine [6,7] are altered by mineral loss [8,9,10]. The difference in fluorescence between carious and sound tooth tissue is much greater in enamel than it is in dentine [11]. Sound enamel
fluoresces in the orange/yellow region of the spectrum, and this fluorescence of apatite mineral is effectively absent in both incipient and well-developed lesions. Consequently, these lesions appear as dark areas when excited by laser light in the visible blue portion of the spectrum (488 nm). There have been numerous studies which have used this discriminating feature for the diagnosis of caries [7-17]. To quantify the altered fluorescence (i.e. “Quantitative light-induced fluorescence” or QLF), the percentage change in mean fluorescence is calculated. This parameter correlates well with mineral loss in enamel, and with the histological depth of the lesion [7].

The fluorescence concept has been applied to other fluorescence signals within apatite mineral. The Diagnodent diode laser system (wavelength 655nm) uses a visible red emission to elicit fluorescence. In a recent clinical study, the Diagnodent technique detected occlusal caries in all 55 posterior teeth with a positive argon laser QLF diagnosis, but where clinical diagnosis (based upon examination and radiography) was doubtful [18]. In this study, 13 per cent of the lesions detected were restricted to enamel and 87 per cent involved the dentine. While laboratory studies using extracted teeth have generally found that laser fluorescence methods yield higher levels of sensitivity and specificity than currently available techniques, the influence of tooth factors such as fissure morphology, saliva, stains, calculus, plaque and restorative materials remains to be determined (Diklic, Facaro and Walsh, unpublished). Also important are operator and equipment factors, both of which have received little attention. An additional concern is selecting the appropriate cut-off levels between sound and carious tooth structure, since this will influence the decision of the operator to intervene (e.g. exploration with a fine bur or air abrasion). Little is known regarding how reproducible measurements are over time.

**Limitations and caveats with Diagnodent®**

With water fluoridation and exposure to other fluoride sources, fissure caries has become the predominant pattern in most children who have caries. Because of the imprecision of current means of caries diagnosis clinically, and the likelihood of missing small fissure lesions in bitewing radiographs, the Diagnodent® is without doubt an important adjunct to the diagnosis of fissure caries. It must be used together with a proper caries risk assessment, which takes into account evidence of past or current fissure caries.

When considering the reading obtained at an individual site within a tooth, it is important to bear in mind the factors which can affect this reading, and the implications this has in terms of the treatment provided. At the present time, the level at which a decision is made to intervene (with exploration using a fine bur or air abrasion, for example) has been obtained empirically (i.e. from relatively unstructured observations) rather than from large rigorously-designed studies. While most clinicians use a level of "30" on the Diagnodent® as the threshold between sound and questionable tooth structure, it is not clear how reproducible the reading obtained on a tooth is over time. This is particularly important for incipient lesions which may give readings close to the threshold.

In addition to the extent of caries, a range of confounding factors may affect the reading obtained (see Table below), and dentists should be alerted to the possibility of errors in judgement and clinical treatment, in terms of

- **Undertreatment:** This may occur from recording a value with the intention being to monitor the situation over an extended time (several months or greater). Given the factors listed below, it is uncertain what limits of change would be applied to a reading obtained at some future time, in other words, what change would be considered clinically significant. In this respect, alignment is a particularly important issue. An identical problem occurs with laser doppler flowmetry (LDF), which is used for measuring pulp blood flow when following up cases of dental trauma. With LDF, a stent is used as a alignment aid to ensure reproducible positioning on the (labial) tooth surface. With caries diagnosis by fluorescence on fissured surfaces, which have a complex anb angular anatomy, aligning the same point at same angle would be challenging to say the least. In any event, the literature on management of incipient fissure caries indicates that "if in doubt, seal" is an appropriate clinical principle to follow.
• Overtreatment: This may occur from setting an arbitrarily low value for non-reversible (tooth cutting) interventions, resulting in overtreatment. One needs to remember that restorations do not cure dental caries. If a restoration is required for caries which has just penetrated to the dentino-enamel junction, care should be taken to use tooth-preserving techniques such as preventive resin restorations (invasive sealants).

Table. Potential factors which may influence readings for caries diagnosis by laser fluorescence.

User factors
- Interval between calibration
- Calibration technique
- Angulation of the tip to the tooth surface
- Interference from ambient light

Tooth factors
- Moisture and saliva on the tooth surface. This introduces additional optical boundaries, with loss at each interface by reflection. This reduces the signal to noise ratio.
- Stains, calculus, plaque and other surface materials. Because of the potential for fluorescence and absorption of light from these deposits, it is essential that teeth be very clean before using Diagnodent®.
- Filling materials. These may absorb light or fluoresce and thus affect readings, particularly at cavity margins.

Equipment factors
- Stability of output of the diode laser. This varies with time because of heat generated within the laser diode.
- Contamination of the optical paths with adherent debris on the surface of the tip
- Degradation of the optical paths, due to autoclaving of the tip or breakage of optical fibers within the cable to the handpiece
- Stability of the fluorescence detector (and related electronics) over time

In summary, the Diagnodent® is a useful adjunct to fissure caries diagnosis, and offers considerable advantages over the "mirror and probe alone" approach. To obtain the best diagnostic value from this device in clinical practice, one must recognize factors which can affect the readings obtained, and bear these in mind when forming clinical judgements as to the treatment required. This is particularly so for lesions which are undetectable visually but give readings near the threshold level. Further studies should address the impact of the factors outlined above on the sensitivity and specificity of caries diagnosis by laser fluorescence.
REFERENCES

1. Walsh LJ. What the GP needs to know about teeth. *Australian Doctor* 1999; 120:s1-s6.