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The Effect of Distance and Tooth Structure on Laser Fluorescence Caries Detection

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Clinical Relevance

Devices used to aid occlusal caries diagnosis are supposed to detect small lesions deep in the pit and fissure system. In detecting small occlusal caries, distance and tooth structure may separate the instrument and the carious lesion. In this study distance and tooth structure were found to reduce the ability of the DIAGNOdent to detect caries.

SUMMARY

The DIAGNOdent, a device used in caries detection, uses a laser to excite fluorescence from pigments in carious tooth structure. In clinical use assessing occlusal surfaces, distance and tooth structure may separate the instrument's tip from the fluorescent source. The aim of this *in vitro* study was to examine the effect of distance and tooth structure on laser fluorescence (LF) readings.

In one set of experiments, a porphyrin pigment in oil suspension was used as a LF signal source. Thin slices of enamel and dentin were obtained from extracted molars. Pigment-induced LF readings were obtained when these slices were placed between the porphyrin pigment and the LF instrument's tip. The effect of either demineralized or intact tooth tissue on pigment-induced LF readings was assessed. In other experiments on extracted molars with small occlusal caries, LF readings were taken from pit/fissure sites before and after removal of the occlusal surface.

LF readings are proportional to pigment concentration and inversely proportional to the distance between the suspension and the instrument's tip. Enamel, demineralized enamel, dentin, and demineralized dentin all caused significant reductions in LF signal, all readings being taken with the same tip-pigment distance. Demineralized enamel (white with

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intact surface) caused the most reduction. After sectioning of carious teeth, there was a significant increase in LF readings.

The results of this study indicate that distance and the presence of tooth structure between the carious lesion and the instrument's tip reduce LF readings. These results indicate that anatomic factors interfere with the LF device's ability to assess occlusal caries. DIAGNOdent readings should not be relied on when making diagnostic decisions.

INTRODUCTION

Carious lesions affecting the occlusal surfaces of posterior teeth can be difficult to detect using conventional clinical examination techniques.[1,2] These lesions begin as areas of demineralization in the enamel lining the walls of pits and fissures that extend below the actual surface of the tooth.[3] In order to assist dentists in diagnosing small occlusal lesions, researchers have examined ways that the caries process can alter the optics and other physical properties of tooth structure.[4–6] This research has resulted in the development of diagnostic devices that are designed to detect inconspicuous lesions.[7] One goal in developing caries diagnostic devices is to have the capability of detecting lesions at a stage before cavitation begins. Areas of subsurface enamel demineralization appear to the unaided eye as white spots. The altered porosity of enamel in these lesions change the tissue's light-scattering characteristics, a property that is used as a basis for a type of caries-detection device.[8] Certain caries-related bacteria produce metabolic products that have characteristic colors and fluorescent properties.[9] These bacterial pigments are responsible for the dark gray or brown color commonly observed in decayed dentin. Porphyrin compounds can be extracted from carious dentin.[10] These pigments fluoresce when excited by red light. The DIAGNOdent (KaVo, Biberach, Germany) is a laser fluorescence (LF) device that transmits 655 nm of laser energy to tooth structure via a specially designed handpiece. The instrument detects fluorescent radiation with wavelengths >680 nm. These wavelengths originate in porphyrin-containing carious tooth structure and penetrate enamel to a degree, allowing the device to detect lesions within the occlusal anatomy.[11] This LF device has a digital display with a maximum reading of 99. Numerous studies have sought to determine the diagnostic sensitivity and specificity of LF, to determine the correlation of this instrument's readings with other methods of caries detection, and to examine the relationship of LF readings with the histological extent of lesions.[12–16] These studies demonstrate a moderate correlation between LF and other methods of caries detection as well as a limited ability to determine the depth and extent of lesions.

When examining lesions set deep in the occlusal anatomy, the pigmented lesion and the LF instrument's tip will be separated by a distance that depends on the depth of the fissures. This separation is due to the fact that the DIAGNOdent's light-emitting and receiving tip is wider than the occlusal fissures and is restricted from entering the fissure. In addition to the physical separation that may exist between the DIAGNOdent tip and the pigmented portion of a carious lesion, intact and demineralized tooth structure lining the superficial portion of the fissures may stand in the light path between the deep areas of bacterial pigment and the LF tip. In small occlusal lesions partially demineralized enamel may cover stained dentin. The effect of this white, highly light-scattering type of tooth structure on the LF readings originating in deeper tissue has not been determined.

The ability of the LF device to detect caries through intact and demineralized tooth structure has not been extensively studied. Iwami and others[17] examined the effect of dentin slices ranging in thickness from 0.2-1.4 mm on the LF readings obtained from occlusal caries in extracted teeth. Dentin slices were prepared by either cutting parallel or perpendicular to the direction of the dentinal tubules. Both orientations of dentin were found to attenuate the LF signal strength in a thickness-related fashion, with slices cut parallel to the direction of the tubules attenuating more than disks cut perpendicular; this was attributed to the light-scattering effect of the tubules.

The purpose of this study was to examine the effect of signal source-LF tip distance and interposed tooth structure on the instrument's readings. By examining the effects of both distance and tooth structure, we simulated the anatomic factors separating the DIAGNOdent tip from the pigmented portion of the carious lesion. The null hypothesis tested was that distance and intervening tooth structure would have no effect on LF readings. In one set of experiments suspensions of porphyrin pigment acted as the LF signal source. Using this suspension, the relationship between the LF tip-signal source distance and the instrument's readings was examined. The impact of tooth structure on LF readings was examined by placing thin slices of

enamel or dentin between the signal source and the LF tip. These measurements were made through the enamel slices both before and after acid demineralization. This allowed us to assess the effect of demineralization on the tendency of enamel and dentin to attenuate the LF signal. The effect of distance and tooth structure on the ability of the LF to detect natural occlusal caries was examined in experiments where readings were obtained from extracted teeth having small occlusal caries before and after the occlusal tooth structure was removed to expose the lesion. It is hoped that the results of this study will not only lead to a better understanding of the LF's limitations, but also assist in developing protocols for evaluating other caries-detecting devices.

MATERIAL AND METHODS

LF Signal Source

Experiments were performed to assess the effect of tooth structure on LF signal intensity. These experiments used a suspension of porphyrin pigment as a laser fluorescent source. Protoporphyrin IX (Aldrich, St Louis, MO, USA) was dispersed in United States Pharmacopeia mineral oil by grinding and mixing to form a homogeneous suspension that did not settle for at least 24 hours. The pigment in oil suspensions were placed in a 1-mL plastic well and covered with a glass cover slip. The LF handpiece was attached to a modified microscope (Wild, Heerbrugg, Switzerland) in such a way that the LF tip could be placed perpendicular to the cover slip covering the pigment suspension. A digital caliper (model CO 030150, Marathon Watch Company Ltd, Richmond Hill, ON, Canada) was also attached to the microscope, allowing the distance between the LF tip and the cover slip to be measured. LF readings obtained from mineral oil covered with a cover slip were negligible. Using this apparatus, the effect of pigment concentration and tip distance from pigment on LF reading could be determined. Also, small slices of tooth structure could be positioned between the LF tip and the fluorescent pigment without changing the distance between the instrument tip and the fluorescent source.

Tooth Tissue Slice Preparation

Sections of enamel and dentin (15 each) were obtained from 30 extracted human third molar teeth that were free of obvious caries or restorations. Due to the specific nature of the tooth sections required, one enamel or dentin slice was obtained from each tooth used. Patients from 18–30 years of age in the New Jersey Dental School Oral Surgery clinic consented to donate their teeth for research purposes. The University's institutional review board approved the tooth collection procedure. Following extraction, teeth were stored in 1% phenol and debrided of soft and hard tissues. Any residual debris found to be adhering to the occlusal surfaces of the teeth was removed gently with a dental probe. The teeth were then examined for the presence of small carious lesions. Molars having small occlusal caries were separated from caries-free teeth. These two sets of teeth were used in separate experiments. All teeth were used within 30 days of collection.

The enamel slices were derived from the lingual surfaces of caries-free molars. First the crowns of the teeth were obtained by fracturing off the roots. Then the crowns were mounted in the sample holding chuck of a low-speed saw (Isomet, Buehler Ltd, Lake Bluff, IL, USA) with a diamond blade, so that the lingual surface of the tooth was parallel to the blade. Under water lubrication, the surface enamel was removed. Then an enamel ribbon, measuring approximately 5 × 3 mm and 0.6-mm thick, was obtained by cutting the tooth superficially to the dentinoenamel junction. These ribbons were polished with 600-grit silicon-carbide paper (Buehler) with water lubrication. Following the first set of LF measurements, the enamel specimen was demineralized by immersing the ribbons for five days into a gel containing 0.1 M lactic acid, adjusted to pH 4.5 with sodium hydroxide and thickened with ethyl cellulose (Natrosol, Ashland Aqualon Inc, Parlin, NJ, USA). Following the demineralization treatment the enamel ribbons were rinsed with deionized water. These enamel specimens were then examined under 8-power illumination to ensure that a white lesion was seen when the tissue was wet and that the enamel surface was intact.

The coronal dentin disks (approximately 0.6-mm thick) free of enamel, pulp horns, and any discoloration suggestive of caries, were cut perpendicular to the long axis of caries-free teeth. These disks contained dentin from under the occlusal pits and fissures, allowing us to examine the effect of this tissue on pigment-evoked LF readings. The dentin disks were polished and subjected to demineralizing treatment, using the same procedure as was used for the enamel specimens. The success of the lactic acid treatment in producing dentin demineralization was assessed by determining whether the acid-treated dentin was softer to tactile examination than the intact dentin.

Both the enamel and dentin sections were prepared in such a way so that the enamel rods and dentinal tubules would be perpendicular to the specimen surface because this resembles the orientation of tissues on the occlusal aspect of molars. The lingual surface of molars is fairly flat, allowing us to create an enamel slice where the LF's light path runs approximately parallel to the enamel rods. In the coronal dentin disks, the dentinal tubules are roughly perpendicular to the dentin surface. The LF's light path would then be approximately parallel to the direction of the dentinal tubules.

Experiments to Determine the Effect of Enamel and Dentin on LF Readings

A pigment suspension was placed into a 1-mL well and covered with a cover slip. The LF tip was then raised above the cover slip to a distance that allowed enamel or dentin slices to be positioned into the laser light path (Figure 1). The LF reading at this pigment-tip distance was then measured. Next, the enamel or dentin slices were gently slid on the cover slip until the center of the specimen was in the LF light path and readings recorded. Following demineralizing treatment, LF readings were taken through the same areas of the dentin and enamel specimens. During the positioning of the tooth tissue slices, the distance between the LF tip and the pigment remained unchanged. Tooth tissue slices were kept moist during these experiments. The slices were placed on the cover slip, covering the pigment suspension in such a way as to avoid trapping air between the tooth slice and the cover slip.

Experiments to Determine the Effect of Occlusal Anatomy on the LF Readings Obtained From Natural Caries

Third molar teeth having small, visually apparent, occlusal caries were used in these experiments. These teeth had dark areas at the base of enlarged occlusal pits and fissures. The occlusal surfaces were photographed at approximately 8-power magnification (DP12 Microscope Digital Camera System, Olympus, Tokyo, Japan). Then with the occlusal surface moist, LF readings were taken from multiple sites on the occlusal surface. These sites were selected to include all pit and fissure sites thought to represent areas of possible decay, as well as sites in the fissure system and areas on the cusp inclines observed to be caries free. Using Microsoft PowerPoint, the LF readings obtained from various occlusal sites were superimposed onto the photograph of the tooth, creating a LF map of the surface. The occlusal surface was then

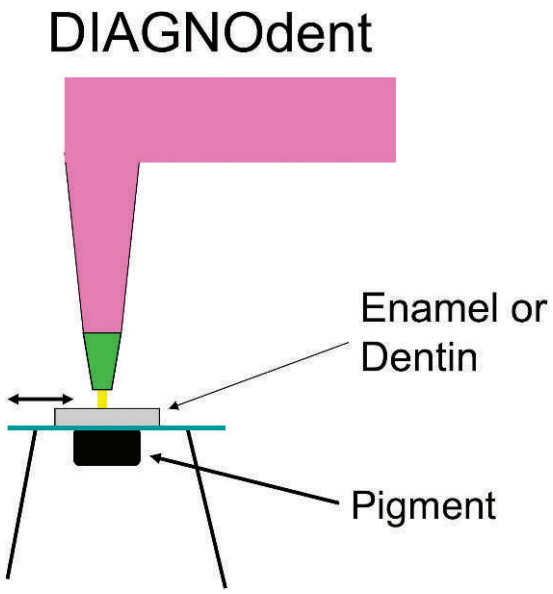

Figure 1. *Experimental apparatus used to examine the effect of enamel and dentin slices on LF readings. A porphyrin pigment in oil suspension covered with a microscope-slide cover slip acts as the LF signal source. The DIAGNOdent handpiece is held in such a way that the tip is positioned at a fixed distance from the cover slip. Enamel or dentin slices can be slid between the instrument tip and the pigment and the effect of tooth tissue on the pigment-induced reading assessed. LF readings were taken through enamel and dentin slices before and after demineralization with lactic acid. LF readings were taken without the tooth slice, through the intact slices, and through demineralized tissues.*

removed from the tooth by cutting perpendicular to the long axis of the tooth with the Isomet saw (Buehler) and water lubrication. This cut was made to a depth that exposed the enamel at the base of the occlusal fissures and differed from one tooth to another. The resulting new tooth surface was photographed as before and sites examined with the LF device, care taken to record measurements from the same sites as were examined on the original occlusal surface. In this way LF maps were created for the cut surfaces. In some teeth, a second cut was then made 0.5 mm below and parallel to the first and a third LF map created for that tooth. The teeth were not allowed to dry out during this process because desiccation has been observed to result in dentin crack formation and unstable LF readings. In total, 31 sites on 12 teeth were evaluated by this procedure. LF readings from the deepest cut were used in the data analysis, comparing the magnitude of the readings taken from the occlusal surface with those obtained from the cut surface.

LF Device Use

In all experiments the DIAGNOdent model 2095 was used with the A-tip because this tip is recommended

for occlusal examinations. The DIAGNOdent unit was calibrated prior to each use according to the manufacturer's instructions, using the instrument's ceramic standard. When measurements were being made on teeth, the instrument was zeroed with the tip in contact with healthy-colored enamel near a cusp tip. Readings from teeth were obtained with the tooth surface in a moist state with low ambient light. The A-tip was placed in gentle contact with the surface then rocked slightly; the peak reading obtained from each site was recorded for later analysis. Calibration exercises were held for the three examiners, using both extracted teeth and various concentrations of porphyrin in suspension. During these calibration exercises the LF readings obtained by the three examiners differed by fewer than ±5 units.

Data Analysis

LF readings are reported as mean ± standard deviation. A one-way analysis of variance with a pairwise Tukey-Kramer test was performed using the JMP statistical program (SAS Institute Inc, Cary, NC, USA) in order to determine whether significantly different LF readings were obtained from a protoporphyrin in oil suspension under the following conditions:

1) A small separation (0.75 mm) between the pigment and the LF tip.
2) Intact enamel slices (≈0.6 mm thickness) placed between the pigment and the LF tip.
3) Demineralized enamel slices placed between the pigment and the instrument's tip.
4) Intact dentin slices (≈0.6 mm thickness) placed between the pigment and the LF tip.
5) Demineralized dentin slices placed between the pigment and the instrument's tip.

When enamel or dentin was placed between the LF tip and the pigment, the tip-pigment distance was maintained at 0.75 mm. LF measurements were taken at this distance prior to taking readings through each enamel and dentin slice. Significance was set at $p<0.5$. A sample-size calculation for this experiment was performed based on pilot study data. Twelve samples in each group would be the minimum number required in order to achieve a statistical power of 0.8 (α level of 0.05).

In order to determine whether significant differences existed between LF readings obtained from the occlusal surfaces of molars with those obtained following removal of the occlusal surface, a two-tailed *t*-test was performed. Significance was set at $p<0.5$.

RESULTS

Relationship Between Porphyrin Pigment Concentration and LF Readings

The relationship between the LF readings and the concentration of pigment dispersed into mineral oil is shown in Figure 2a. Six replicate readings were taken for each pigment concentration. These readings were taken when the distance between the pigment and the LF tip equaled 0. As pigment concentration in the suspension was raised, the LF reading increased. At a pigment concentration of 12.5 mg/mL, a mean LF reading of 95.4 was recorded. When a suspension containing 25 mg/mL was examined, a reading of 99 was recorded; this is the instrument's maximum reading. Further increases in pigment concentration did not cause the LF readings to increase further.

Effect of Fluorescent Signal Source Distance on LF Readings

As shown in Figure 2b, LF readings dropped as the distance between the probe tip and the pigment increased. The relationship between distance and LF reading is shown for two pigment concentrations. One suspension contained a pigment concentration of 12.5 mg/mL. This concentration induced a mean reading of 95.4 when the distance between the instrument tip and the pigment equaled zero (three measurements per data point). With this pigment concentration, each 0.1-mm increase in distance resulted in a reduction in LF reading. The other suspension examined contained a higher (50 mg/mL) concentration of pigment. With this high pigment concentration (each data point represents one reading), increasing the distance between the tip and the pigment failed to reduce the LF reading from the maximum value displayed by the LF device (99) until the separation exceeded 0.4 mm. Beyond this separation, increasing the tip-pigment distance resulted in a drop in LF readings.

Effect of Enamel and Dentin on Pigment-induced LF Readings

At a distance of 0.75 mm a suspension containing 25 mg/mL porphyrin induced a mean LF reading of 51.0 ± 1.79 (n=30). At this LF tip-cover slip distance, enamel and dentin slices can be slid into the laser light path and the effect of tooth structure on LF

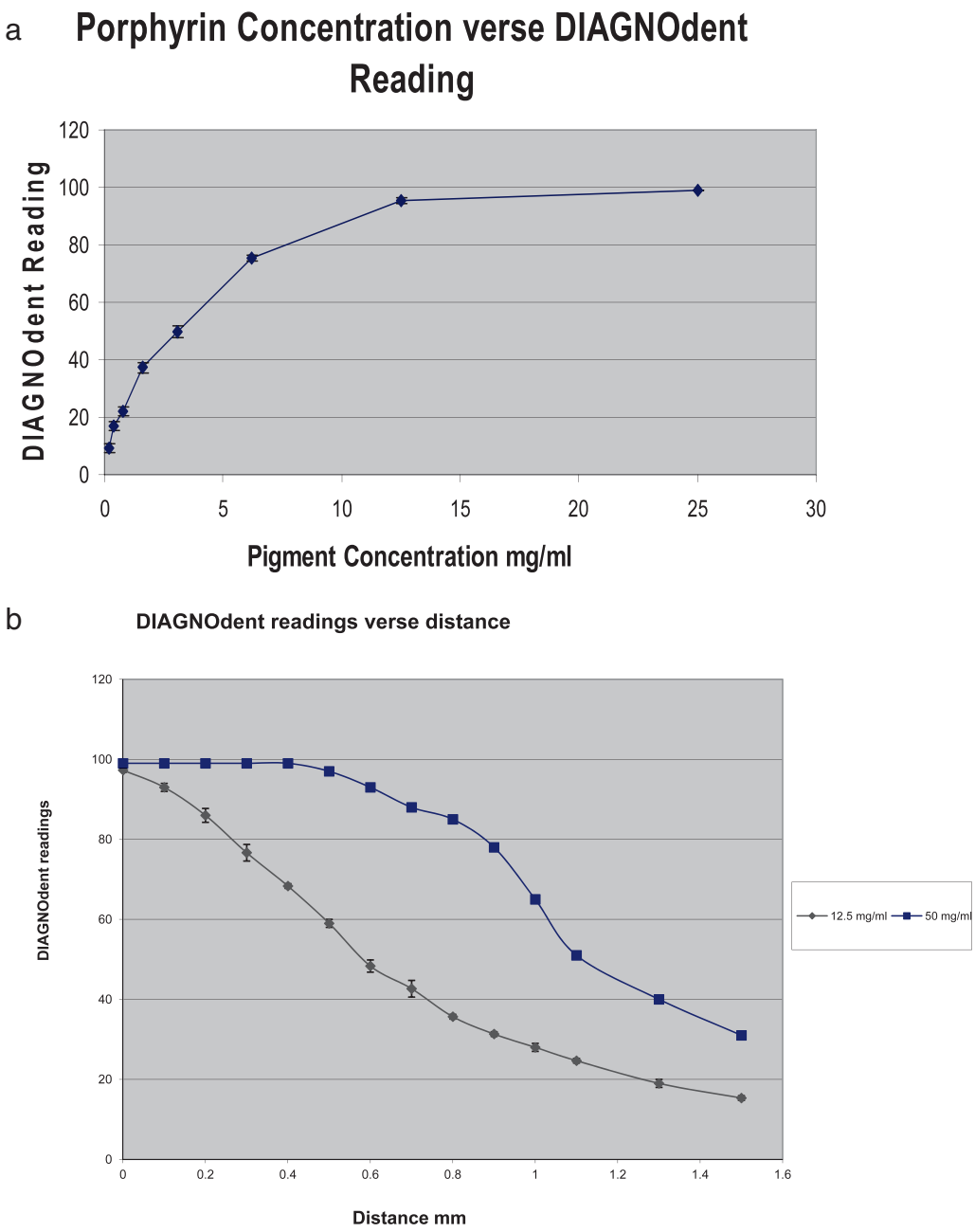

Figure 2. *(A): Effect of protoporphyrin pigment concentration on LF readings, mean ± standard deviation (n=6). (B): Effect of LF tip-pigment distance on readings measured from protoporphyrin pigment suspensions. Squares represent mean LF reading ± standard deviation (n=3) using a pigment concentration just sufficient to elicit a mean LF reading of 95.4 (maximum LF reading, 99) when the distance between the instrument's tip and the pigment equals zero. The diamonds represent a single set of LF readings taken using a suspension containing a higher pigment concentration.*

readings assessed. LF measurements were taken through both the intact and demineralized areas of the tooth slices (Figure 1). The mean thickness of the 15 enamel and 15 dentin slices used in this study was 0.61 ± 0.04 mm and 0.6 ± 0.03 mm, respectively. A two-tailed *t*-test indicated that the enamel and dentin slices did not differ significantly in terms of thickness ($p<0.05$).

Placement of either dentin or enamel slices between the LF tip and the porphyrin pigment significantly reduced the amplitude of the instrument's reading compared with readings obtained without intervening tooth tissue (Figure 3). The mean reading through intact enamel was 28.4 ± 2.8, a significant 45.1% decrease compared with the readings obtained without enamel. The mean LF

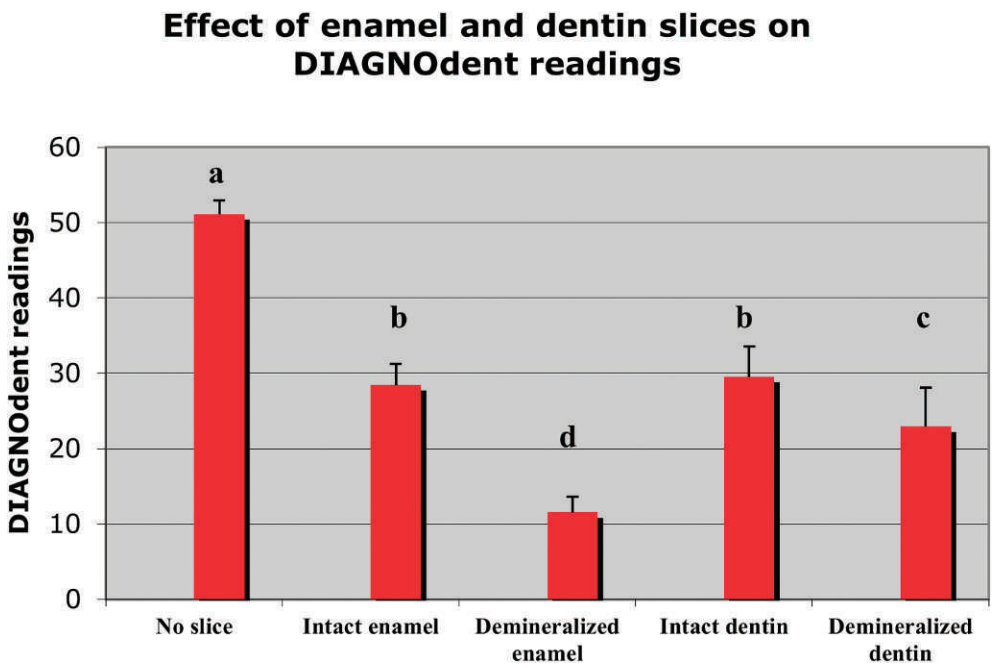

Figure 3. *Effect of tooth structure on LF readings (mean ± standard deviation) evoked by a porphyrin pigment suspension. Column on the left represents readings obtained with a 0.75 mm gap between the LF tip and the pigment (n=30). The remaining measurements were obtained when ≈0.6 mm-thick slice of tooth tissue was placed into this gap and the readings repeated. LF readings, from left to right (starting with the second bar), taken through intact enamel (n=15), demineralized enamel (n=15), intact dentin (n=15), and demineralized dentin (n=15). Groups that had the same letter above the bar had LF readings that were not significantly different. Both enamel and dentin significantly attenuated the LF signal strength; demineralized enamel caused the most attenuation.*

reading through demineralized enamel was 11.5 ± 2.1, corresponding to a 77.5% decrease. Demineralized enamel induced a significantly greater reduction in LF signal strength than did intact enamel. The mean LF reading obtained through intact dentin was 29.5 ± 4.1, a significant 42.2% reduction compared with the value for no tooth structure. The readings obtained through intact dentin were not significantly different from the readings obtained through intact enamel but were significantly higher than the reading measured when the laser passed through demineralized enamel. The mean LF reading through demineralized dentin was 22.9 ± 5.2, a significant 55.1% reduction compared with the measurements made with no tooth structure between the instrument's tip and the pigment. Though demineralized dentin attenuated the LF signal more than intact dentin or intact enamel, the readings obtained through demineralized dentin were significantly higher than those measured through demineralized enamel, indicating that demineralized dentin attenuated the LF signal less than did demineralized enamel.

The enamel and dentin specimens used in this study did not generate significant LF readings. Measurements of LF readings were taken from both the intact and demineralized sides of these enamel and dentin slices. Intact and demineralized enamel induced a mean LF reading of 1 and 1.3, respectively (N=3). In the case of dentin, both intact dentin and demineralized areas induced a mean reading of 3.3 (N=3).

Comparison Between LF Readings Obtained From the Occlusal Surface With Those Taken Below the Surface

Photos of the occlusal surfaces of two extracted molars with dark areas on the occlusal fissures indicative of caries are shown in Figures 4a,d along with LF readings obtained from the areas over which the numbers are superimposed. Figures 4b,e present photographs and LF readings of the same teeth taken after the removal of the occlusal surface. White discoloration of the enamel lining the occlusal fissures is clearly visible, as are dark areas in the dentin adjacent to or at the base of the fissures. LF readings taken from these cut surfaces were higher than those measured at corresponding sites on the tooth surfaces. The surfaces shown in Figure 4c,f are from deeper sections. These reveal dark dentin having high LF readings. Twelve teeth with discolored occlusal fissures were evaluated by this proce-

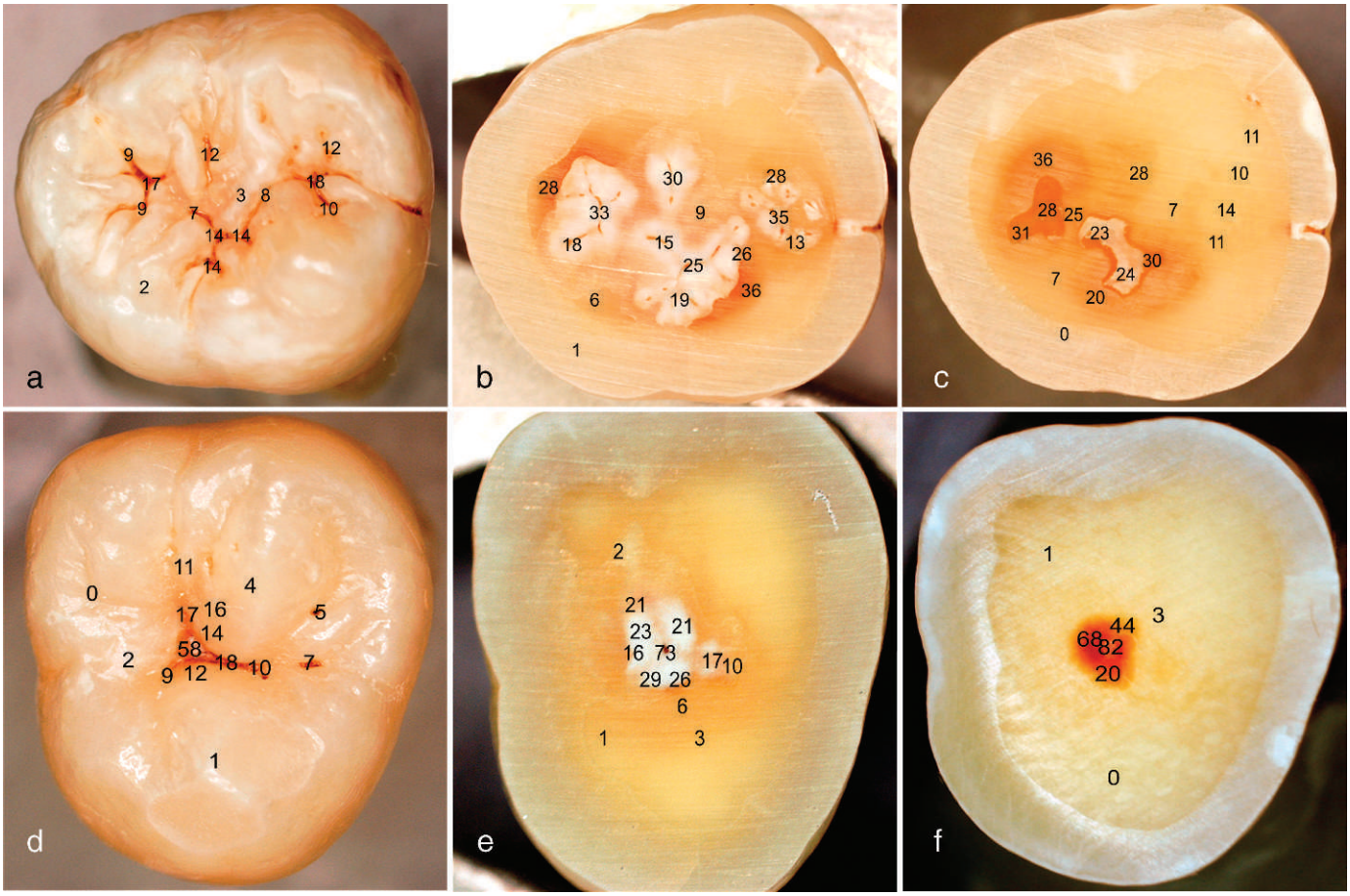

Figure 4. *Photographs and LF readings of two molars having small occlusal caries. (A) and (D): Surface views of these teeth and LF readings obtained from occlusal sites. (B) and (E): photo and LF readings taken from these teeth following removal of the occlusal surface. Notice the areas of white-demineralized enamel lining the fissures and adjacent areas of stained dentin. LF readings from the cut surface are generally higher than those obtained from the original surface. (C) and (F): photograph and LF readings obtained following a second cut performed on the same two teeth. Notice the dark dentin area below the fissures with high LF readings.*

dure. A total of 31 occlusal sites were measured with the LF before and after removal of the occlusal surface. The mean LF reading obtained from the surface was 26.3 ± 12.8. Following the removal of the occlusal surface the mean LF reading was 58.9 ± 26.5; this value is significantly higher than the readings obtained from the intact surfaces (Table 1).

DISCUSSION

The basic premise behind the use of caries detectors is to enable clinicians to diagnose lesions that are not apparent with conventional examination methods. It is also desirable to quantitatively assess and record the severity of lesions so that changes over time can be monitored. The field of caries management is evolving rapidly. Nonsurgical treatment of early lesions along with caries management by risk reduction is considered appropriate care.[18] These trends do not mitigate the need for the accurate diagnosis of occlusal caries. Detection of early lesions can help identify individuals and teeth at risk and in need of preventive intervention.[19] Since its introduction, the DIAGNOdent has been subjected to

Table 1: *Mean and Standard Deviation of LF Readings Obtained From 31 Occlusal Sites on 12 Extracted Molars Obtained Before and After Removal of the Superficial Portion of the Occlusal Surface. All 12 Teeth Had Visual Signs of Occlusal Caries.*

Surface	Mean ± Standard Deviation
Occlusal surface	26.3 ± 12.8
Cut surface	58.9 ± 26.5*

*Difference significant, $p<0.05$.

several investigations aimed at assessing its utility as a means of improving the diagnosis of occlusal caries. These studies examined the reproducibility of LF readings as well as diagnostic agreement with other methods. In general these studies support use of the LF as an adjunctive diagnostic method.[14,20] The purpose of this study was to examine the effect of anatomic factors on LF readings.

The LF device does not detect hard tissue demineralization directly but rather senses the presence of bacterially generated fluorescent pigments.[10,11] Noncarious stains, plaque, and pigmented material from prophylaxis pastes are sources of false positive readings influencing this instrument.[20] In contrast, clinically relevant factors such as the position of the pigmented part of the lesion with respect to the location of the LF-probe tip, factors that may reduce the LF signal strength, have not been investigated extensively.

In some of these experiments we used a porphyrin in oil suspension as a LF signal source in order to reproduce the LF signal generated by carious dentin. As has been observed previously,[10] we observed that the magnitude of the LF readings are related to the porphyrin pigment concentration. The maximum reading that is obtainable with the LF device is 99. At high pigment concentrations the instrument's response saturates and can increase no further. In clinical use, very dark lesions may possess quantities of pigment that saturate the instrument's response. We observed that the LF reading declines as the distance between the instrument's tip and the fluorescent pigment increased. We assessed this using a pigment concentration (12.5 mg/mL), below that which saturated the instrument's response. With this pigment concentration, a distance of 0.6 mm resulted in a 50% reduction in the LF signal strength compared with the signal measured with a distance of zero. Using pigment concentrations above those that saturate the instruments response, the effect of small separations between the LF tip and pigment are not seen. In experiments examining the effect of tooth slices on LF readings a pigment concentration of 25 mg/mL was used. This concentration was sufficient to induce a high enough LF reading to allow the attenuating effects of enamel and dentin to be assessed.

Due to the attenuating effect of distance, the LF device may underestimate lesions that exist deep in the pit and fissure system. These results underscore the need to correctly place the instrument tip during clinical use.

Tooth structure was also found to have an attenuating effect on the LF readings measured from porphyrin pigment dispersions. These experiments used slices of enamel and dentin placed between the porphyrin pigment and LF tip. Measurements were made before and after the enamel and dentin slices were demineralized using a pH 4.5 lactic acid gel. When performing this procedure, each slice was exposed to the acid on both its inner and outer flat surfaces. Care was taken to ensure that measurements were taken from the same area in both instances. Demineralized enamel attenuated the LF signal more than intact enamel, intact dentin, or demineralized dentin. This tissue has a white opaque appearance indicating a tendency to scatter light. This light scattering is the likely explanation for the reduced LF signal. The ability of dentin slices to partially block LF signal has been reported previously.[17] Next to demineralized enamel, demineralized dentin was the second most LF attenuating. The dentin specimens were cut in such a way that the LF's light path would be parallel to the direction of the dentinal tubules in an area corresponding to the dentin located below the occlusal fissures. The dentinal tubules scatter light.[21] This light scattering is probably responsible for the reduced LF signal strength. In dentin, lactic acid treatment results in the removal of the smear layer, demineralization of the intertubular dentin, and widening of the tubules. When exposed to caries acids, intratubular mineral precipitation occurs below the surface.[22] Although the appearance of dentin was not markedly changed by acid treatment, these results indicate that demineralization alters the optical properties of dentin, resulting in a greater attenuation of the LF signal. In contrast to demineralized tooth tissue, intact enamel and dentin attenuated the LF signal strength the least.

As seen in Figure 4, both intact and demineralized enamel line the fissures and may stand between the LF tip and pigmented dentin. Based on these features of occlusal anatomy, the observations concerning the LF signal–attenuating properties of intact and demineralized enamel are judged to be clinically relevant. The path taken by laser entering or fluorescent emissions exiting the carious lesions may also pass through dentin, depending on the instrument's position and the anatomy of the pit and fissure system.[23] In our observations of sectioned teeth with small occlusal lesions, it was noted that affected dentin is generally pigmented. Thus, the acid-demineralized dentin examined in this study may not represent a clinically relevant tooth tissue

type as far as its effect on caries detection is concerned.

The effect of distance and intervening tooth tissue on the LF device's performance was further evaluated in experiments where readings were recorded from small lesions before and after removal of the tooth's occlusal surface. Cutting revealed sites of enamel demineralization and dentin staining in teeth that appeared grossly intact. These subsurface areas were observed to be soft to tactile examination (performed after LF examination). Removal of the occlusal surface resulted in a significant increase in the LF readings obtained from 31 sites containing discolorations suggestive of early caries. Compared with readings obtained from the surface, measurements made after removal of the occlusal surface were higher even when the dentin was still covered by white-demineralized enamel, indicating that the attenuating properties of both distance and tooth structure are important in influencing the LF's readings.

The challenge for any caries detection device is to aid clinicians in the detection of lesions that are not apparent with conventional examination alone. The effect of lesion-detector distance and intervening tooth structure should be investigated when assessing the performance of technologies intended for use in occlusal caries detection. It has been noted that teeth stored in chemical preservatives lose LF signal strength with time.[24] Although the effect of phenol, the preservative used in this study was not assessed, the use of the nonoxidizing preservatives examined caused an approximately 30% reduction in LF signal strength over short time spans.[24] In this study the subsurface LF readings were 55.3% higher than the surface readings. The effect of the tooth storage conditions may have influenced the results but cannot account for the differences between the surface and subsurface readings.

The presence of factors that cause false positive LF readings as well as the factors described here that lead to underrating lesions indicate that LF readings must be interpreted with caution, and these readings should not be the exclusive basis for diagnosis. A further limitation is the inability of the LF device to distinguish between active and arrested caries. Although this study indicates that the occlusal anatomy hinders the ability of the LF to detect caries, we are not suggesting that clinicians use a low reading threshold when using LF in restorative treatment planning and decision making. When used in clinical practice, correlation between LF readings and other diagnostic findings are critical to therapeutic decision making.

This instrument may be a useful tool in the longitudinal monitoring of occlusal lesions. Increases over time in a site's LF reading may be indicative of lesion progression because the distance and amount of intact tooth structure standing between the carious dentin and the instrument's tip would decline as the lesion expands and as the enamel walls of the fissure fail.

Many contemporary systems of caries detection seek to identify signs of caries that exist before cavity formation takes place, the goal being the institution of preventive measures aimed at preventing destruction of tooth structure. On occlusal surfaces, LF and/or other technologies can be used to identify suspicious areas in need of sealants or monitoring with other preventive measures. It is hoped that this and other caries detection devices will be used in diagnostic protocols aimed at identifying patients and teeth at risk[25] and not just as a means of justifying operative intervention.

CONCLUSIONS

The DIAGNOdent and other caries detector devices are supposed to aid in the identification of occlusal lesions that are difficult to diagnose by visual inspection. LF detects bacterial pigments that are deposited within carious tooth structure. This study examined the effect of distance and interposed tooth tissue on the ability of the LF to detect caries. Distance and interposed tooth structure interfered with the detecting ability of the LF device. These results indicate that when lesions occur deep inside the pits and fissures, the distance between the lesion and the LF tip as well as intervening tooth structure hinders the ability of this instrument to detect caries. In clinical use, low LF readings do not allow the presence of caries deep in the fissures to be ruled out.

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