

In Vitro Evaluation of the Spectra™ Early Caries Detection System

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Abstract

- **Objective:** The goal of this study was to perform an *in vitro* evaluation of the Spectra™, a new caries detector that uses light-induced fluorescence of healthy tooth structure and bacterial pigments to optically detect caries. The Spectra generates a storable color map image of examined tooth surfaces which shows areas of enamel and dentin caries. In this study, Spectra readings of occlusal surfaces were compared to clinical, radiographic, and histological assessments of caries.
- **Methods:** Two examiners evaluated 41 extracted molars. The teeth were radiographed and then visually assessed. The International Caries Detection and Assessment System (ICDAS) was used to classify the extent of caries. The teeth were then sectioned and assigned a histological score based on the extension of caries into enamel or dentin.
- **Results:** Teeth lacking radiographic caries had a mean Spectra reading of 1.5. Teeth having radiographic caries had a mean Spectra reading of 2.0. This difference was statistically significant. In general, higher ICDAS scores were associated with higher Spectra readings. Teeth with histologically evident deep dentin caries had significantly higher Spectra readings than intact teeth or teeth with superficial enamel demineralization. Spectra assessment of occlusal caries agrees with clinical and radiographic methods.
- **Conclusion:** Spectra images illustrate the full spectrum of caries severity, from enamel demineralization to dentin decay. The Spectra is a promising technology for the diagnosis and for monitoring the progression of occlusal caries.

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Introduction

The diagnosis of dental caries is an integral component of a clinician's practice. During intra-oral examinations, dentists attempt to discern whether or not lesions are cavitated or non-cavitated, active or arrested, and to estimate the depth of a lesion, questioning whether it is limited to the enamel, entering the dentin, or even approximating the pulp. These considerations ultimately will lead to a treatment plan that includes preventive intervention, monitoring, sealing, or providing restorative treatment for carious lesions.^{1,2}

For years, visual/tactile examinations served as the principal diagnostic methods for occlusal caries detection.³ As research progressed, the notion that excessive probing with an explorer can lead to premature cavitation of the enamel encouraged dentists to put down their explorers and rely solely on visual detection.⁴ Unfortunately, as studies have shown, visual detection lacks high sensitivity.⁵ Radiographic examination is a useful

adjunct to the detection of occlusal caries. As studies have indicated, occlusal caries must be quite large and well into the dentin in order to be diagnosed using bitewing radiographs.^{6,7}

Newer diagnostic methods have been introduced to the dental community, and several optical methods of caries detection are available to clinicians. These devices direct a particular wavelength at tooth structure and detect light emissions from the tooth tissue that are indicative of intact tissue or decay. The Quantitative Light Fluorescent device QLF™ (Inspektor Research Systems BV, Amsterdam, The Netherlands) uses a wavelength of light that induces fluorescence in dentin. Healthy enamel allows this fluorescent light to pass through with minimal scattering. Enamel white spot lesions, areas having subsurface areas of demineralization, will scatter the fluorescent light and appear in QLF images as dark areas with low fluorescence.⁸ Quantitative changes in QLF fluorescence correlate well with the magnitude of enamel mineral loss. This device's accompanying

software allows changes in lesion status to be tracked over time. The QLF has been used in clinical studies to assess the remineralization of white spot lesions.⁸

The DIAGNOdent® (KaVo, Biberach, Germany) uses a laser to induce fluorescence in bacterial pigments such as porphyrins, that are deposited into carious dentin.⁹ This instrument has a 0–99 numerical display and generates an audible tone. Numerous studies have been conducted analyzing both the repeatability and validity of this technique. The DIAGNOdent detects dentin caries, but unlike the QLF, does not detect enamel demineralization.^{1,10,11}

In 2008, a new caries detection device, the Spectra™ (Air Techniques, Melville, NY, USA), was introduced. The Spectra unit emits a blue-violet light at a wavelength of 405 nm, in turn causing the porphyrins deposited by caries-producing bacteria to fluoresce. This aspect of the Spectra is similar to DIAGNOdent detection. The Spectra also differentiates fluorescence from healthy and demineralized tooth structure. The Spectra handpiece interfaces with computer software to create an image of the tooth surface of interest with different image colors, representing intact tooth structure, demineralized enamel, or carious dentin (Figure 1). The Spectra is able to store the fluorescence images in a patient's record so changes in individual lesions can be monitored over time.



Figure 1. Photograph of the Spectra handpiece showing connection to a laptop computer.

The aim of this *in vitro* study was to assess the diagnostic performance of the Spectra device by comparing Spectra readings to other methods of occlusal caries detection, and against a histological gold standard of carious involvement. Occlusal Spectra readings, obtained from extracted human teeth, were compared to clinical caries scores, radiographic assessment, and histological evaluation.

Materials and Methods

Forty-one extracted human third molar teeth were used to perform this investigation. Patients 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 (Protocol number 0120050074).

Following extraction, teeth were stored in 1% phenol and debrided of adherent 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. Two examiners (MG and KM) independently evaluated the teeth using three caries detection methods: clinical-visual examination, radiographic examination, and the Spectra device.

For the clinical examination, teeth were dried and evaluated separately by the two examiners using standard dental operator illumination. The International Caries Detection and Assessment System (ICDAS)¹² was used to score all teeth. ICDAS consists of the following scores: 0: Sound tooth surface; 1: Pits and fissures showing opacity with prolonged drying; 2: Distinct visual change in enamel when wet, carious opacity wider than the natural fossa; 3: Localized enamel breakdown because of caries with no visible dentin or underlying shadow; 4: Underlying dark shadow from dentin with or without localized enamel breakdown; 5: Distinct cavity with visible dentin; and 6: Extensive distinct cavity with visible dentin. In the rare cases where the two examiners differed in their ICDAS score, the disagreement was reconciled by joint examination. The teeth were then photographed with a digital camera (Canon USA, Lake Success, NY, USA).

Radiographs were prepared of each tooth. The teeth were placed on standard size #2 films with the lingual surface facing the film, and a radiograph of each tooth was obtained using a perpendicular angle of the cone to the film. The examiners evaluated the radiographs on a light box in a darkened room. After individually analyzing the films, the examiners assigned each tooth a "Yes" or "No," indicating the presence or absence of radiographic decay.

The teeth were then examined using the Spectra handpiece and accompanying software. The Spectra unit's 10 mm distance spacer was rested on the occlusal surface of each molar, the overhead fluorescent light was turned off, and an image for each tooth was collected. After collection of an image, the analysis was performed using the Spectra's Visix® software, which produced both numerical and color ratings of regions of tooth structure using the following color coded and numerical scale: Green: 0–1.0—sound enamel; Blue: 1.0–1.5—initial enamel decalcification; Red: 1.5–2.0—enamel caries up to the DEJ; Orange: 2.0–2.5—dentin caries; and Yellow: 2.5 or higher—deep dentin caries. A training and calibration exercise was held where the two examiners obtained Spectra readings from a group of 12 teeth, that included teeth in various ICDAS categories. By using a uniform method of positioning the Spectra handpiece with respect to the tooth, the two examiners were able to generate equivalent color maps of the teeth with peak Spectra readings which disagreed by no more than 0.2.

Following visual, radiographic, and Spectra analysis, the teeth were sectioned perpendicular to the long axis of the tooth using a slow speed saw (Isomet®, Buehler LTD., Lake Bluff, IL, USA) with diamond blade and water lubrication. Cuts were made to a depth that exposed the base of the occlusal pits and fissures. A histological evaluation of each tooth was performed to verify the presence of caries, and the depth/extent of enamel and dentin involvement. The following histological scale was used: H₀—no whitening of enamel and no dentin staining; H_{E1}—cut surface

reveals small white patches within the enamel; H_{E2} -cut surface reveals extensive white patches within the enamel; H_{D1} -cut surface reveals white discoloration of enamel and dark discoloration of dentin; and H_{D2} -cut surface reveals areas of white enamel and extensive dark discoloration of dentin. The two examiners performed a joint examination in uncommon cases where their histological scores differed.

Data Analysis

Spectra readings were expressed as mean \pm standard deviation. A two-tailed Student's t-test was performed to determine if Spectra readings were significantly different between teeth judged to have radiographic caries and radiographically intact teeth. In order to determine whether teeth in different ICDAS and histological categories had significantly different Spectra readings, an ANOVA with a pair-wise Tukey-Kramer HSD test was performed using the SPSS (SAS Institute Inc., Cary, NC, USA) software package. Statistical significance was set at the $p < 0.05$ level.

The sensitivity and specificity of the various diagnostic methods was calculated in order to determine how the techniques compared to each other.¹³ The sensitivity is the proportion of teeth where the test correctly made the diagnosis, and the specificity is the proportion of teeth where the test correctly identified teeth not having the caries diagnosis. In calculating the sensitivity and specificity of the various diagnostic methods, the correctness of each tooth's radiographic, clinical, or Spectra assessment was determined using that tooth's histological evaluation as a gold standard means of determining whether the occlusal surface was intact, had areas of enamel demineralization, or dentin caries. For the purpose of the sensitivity and specificity calculations, teeth with histological scores of H_{E1} or H_{E2} were classified together as having enamel lesions. Teeth with histological scores of H_{D1} or H_{D2} were classified together as having dentin caries.

Results

All radiographs were analyzed by both examiners, and recorded as either "Yes," having radiographic decay or "No," containing no radiographic evidence of decay. The examiners were in agreement for the analysis of the 41 teeth, with thirty-two teeth displaying no radiographic indications of decay and nine teeth having radiographic decay. For Spectra readings, the "No" radiographic caries group had a mean value of 1.5 ± 0.4 , and the "Yes" radiographic caries group had a mean value of 2.0 ± 0.2 ; the difference between these values was significant ($p < 0.001$).

Next, the relationship between Spectra readings and the ICDAS scores was determined for the 41 teeth used in the study. There were seven teeth with a score of 0, nine rated as ICDAS 1, 12 assigned a score of 2, 10 given a score of 3, and three rated above 3. In Figure 2A, the occlusal view of an ICDAS 2 tooth is presented. The Spectra map for the same tooth is shown in Figure 2B. The blue areas at the periphery of the fissures represent superficial enamel caries, the red are deep enamel caries, and the orange spots are areas of dentin caries. The cut surface of this tooth is shown in Figure 2C. The dark areas observed on the cut surface confirm the presence of dentin caries. Comparison of Figures 2B and C indicates that the Spectra correctly identified areas of dentin caries.

The mean Spectra values were determined for the teeth in each ICDAS category (Figure 3). An ANOVA with a Tukey's *post hoc* test was used to determine if the instrument readings from the various ICDAS groups differed significantly from one another. Teeth with higher ICDAS scores generally had higher Spectra readings. For the Spectra readings, ICDAS 0 teeth did not differ significantly from ICDAS 1 teeth, but did have significantly lower Spectra readings than teeth with ICDAS scores of 2 or greater. The Spectra readings obtained from ICDAS 1 teeth did not differ from readings obtained from ICDAS 2 teeth, but were significantly lower than the Spectra readings obtained from teeth with ICDAS scores ≥ 3 . Spectra readings from teeth with an ICDAS score of 2 did not differ significantly from teeth in other ICDAS categories, except ICDAS 0 as noted. Teeth with ICDAS scores of 3 had higher Spectra readings than ICDAS 0 or 1 teeth, but did not significantly differ from teeth in other categories. The small number of teeth with ICDAS scores greater than 3 had significantly higher Spectra readings than ICDAS 0 or 1 teeth, but did not differ significantly from other ICDAS categories.

The histological extent of caries was evaluated by examination of the cut occlusal surface (Table I). For the four teeth that were histologically identified as being without caries, lacking subsurface discoloration of the enamel or dentin, the mean Spectra reading of 1.0 ± 0.7 is consistent with sound tooth structure. For the 15 teeth with small demineralized white areas in the deep fissures, the mean Spectra reading of 1.2 ± 0.6 indicates early enamel demineralization. The three teeth with extensive white patches limited to the enamel had a mean Spectra reading



Figure 2. (A) Photograph of a molar assessed as ICDAS 2 (distinct color changes, wider than natural fissures). (B) Spectra image of the same tooth as is shown in 2A. Blue areas indicate enamel demineralization, red area indicates deep enamel decay, and orange area indicates dentin decay. (C) Photograph of the same tooth as shown in Figures 2A and B following removal of the occlusal surface. Dark areas confirm the presence of dentin decay.

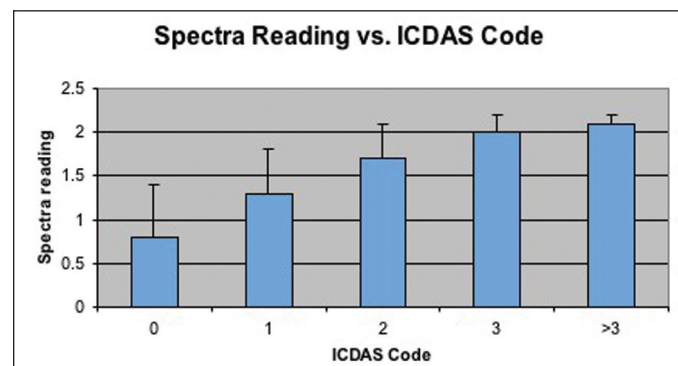


Figure 3. Peak occlusal Spectra readings (\pm standard deviations) obtained from molars whose caries status was classified using the ICDAS system. Teeth with higher ICDAS scores had higher Spectra readings.

Table I
Spectra Readings \pm Standard Deviations for Teeth
with Different Histological Scores

Histological Score	Number of Teeth	Mean Peak Spectra Reading \pm SD
H0	4	1.0 \pm 0.7
He1	15	1.2 \pm 0.6
He2	3	1.6 \pm 0.6
Hd1	3	1.5 \pm 0.2
Hd2	16	2.0 \pm 0.2

of 1.6 ± 0.6 , indicating deep enamel caries. For the three teeth in the histological group identified as small dark patches within the dentin, the mean Spectra reading of 1.5 ± 0.2 incorrectly identified the lesion as deep enamel caries. The cut surface of 16 teeth had extensive dark patches in dentin. These teeth had a mean Spectra reading of 2.0 ± 0.2 , indicating dentin caries. Teeth with deep dentin caries had significantly different Spectra readings than caries-free teeth and teeth with superficial enamel caries. Figures 4A and B show photographs and Spectra images obtained from the cut surface of an ICDAS 2 tooth, histologically classified as having dentin caries. The Spectra image clearly highlights areas of demineralized enamel and caries involved dentin on the cut surfaces.

Using each tooth's histological caries assessment as a gold standard, the sensitivity and specificity of each diagnostic method was calculated (Table II). The sensitivity of the radiographs in detecting dentin caries was 0.47, indicating that radiographs detected dentin caries in less than half the teeth in which they were present. The specificity of the radiographs was 1, indicating that radiographic evidence of occlusal caries was never observed in teeth that lacked dentin caries. Compared to radiographs, the Spectra showed superior sensitivity (0.57) at detecting dentin caries. For this determination, a Spectra score of 2 was the cut-off for dentin caries. The specificity of the Spectra in detecting dentin caries (0.9) was lower than 1.0, indicating some instances of the Spectra detecting dentin caries when dentin lesions were not present histologically. ICDAS code 3 denotes a visually detectable cavitation. The sensitivity of cavitation as a clinical sign of dentin caries was 0.68, and the specificity 1.0 indicates that the visual finding of small cavitation is a good indicator of dentin caries. Using Spectra readings of 1–2 as an indication of

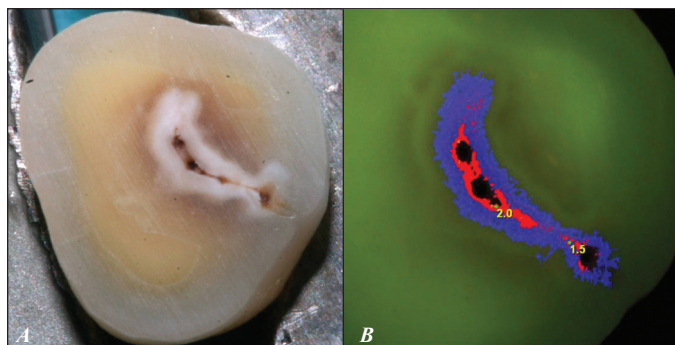


Figure 4. Cut surface photograph (A) and corresponding Spectra images (B) of a tooth having small occlusal caries (ICDAS 2). Spectra image of cut surfaces indicates areas of demineralized enamel shown by blue and red, as well as dark areas of carious dentin.

Table II
Sensitivity and Specificity of Spectra Measurements
Compared to Other Methods of Caries Detection

Diagnostic Parameter	Sensitivity	Specificity
Radiographic detection of dentin caries	0.47	1.0
Spectra detection of dentin caries (Spectra \geq 2)	0.57	0.9
Clinical detection of dentin caries (ICDAS \geq 3)	0.68	1.0
Spectra detection of enamel caries (Spectra 1–1.9)	0.78	0.52
Clinical detection of enamel caries (ICDAS 1 or 2)	0.72	0.65

enamel demineralization, the Spectra's sensitivity in detecting enamel demineralization was 0.78, and the specificity was 0.52. Of the 11 teeth incorrectly diagnosed by the Spectra as having enamel caries, eight had dentin caries, indicating that these teeth were under-diagnosed as having enamel lesions. ICDAS scores of 1 and 2 denote visible enamel color changes with intact surfaces. Using these clinical criteria to detect enamel demineralization, the sensitivity of ICDAS in detecting enamel caries was 0.72, and the specificity was 0.65.

Discussion

The aim of this laboratory study was to assess the usefulness of the Spectra in the diagnosis of occlusal carious lesions by comparing the performance of this device to other diagnostic techniques. Each tooth's histological score was used as the gold standard determination of the tooth's caries status. The low sensitivity and high specificity of the radiographs observed in this study agree with previous results demonstrating that radiographic diagnosis of occlusal caries is restricted to large lesions.¹⁴ Significantly higher Spectra readings were observed in teeth that had radiographic occlusal caries. The Spectra demonstrated superior sensitivity at detecting dentin caries than radiographs. None of the teeth used in this study had lesions that were not clinically apparent but observed radiographically. Clinical studies are required to assess the performance of caries detectors in the diagnosis of hidden caries.¹⁵

The ICDAS classification system grades carious lesion severity according to visual criteria.¹⁶ The 41 molars used in this study were evaluated by both examiners and separated into different visual categories based upon the ICDAS scores. Generally higher Spectra readings were measured from teeth with higher ICDAS scores. These results indicate that the readings obtained with this caries detector agree with the researchers' visual examinations.

The groups of teeth identified histologically as being intact, having superficial and deep enamel demineralization, and having deep dentin caries all had mean Spectra readings consistent with those classifications. The small group of teeth histologically classified as having early dentin caries was diagnosed by the Spectra as having lesions restricted to enamel, indicating that the Spectra under-diagnosed these lesions.

Comparing the sensitivity and specificity of the Spectra to the clinical evaluation scores indicates that the Spectra reliably detected dentin caries with a superior sensitivity to radiographic diagnosis. In small occlusal lesions extending into dentin, the fissures are lined with demineralized white opaque enamel. This tissue scatters light and makes it difficult for caries detectors to sense dentinal pigmentation. This characteristic of occlusal le-

sions makes longitudinal monitoring very important, since small dentinal lesions can be obscured by overlying enamel changes.

An important objective of caries examinations is the accurate detection of occlusal lesions which extend into dentin, since these lesions are typically managed with some form of surgical/restorative treatment. Using the manufacturer's Spectra cutoff score of 2.0 as the criteria for dentin caries, the sensitivity of the Spectra was higher than that of radiographic detection, but lower than that of clinical examination. We are currently performing further *in vitro* evaluations where an individual tooth's Spectra scores are compared to their histological score. Using this data we may be able to propose revised Spectra cutoff scores for dentin caries that would have higher sensitivity and comparable specificity to the currently recommended cutoff scores.

These results are noteworthy in establishing the utility of the Spectra in documenting the presence of occlusal caries that is restricted to the enamel. The sensitivity of the Spectra, with regard to enamel lesions, is higher than that of the clinical examination. This is important, since the anatomy of the occlusal surface makes detection of these early carious changes difficult. Future studies will examine the ability of the Spectra device to detect artificial enamel caries induced with a lactic acid gel.

The current study indicates that when used with proper visual and radiographic examination, Spectra is an effective adjunctive means of analyzing the occlusal surface of molars, and is well suited to detecting early stages of the carious process. The Spectra shares with the DIAGNOdent the ability to detect caries derived pigment in dentin. In contrast to the DIAGNOdent, the Spectra is able to detect areas of enamel demineralization as well as dentin decay. This enables this device to create a continuous scale that represents the full extent of the caries process. This is done through both numerical values and color graphic representations. A clinical study by Kühnisch and coworkers demonstrated that the QLF is like the Spectra, effective at detecting early occlusal lesions. Despite these encouraging results, these authors concluded that the time-consuming nature of the QLF's image capture and data analysis made this device impractical for widespread clinical use.¹⁷

The results of this study show that caries assessment by the Spectra and visual examination generally agree. This may provoke the question as to why use these new technologies if visual inspection alone is effective. For clinicians, the goal is to educate patients and parents. The Spectra provides color images and numbers to show patients the severity and extent of lesions. The Spectra allows clinicians to save an image as well as numerical data, and re-evaluate the same area at recall examinations. Clinicians can use the Spectra to monitor lesion progression or regression over time. The ability of the Spectra to image caries on cut tooth structure suggests that this device may also aid clinicians in determining the completeness of caries excavation.

In this *in vitro* study, the researchers were able to evaluate the extracted molars using ideal conditions, outside of the oral cavity. Clinical studies are needed to confirm the correlation between various commonly used methods of caries detection and Spectra readings within patient populations. These studies should also examine the reproducibility of Spectra measurements taken under clinical conditions.

Diagnosis of occlusal caries remains a subjective matter.^{1,16} Spectra and other caries detectors can provide quantitative information on difficult-to-diagnose lesions. The Spectra can detect enamel decay, provide insight to the depth of a carious lesion, and perform with more sensitivity than radiography. Unfortunately, few methods of caries detection allow the examiner to determine if the caries process is active, and likely to progress with time.

When dentists detect early occlusal lesions, the objective should be to utilize therapies that will result in the remineralization or long-term arrest of the caries process.¹⁸ Restorative treatment is usually reserved for cavitated surfaces.¹⁹ The ability of the Spectra to detect and document non-cavitated occlusal lesions indicates that this device can be useful in identifying patients and teeth in need of preventive interventions, as well as treatments designed to arrest lesion progression. Although the ability of oral hygiene practices to remineralize occlusal surfaces is unclear, non-cavitated occlusal lesions can be managed by placing sealants and periodic monitoring.^{20,21} Future studies will examine the ability of the Spectra to assess caries on sealed teeth. It is hoped that new diagnostic technologies such as the Spectra can facilitate the dentist's ability to document and communicate information concerning caries risk to patients and parents.

Conclusions

- The Spectra is able to detect caries over a broad range, from enamel demineralization to deep dentin caries.
- Although clinical criteria such as ICDAS are reliable methods of caries detection, caries detectors could be an adjunctive method, providing quantitative analysis and, in the case of Spectra, photographic documentation of difficult-to-diagnose early occlusal lesions. The Spectra can also allow lesions to be monitored longitudinally.

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