

CARIES DETECTION WITH LASER FLUORESCENCE DEVICES. LIMITATIONS OF THEIR USE

Andreas Spaveras^{1a}, Angeliki Tsakanikou^{2b}, Frantzeska Karkazi^{3c}, Maria Antoniadou^{1d*}

¹Department of Operative Dentistry, Dental School, National and Kapodistrian University of Athens, Greece

²Department of Operative Dentistry, Dental School, Semmelweis University, Budapest, Hungary

³Department of Operative Dentistry, Dental School, Comenius University of Bratislava, Slovakia

^aDMD, Postgraduate Student

^bDMD

^cMD Dr

^dDDS, PhD, Assistant Professor

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ABSTRACT

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Background: Dental caries is one of the most prevalent human diseases worldwide. The modern concept of minimal invasive dentistry includes early detection of incipient caries lesions and its treatment. Several optical and digital detection methods are available.

Objective: This literature review presents the utility and limitations of laser fluorescence caries detection devices DIAGNOdent (DD) and DIAGNOdent Pen (DDpen) (KaVo Dental GmbH, Biberach/Riß, Germany) for carious lesions on the occlusal surfaces of the permanent dentition.

Data sources: All available in vitro and in vivo studies from Google Scholar, PubMed and Scopus machines corresponding to caries, DIAGNOdent, DIAGNOdent Pen and laser fluorescence as key words, were reviewed.

Data extraction: Certain limitations of the studies were the inadequate analysis of the experimental protocols, the widespread sample use of the third molar, mistakes in sample handling and the limited number of studies evaluating the detection capability of DD and DDpen for secondary caries.

Data synthesis: DD and DDpen are useful devices for caries detection on the occlusal tooth surfaces. Their main advantages are the very high reproducibility of measurements (>0.90), the ease of handling and the quantification and monitoring capacity. Their main limitations are the relatively low specificity for enamel lesions, the necessity of unstained surfaces and absence of plaque and pastes during measurements and the absence of a universal, clinically functional calibration value (COV).

Conclusion: Further studies are required for more reliable data analysis and clinical interpretation of the relevant results.

Keywords: caries, DIAGNOdent, DIAGNOdent Pen, laser fluorescence, laser.

1. Introduction

Dental caries is one of the most widespread human diseases around the world and one of the most important problems in contemporary dentistry. The prevalence of dental caries is higher in the elderly and people of lower socioeconomic status. Nevertheless, it affects not only children but also adults.¹ A substantial decline of caries prevalence has been documented during the last decades, especially in the western world, primarily due to multiple fluoride products and the caries prevention methods available.²

Nowadays, dental caries in smooth and interproximal surfaces of permanent dentition is not

so frequent as compared to caries in pits and fissures of the posterior teeth. Most commonly, occlusal caries occur more often in premolars and first molars.^{3,4} The difficulty of prompt clinical diagnosis in occlusal areas is due to the anatomical features of these surfaces as well as the use of topical fluoride products. Fluoride can prevent the collapse of the superficial enamel layer and influence the remineralization process. Therefore, large dentine lesions might be less visible even when they have progressed substantially. This phenomenon reaches the percentage of 10-40% in molars and it is described as "hidden caries".⁵ The caries disease is an imbalance of the

*Corresponding author:

Dr Maria Antoniadou, DDS, PhD, Assistant Professor, Department of Operative Dentistry, Dental School, National and Kapodistrian University of Athens, Greece. Thivon 2 Str., PO Box 11527, Goudi, Athens, Greece, Tel/Fax: +306.944.342.546, e-mail: mantonia@dent.uoa.gr

dynamic processes of demineralization and remineralization of the teeth and in its initial stages it can be halted. Enamel demineralization is a daily process that does not necessarily lead to caries. Early intervention can turn an active lesion into an inactive one. If the degree of demineralization does not exceed a certain point, the process may come to a standstill, even if the enamel surface has been minimally affected. The conversion of a lesion from active to inactive requires early diagnosis and careful monitoring, in order to minimize the restorative intervention.⁶ From this point of view, modern caries detection means should permit monitoring of the caries process before the early lesion progresses to an extensive cavity.

The main objective of this paper is to give an overview of the use and utility of the two available caries detection devices of the occlusal surfaces of the permanent dentition, DIAGNOdent (DD) and DIAGNOdent Pen (DDPen) (KaVo Dental GmbH, Biberach/Riß, Germany), whose function is based on the fluorescence laser beam.

2. The criteria for the evaluation of caries diagnostic means

The criteria used for the diagnostic evaluation of caries are expressed through specific indicators which are defined in numerical scales and form the diagnostic accuracy of a test. Specificity and sensitivity are the two dimensions, widely used for the description and quantification of several diagnostic techniques. Specificity refers to the correct identification of the healthy dental tissues, while sensitivity refers to the correct identification of caries. The above indicators are expressed as values between 0 and 1 (100%). As these values approach 1, the qualitative effect is higher and they should be at least 0.75 for sensitivity and above 0.85 for specificity.⁷ Methods with low sensitivity can lead to suboptimal treatment, whereas methods with low specificity, to overtreatment. The caries detection methods with low sensitivity should be combined with techniques that are distinguished by high specificity and vice versa.

The accuracy of a method in most studies occurs from the sensitivity and specificity values and is often described by the area below the ROC curve (Receiver Operating Characteristics). The accuracy of the sum of the measurements obtained in a procedure is called reliability or otherwise repeatability and has a key role in the effectiveness of the procedure.

2.1. Conventional caries diagnostic means

In everyday clinical practice, direct visual observation is the most established method of tooth decay detection as it is easy and inexpensive. This method is mainly based on the subjective interpretation during visual examination and is often combined with radiographs and tactile examination with a metal probe.⁸

Many studies indicate that visual observation is characterized by lower sensitivity in relation to specificity with the latter exceeding 0.85 for caries

diagnosis in occlusal surfaces.^{9,10,11} Lussi et al.¹², in an *in vitro* study, showed that the sensitivity of visual observation as a diagnostic method becomes double in case of dentine caries (0.62) when compared to that of enamel (0.31). Gimenez et al.¹³ in a systematic review report that publications in respect to the accuracy of optical observation as a 'diagnostic instrument' do not exhibit sufficient qualitative methodology as far as the selection of the samples is concerned. They also underline that visual observation constitutes a reliable a clinical caries detection method. In another systematic review, Bader et al.¹⁴ mention that the optical observation displays high specificity, but low efficiency for sensitivity and repeatability.

As compared to the above laboratory studies, clinical studies report higher specificity than sensitivity in response to visual observation.¹⁵ The difficulty with the clinical studies is the lack of proper identification of the healthy dental tissues by the devices due to the frequent presence of dental calculus, bacterial plaque, saliva and food remnants. The use of established optical calibration systems such as ICDASII or Ekstrand's criteria seems to contribute to a more accurate caries detection system, given the fact that they provide guidelines and a rational quantification of lesions.¹⁵ The combined use of visual observation and tactile sensation with the use of metal probe does not appear to significantly improve the diagnostic capability of direct visual observation. Agnes et al. emphasize the possibility of damaging the adjacent tooth with the sharp edge of the probe.¹⁶ On the other hand, the visual observation assisted by loops of 1,5X to 4,5X shows increased detection sensitivity.¹⁷

Bitewing radiographs are a useful means of detecting interproximal caries; however, their advantage is quite limited to occlusal carious lesions, due to the overlay phenomenon.¹⁸ Furthermore, 40-60% of the tooth's metal ions have to be lost so as the lesion becomes visible radiographically. This is another reason why the radiographic imaging is not used clinically for the detection of incipient caries lesions.¹⁹

Therefore, the most important limitations of conventional diagnostic tools are their low sensitivity, specificity and reproducibility, the difficulty to determine the activity of the lesion and the inability to monitor its progression. For all these reasons, either more accurate detection methods or a combination of the above methods should be used. In this respect, the dental technology has invested in the development of numerous caries detection devices. Some of these diagnostic tools are based on infrared radiation, impedance spectroscopy, digital imaging as in the DIFOTI system (Electro-Optical Sciences N.Y.), photo thermal radiometry as in the Canary System (Quantum Dental Technologies, Canada) as well as on visible spectrum fluorescence and laser fluorescence.

2.2. Fluorescence of sound and carious tooth substance

Fluorescence is the property of a medium to absorb low wavelength radiation such as ultraviolet (1-400nm) emitting longer wavelengths of visible light (430-450nm). Teeth have the ability to emit fluoresce. This phenomenon can be observed when the incident radiation is shown in the ultraviolet spectrum, as in the cases of exposure to black light illumination or when the person is found at high altitude. The primary fluorescence of teeth, otherwise known as auto-fluorescence, arises from the internal biological structures of the cells, with responsible elements being several enzymes, vitamins, uranium glass and endogenous fluorophores, present in dentin and enamel.²⁰ Dentin emits more autofluorescence than enamel, with the emission peak being at 450nm. Although the exact chemical mechanism of tooth auto-fluorescence has not yet been ascertained, the greater amount of organic components of dentine seems to be the reason for its higher fluoresce values.²¹ It has been found that decayed tissues emits more fluoresce than healthy ones upon stimulation by red laser or infrared irradiation. This seems to be the result of both demineralization processes and the presence of bacteria byproducts in the decayed tissue.²²

2.3. Caries detection methods based on visible spectrum fluorescence

Quantitative fluorescence (Quantitative Light - induced Fluorescence, QLF) is a method used to detect the demineralization of enamel in the early stages. The technique relies on the ability of enamel to emit strong auto-fluorescence under certain circumstances. Hypomineralised enamel shows a decrease demission of fluorescence spectrum as compared to that of healthy enamel. With the use of the QLF method, demineralized areas can be detected before they become clinically visible, since the sensitivity of the specific technique is particularly high. Limitations of this technique were found in the detection of dentine caries also in the deep enamel lesions (400µm), where the results were not so accurate.²³

2.4. Caries detection devices based on laser fluorescence

The difference in fluorescence between sound and carious tooth structures was the fundamental concept behind the development of devices capable of quantifying the decayed tissue fluorescence. Methods based on fluorescence are divided into those that use visible spectrum stimulating rays such as the QLF and those based on laser ray fluorescence such as the DIAGNOdent and the DIAGNOdent Pen (KaVo Dental GmbH, Birebach/Riß, Germany).²³ Sundström et al.²⁴ in a pioneering study, stimulated carious and sound tooth structures by laser beams of different wavelengths (337nm, 488nm, 515nm, 633nm), and calculated the emitted fluorescence. The 488nm wavelength was selected as the most appropriate wavelength for the detection of incipient caries

with this technique.

3. DIAGNOdent Device and DIAGNOdent Pen Device

3.1. DIAGNOdent Device

The light source of DD is a diode laser with a wavelength of 655nm and a maximum power of 1mW. The red laser beam is transferred through a descending optical fiber to its edge, made of sapphire. Two different tip designs are available. The wedge-shaped which is used for occlusal surfaces and the straight one designed for smooth dental surfaces. The excitation optical fiber, i.e. one that carries the light beam on the tissues, is surrounded by nine concentric optical fibers of smaller diameter that collect the fluorescent radiation together with the surrounding light from the dental surfaces. All optical fibers have a diameter of 40 microns and they are carved at their end to receive or transmit the light radiation in similar manner.²⁵ A specially designed filter prevents the diffusion of ambient light ($\lambda < 655\text{nm}$) and thus only the fluorescent light is collected and converted into an electrical signal. Then, the signal is displayed on two LED screens and expressed as a integer number between 0 and 99. One screen displays the current measured value while the other records the maximum value of detection.²²

3.1.1. Correlation detection values of DD

Most clinical studies currently use the suggested measurements [Cut-Off Values (COV)] of the DD as they appeared in the clinical study of Lussi et al.¹² In this study, seven examiners evaluated 332 occlusal surfaces of 240 patients. After histological examination, they found that the values between 0-13 correspond to healthy dental tissues; values between 14-20 correspond to enamel caries and values between 21-29 to dentin caries.¹² In the same study, the restorative intervention is suggested for values between 20-29. However, Traanaeus et al.²⁶ suggested lower intervention values.²⁰⁻²⁵ Anttonen et al.²⁷ suggested intervention values greater than 30, emphasizing that for values greater than 40, the probability of overtreatment is greatly reduced. Heinrich-Weltzien et al.²⁸, compared the validity of various proposed COV, concluding that the superficial lesions in dentin (D3) with rates between 17-21 showed the lowest discrepancy (0,48 to 0,51). For deeper dentin lesions (D4), the manufacturer's suggested values (>34) had the best performance (0.51). Therefore, the proposed correlations of COV for DD vary considerably between studies and have changed several times even by the manufacturer. As a general observation, it is worth mentioning, that laboratory studies use lower COV for dentin caries in relation to clinical studies.

3.1.2. Effect of exogenous factors on DD measurements

Exogenous factors that could possibly influence DD values are various toothpastes and polishing pastes. In an in vitro study, the potential effect of ten different polishing pastes and four toothpastes

on DD measurements was examined, after their application to occlusal surfaces of molars and premolars. While toothpaste did not affect at all the DD values, seven of the polishing pastes have an effect on the measurements with pumice being the leading one. It seems that the intense auto-fluorescence of certain polishing pastes may alter the DD measurements, since their components cannot be completely removed from the pits and fissures of the occlusal surfaces of posterior teeth even after brushing and rinsing.²⁹ Also, Lussi et al.³⁰ in another in vitro study examined the influence of various toothpastes and prophylaxis paste remnants, as well as, powder remnants influencing DD readings. The results of this experiment showed, that only one toothpaste (Nupro mint/cherry medium, Dentsply De Trey, USA) and one polishing paste (Clinic, 3M, Bioggio, Switzerland) had a statistically significant effect on the measurements ($p < 0.01$), after rinsing for 3-6 seconds. These formulations contain sticky elements, which in combination with the high porosity of the decayed tissue, are not sufficiently removed and thereby increasing the DD measurements. If the teeth are not intensely rinsed with water-air combination for at least ten seconds, an incorrect assessment may occur. This is more significant for the long term monitoring of lesions, rather than the detection of lesion per se.³⁰

3.1.3. Effect of sample storage means in the DD measurements

The different storage means of the samples used in laboratory studies, such as chloramine solutions, formalin and thymol affect the final measurements of DD.³¹ Kaul et al.³² used 90 extracted molars in groups of ten and stored the eight groups in eight different solutions and one of them in a frozen state of -20°C for one year. It was shown that the most reliable method for teeth storing was the frozen state. According to this statement it has to be noted that only a few in vitro studies so far have used samples that were stored in a frozen state, a fact that should have an impact upon the clinical interpretation of the results.

3.1.4. Accuracy and repeatability of DD

The characteristics of accuracy and repeatability of the measurements of the DD and DDPen devices are well documented. Chu et al.³³ mention that different COV values show different results. In an in vivo study using COV by Lussi et al.,¹² the sensitivity (0.95) and specificity (0.11) differ considerably, while for COV=40, the sensitivity (0.70) and specificity (0.84) differ less. The authors propose the combination of visual observation with the use of DD for caries detection, as it offers better results in terms of specificity and quite good results in respect to sensitivity.

Jablonski-Momeni et al.,⁵ in an in vitro study, examined 181 points of 100 posterior teeth comparing the DD detection capability with that of direct visual observation during ICDASII. The

repeatability of the measurements for the DD between examiners was very high (0.957). Enamel (D1) and middle dentin (D3) have a specificity of D1:0.54, and D3:0.91 respectively, whereas the sensitivity was D1: 0.91 and D3: 0.70. Therefore, the ICDASII values were higher than those of DD. The researchers conclude that combining ICDASII and DD investigating methods provide better diagnostic results.

The first combined in vivo/in vitro study for the DD device was conducted by Reis et al.³⁵ who studied the caries detection of 57 third molars, both by direct visual observation and DD. The direct visual observation showed almost double in vivo and in vitro repeatability, both between different examiners (IR) (0.559) and between measurements of the same examiner (IA) (0.559) compared to that of DD. This study shows higher sensitivity of DD measurements than the visual method, which is not an usual finding in laboratory studies. The presence of pigments in pits and fissures of the occlusal surfaces may explain the above finding. The authors suggest using 19-20 COV for the differentiation of healthy versus carious dentin. They also proposed that the visual observation using ICDASII is quite a reliable caries detection system.⁵

Also in the study of De Paula et al.,³⁵ visual observation gave higher precision values than the DD. These findings are in agreement with the results by Rodrigues et al. and Agnes et al.^{36,16} The combination of detection techniques e.g. visual observation, radiography and DD seems though to result to more accurate diagnosis of caries as mentioned also elsewhere.³⁷ But it should be noted that the actual clinical experience of the operator can affect the objectivity of the detection, either by visual observation or by using devices such as DD. Specifically, in a laboratory study, 3 undergraduate dental students, 3 general dentists and 3 academics were asked to evaluate 25 molars by visual observation and by using DD.

The results showed a substantial variation. The sensitivity of the measurements ranged from 0.188 to 0.769 and the specificity from 0.714 to 0.969. The group of the academics recorded the highest sensitivity of DD (0.667), while the group of the general dentists the highest specificity (0.942).

A substantial variation of measurements occurred in respect of sensitivity (0.755-0.953) and specificity (0.755-0.953) of the visual observation, with the students reaching the greatest sensitivity (0.80).³⁸ Ideally, a detection technique for the occlusal surfaces must have a very high sensitivity for D3 and D4 and moderate high specificity for detecting enamel caries.

The DD shows higher specificity for lesions at the level of dentin and lower for enamel lesions, since it is unable to identify the healthy tissues from the carious ones extending to the half of the enamel.

The sensitivity of DD can be increased for more deep caries, with values of 0.66 in D2 and 1 in D3. Sensitivity for the D1 level was reported at 0.74.³⁹

3.2. DIAGNOdent Pen Device

The inability of DD to detect approximal caries was the primary cause of creating the DDPen (Fig. 1).



Figure 1. The handpiece of the DDPen.

The DDPen follows the basic principles of the DD model. The main difference is the design of its tip which can be rotated to the longitudinal axis and thus permitting the detection of approximal caries. Also, DDPen uses the same optical sapphire fiber for the distribution of radiation and the detection of tooth fluorescence without the interference of other optical fibers (Fig. 2).

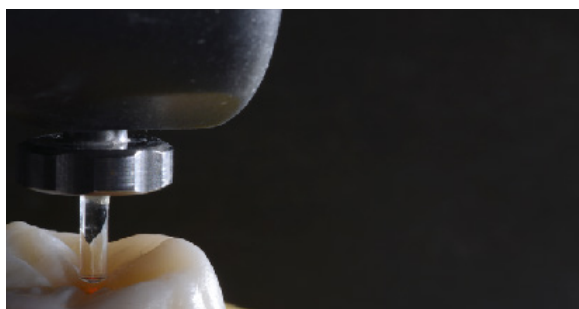


Figure 2. The DDPen tip over an occlusal surface of a molar.

Two different tips are available; a cylindrical one (CYL) with a diameter of 1.1 mm and a conical one (CON) with a diameter of 0.7mm. Although, the diameter of the CON is about 0.3mm thinner than that of DD and thus it would be expected to show better accuracy on pits and fissures, it seems that there is no significant difference between them⁴⁰ (Fig. 3).



Figure 3. The different tips of the DDPen.

3.2.1. Accuracy and repeatability of DDPen

Lussi et al.⁴⁰ compared in vitro the accuracy of caries detection by DD and DDPen. In their study, 119 third molars, kept in frozen state at -20°C, were examined. DDPen showed higher specificity (0.71 to 0.91) compared to the DD (0.69-0.79), but relatively lower sensitivity (0.78 to 0.91) against the latter (0.81 to 0.96).

The main limitation of the study is that only third of the molars were used, whose occlusal surface varies considerably in different individuals as compared to other posterior teeth. Kuhnisch et al.⁴¹ found that the reproducibility of DD of the same examiner (0.89) was similar to that of DDPen (0.88), while between different examiners reliability (0.86) was noted.

Sinanoglou et al.⁴² evaluated in vivo the occlusal surfaces of 217 permanent molars and premolars, comparing the visual observation (ICDASII), DDPen and bitewing radiography.

One week after the first measurements, the patients were invited for re-examination and 82 teeth were reassessed with the above-mentioned techniques. Only the teeth with dentine caries were examined (64 of 227) and the clinical depth of the lesion was measured.

The reliability of DDPen was moderate to good, with AUC 0.55-0.64, but noticeably inferior in contrast to that of visual observation (AUC 0.71-0.76) that reached higher specificity values than sensitivity. At this point, it should be mentioned that the results of the evaluation for visual observation could have been affected by the subjective skills and the level of the examiner's acquaintance with the device.¹⁵

Moreover, the device detection capability was better for dentin caries (D3), a finding supported by many other studies.^{14,15,43} The reproducibility for DDPen between different examiners (0.61, 0.65) and the same one (0.59, 0.65) was relatively low (16.42).

It is worth noting that in the study by Seremidi et al.¹⁷ the teeth were stored in tap water for a long time, which is likely to have an impact on the fluorescence levels of the teeth.

The study by Achilleos et al.⁴³ revealed low sensitivity values (0.66-0.75) for DDPen, which may be attributed to the fact that the study was focused on the D1 level, where the performance of this device is reduced compared to the D3 level. Additionally, the relatively small number of samples³⁸ and the only one week period among the two measurements were reported as limitations of this study.

Mortensen et al.,⁴⁴ focusing on the level of D3, showed high repeatability for DDPen between different examiners (0.98). For COV=40, there was a very high specificity (0.97) but very low sensitivity (0.07). The authors support the idea that if the manufacturer's COV are applied in clinical practice, there will be a significant reduction of overtreatment, but also the detection of caries in D3 will be very low.

4. Secondary Caries detection with DD and DDPen devices

There are not many studies evaluating the detection capability of DD and DDPen for secondary caries, reported exclusively on the occlusal surfaces of permanent dentition. In a 2014 study, four examiners with different clinical and dental experience reviewed 60 posterior teeth restored with composite resin, by visual observation (Ekstrand criteria) and DDPen device. The reproducibility among the different examiners was very high (0.954). The researchers concluded that DDPen is a reliable method for secondary caries detection and should be combined with the visual observation for the correct diagnosis of secondary caries.⁴⁵

Kositbowornchai et al.⁴⁶ investigated the detection capability of DD, under occlusal composite restorations, rather than tooth-resin interface. From the 100 teeth examined, only half were decayed and part of the caries was left on the pulpal wall. All the teeth were restored with composite resin (Z100 TM, 3 M, St. Paul, MN, USA) and the steps of etching and bonding were omitted. The repeatability values between different examiners (from 0.60 to 0.77) were lower than that of Hamishaki et al.,⁴⁵ while for the DD showed moderate sensitivity (0.74) and specificity (0.84). AUC value of the DD was moderate to good (0.79) and higher than that of digital radiography (0.65). Also there was no statistically significant difference in detection ($p>0.05$) between the two means. So it was suggested that the amount of fluorescence of composite resins does not affect the measurements of DD. However, the device is only recommended as an auxiliary means of caries detection. These results are similar to an in vitro study which examined the diagnostic capability of DD in 66 teeth with secondary caries, of which 48 were restored with amalgam and 18 with composite resin, where the sensibility was 0.77 and the specificity 0.81.⁴⁷ In another in vivo study, 30 molars were examined for the possible development of secondary caries, 12 months after the restoration with glass-ionomer cement and amalgam. The diagnostic methods were the DD and the radiographic control by using bitewing

radiographs. The statistically significant difference between the minerals of dentin presented in all evaluation periods ($p>0.001$) shows the highest value before the removal of caries (0.74) and the lowest value after 12 months (0.04). This study evaluated the DD measurements only through the demineralization rate of tooth without any disclosing measured values of DD or the results of sensitivity, specificity and reproducibility.⁴⁸ As a result, although DD and DDPen show accurate measurements with high repeatability for the detection of secondary caries, most authors are reluctant to their use compared to primary means such as the visual and radiographic examination proposing their combined use.

5. Conclusions

DD and DDPen are useful methods for occlusal caries detection. Their main advantages are the high reproducibility of measurements (>0.90), the ease of handling, the quantification of the carious lesions and the monitoring ability. However, they present significant limitations, such as the relatively low specificity for enamel lesions, the necessity of absence of stains, plaque and pastes during measurements and the absence of a single, clinically functional calibration value (COV). These limitations support the view that these means are to be used as auxiliary in detecting or monitoring caries lesions of questionable activity. Ideally, all optical and digital caries detection methods should have sensitivity, specificity, accuracy, repeatability, easiness in handling and access to all tooth surfaces. Nowadays, under the scope of the minimally invasive dentistry, it seems necessary for professionals to know and use both traditional and newer methods for incipient caries' detection in order to avoid overtreatment. As in vivo and in vitro data are based on methodological limitations, further studies should be conducted estimating the previous limitations and proceed with a more accurate evaluation of the specific devices.

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Andreas SPAVERAS

Dentist, DMD, Postgraduate Student
Department of Operative Dentistry

Dental School, National and Kapodistrian University of Athens, Athens, Greece



CV

Dr Andreas Spaveras received his degree in dentistry (DMD) in 2013 from the Semmelweis University of Budapest, Hungary. Currently, he is a second year postgraduate student (MSc) at the Operative Department of the National and Kapodistrian University of Athens, Greece. He is a member of numerous dental study clubs such as the International Team for Implantology - ITI and has published several scientific articles. He is an enthusiast of esthetic dentistry and photography.

Questions

Hidden caries are predominantly found in:

- a. Incisors;
- b. Canines;
- c. Premolars;
- d. Molars.

The caries diagnosis in everyday clinical practice is based on:

- a. Visual inspection;
- b. Laser fluorescence;
- c. Visible spectrum fluorescence;
- d. Infrared radiation.

The most appropriate wavelength for the detection of incipient caries by laser fluorescence is:

- a. 337 nm;
- b. 488 nm;
- c. 515 nm;
- d. 633 nm.

Which are the most appropriate Cut-Off Values of the DIAGNOdent for dentin caries:

- a. 0-13;
- b. 14-20;
- c. 21-29;
- d. 20-29.