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ORIGINAL ARTICLE

In vivo evaluation of laser fluorescence performance using different cut-off limits for occlusal caries detection

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Abstract The aim of this in vivo study was to evaluate the performance of laser fluorescence (LF) comparing different cut-off limits for occlusal caries detection. One hundred and thirty first permanent molars were selected. Visual examination and LF assessments were performed independently. The extent of caries was assessed after operative intervention. New cut-off limits were established and compared with those proposed by the manufacturer and by Lussi et al. (Eur J Oral Sci 109:14–19, 2001). Similar sensitivity and higher specificity was found at D_2 (considering as disease only dentin caries) when the LF cut-off limits proposed by Lussi et al. and the new one were compared. At the D_3 threshold (considering as disease only deep dentin caries), no statistically significant difference among the cut-off limits for sensitivity was found. However, the new cut-off limits showed higher specificity. The LF device provided good ability to detect dentin caries lesions. Furthermore, the new cut-off limits and the values proposed by Lussi et al. could be suggested for the in vivo detection of occlusal caries.

Keywords Occlusal caries · DIAGNOdent · Laser fluorescence · In vivo

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Introduction

Caries detection is a difficult task, since there may be caries lesions involving dentin beneath seemingly intact surfaces [1]. As the prevalence of occlusal caries lesions has increased, a clear detection of non-cavitated lesions by the clinician, based on the progression and clinical features of the caries lesions, has become complicated [2, 3]. Therefore, several studies have been performed in an attempt to establish the most accurate method for the detection of enamel and dentin caries, and, consequently, limiting the treatment to preventive and non-invasive procedures.

As the conventional methods for occlusal caries detection present high specificity and poor sensitivity [1], new methods have been developed and investigated in order to detect initial stages of mineral loss [4], such as electrical conductance measurement (ECM), digital fiber-optic transillumination (DIFOTI), quantitative light-induced fluorescence (QLF) and laser fluorescence (LF).

The LF device (DIAGNOdent 2095, KaVo, Biberach, Germany) is able to capture the fluorescence emitted from bacterial porphyrins and other chromophores when the teeth are stimulated by its diode laser with a wavelength of 655 nm [5, 6]. This device has been used to detect and quantify the level of mineral loss [1, 7]. The changes in the fluorescence intensity are numerically quantified and translated to values ranging from 0 to 99, according to the lesion's depth, which can then be used to help clinicians in deciding whether a tooth should be restored [8].

The clinical performance of the LF device is related to the cut-off limits used in the clinical practice that helps the clinician to define the better treatment. Several cut-off limits have been suggested, not only by manufacturers but also by in vivo [1] and in vitro [9–12] studies, but the conflicting information among them complicates the clinician's treatment decision. Therefore, additional clinical studies are necessary to determine the most appropriate cut-off limits for daily use in clinical practice.

The clinical studies evaluating the effectiveness of LF in detecting caries lesions have suggested its combination with other methods, as LF itself can lead to a large number of false-positive results [13–17]. These deficiencies, as reported in clinical studies, have led to many recommendations for further research [18].

Therefore, the aim of this study was to evaluate in vivo LF performance, comparing different cut-off limits for occlusal caries detection.

Materials and methods

Sample selection

This study was conducted in accordance with the declaration of Helsinki, and it was approved by a research ethics committee. Signed and informed consent was obtained from the parents or guardians of all volunteer subjects before the start of examination.

Thirty-five patients aged between 7 years and 12 years were involved in this study. One occlusal site per tooth was selected from 130 first permanent molars with macroscopically intact surfaces, varying from sound to different degrees of non-cavitated caries lesions. Teeth with caries lesions of approximal, buccal or lingual surfaces, fillings, fissure sealants, hypoplasia, fissure stain, orthodontic bands and teeth in eruption checked by full occlusion were excluded.

All occlusal surfaces were cleaned with pumice slurry and extensively washed with water for 10 s [19]. Before the start of examinations, the sites were examined by a dentist, and the teeth were drawn to aid the other examiners. Examinations were performed by three experienced dentists (I, II and III) trained with a tutorial regarding techniques and problems relating to the detection of occlusal caries.

Visual examination

Visual examination with patients positioned in a dental chair was performed by examiner I, after the teeth had been cleaned, using a dental light, 3-in-1 air syringe and a plane buccal mirror, according to the criteria proposed by Ekstrand et al. [20] and shown in Table 1.

Table 1 Visual examination and clinical interpretation

Score	Interpretation	Visual examination
0	Sound	No or slight change in enamel after prolonged air-drying (>5 s)
1	Caries lesion in enamel	Opacity or discoloration hardly visible on wet surface but distinctly visible after air-drying; opacity or discoloration distinctly visible without air-drying
2	Caries lesion in the outer half of the dentin	Localized enamel breakdown in opaque or discolored enamel and/or grayish discoloration from the underlying dentine
3	Caries lesion in the inner half of the dentin	Cavitation in opaque or discolored enamel exposing dentine

LF assessments

The LF (DIAGNOdent 2095, KaVo) was measured by examiner II after calibration on a ceramic standard using a fiber-optic conical tip (tip A), which had been specifically designed by the manufacturer for the detection of occlusal caries. This tip is made of a fiber rod consisting of a bundle of singles fibers, each with a diameter of 40 µm [12]. The fluorescence of a sound spot on the cuspal area of the buccal surface was recorded for each tooth (zero value) in order to provide us with a baseline value for that tooth. Sites were assessed under cotton roll isolation and after briefly being air-dried with a 3-in-1 syringe. The tip was positioned perpendicular to the test site and rotated around its long axis, according to the manufacturer's instructions. The highest LF reading was recorded, and the zero value was subtracted from this value [12].

Validation

The decision on how to treat each tooth was based on the visual and radiographic examinations, since fluorescence values were not previously known for in vivo measurements [1]. Recent bitewing radiographs were examined by an independent experienced dentist to determine the presence of radiolucencies in dentine on a black-lit screen. When radiolucencies were detected radiographically, and clinical alterations suggesting caries lesions were observed, the dentist decided to open the occlusal fissures [1, 21].

The test sites with operative intervention indicated (89) were drilled by examiner III, respecting the philosophy of conservative and minimal cavity preparation. Lesion extent was determined after its removal, an explorer being used to check changes in color and texture to differentiate carious from sound dentine. To quantify the extent of the lesion, we used a probe with a 2 mm graduation for measuring the distance between the cavity floor and the outer enamel margin of the cavity [14]. Validation rates were attributed according to Lussi et al. [1] as follows: sound (0), enamel caries (1), caries lesion in outer half of the dentin (2) and caries lesion in the inner half of the dentin (3). After a rubber dam had been placed, the cavities were filled with the appropriate restorative material (light-cured composite, bonded amalgam, flowable resin composite, resin-modified glass-ionomer cements) according to the patients' risks of caries and the extents of the cavities.

The sound sites were coded, after being carefully dried and visually examined, as having absolutely no signs of caries, as demineralized fissures, no stains in the fissure and no abnormal radiolucencies on bitewing radiographs [1].

Statistical analysis

New cut-off limits for the LF device were determined in a way that enabled the highest sum of specificity and sensitivity by receiver operating characteristic (ROC) analysis at each threshold (MedCalc version 19.3.0.0, Mariakerke, Belgium). The area under the ROC curve (A_z) reflected the diagnostic performance of the laser fluorescence method, and an A_z value near 1 expressed an excellent accuracy [14].

We assessed the LF performance, using the cut-off limits proposed by: (A) the manufacturer [22], 0–4, sound; 5–10, enamel caries; 11–20, >20, dentin caries; (B) an in vivo study [1], 0–13, sound; 14–20, enamel caries; 21–29, caries in dentin–enamel junction; >29, dentin caries; and (C) the new cut-offs obtained from the ROC curve analysis.

Sensitivity, specificity and accuracy for the LF device were calculated for the D_2 threshold (considering as disease both gold-standard scores 2 and 3) and the D_3 threshold (considering as disease only gold-standard score 3) for each LF cut-off limit described earlier. We compared the performances of the different LF cut-off limits, using the McNemar test at the 5% significance level.

Results

In the 35 patients, 130 sites in the first permanent molars were examined visually and by LF device. Determination of the extent of caries lesions showed enamel caries in 20 sites, superficial dentinal caries in 51 sites and deep dentinal caries in 18 sites. Forty-one sites were free of caries, showing no discoloration, opacities, staining, or any signs of caries clinically or on radiographic examination.

ROC curves were plotted for the LF measurements using lesion extent as validation to determine the best cut-off limits. Highest specificity and sensitivity for the D_1 threshold (considering as disease gold-standard scores 1, 2 and 3) were found with a value of 14. This value was 21 for D_2 and 37 for D_3 thresholds. The A_z value at D_3 (0.93) was higher than that at D_2 (0.81) and at D_1 (0.72), showing the great accuracy of the method (Fig. 1). Based on the results, the best cut-off limits obtained by ROC curves are shown in Table 2.

Table 3 presents the sensitivity, specificity and accuracy of the LF device according to the recommended LF cut-off limits by KaVo [22], by Lussi et al. [1], and by the new cut-off limits at the D_2 and D_3 thresholds. At the D_2 threshold the McNemar test showed similar sensitivity and higher specificity when the LF cut-off limits proposed by Lussi et al. [1] and the new ones were compared. At the D_3 threshold no statistically significant difference among the cut-off limits for sensitivity was found; however, the new cut-off limits showed higher specificity. The accuracy at the D_2 level was similar, when we compared the cut-off limits proposed by Lussi et al. [1] and the new one. At the D_3 level the new cut-off limits presented higher accuracy than the cut-off limits proposed by the manufacturer [22] and by Lussi et al. [1].

Visual examination showed low sensitivity (0.45) and high specificity (0.89) for the D_2 level; however, this method was not able to detect any deep dentin caries lesions in this study.

Discussion

An LF device is an adjunct tool for dental caries detection, which has been used for occlusal and smooth surfaces and has shown good reproducibility and accuracy [9, 23, 24].

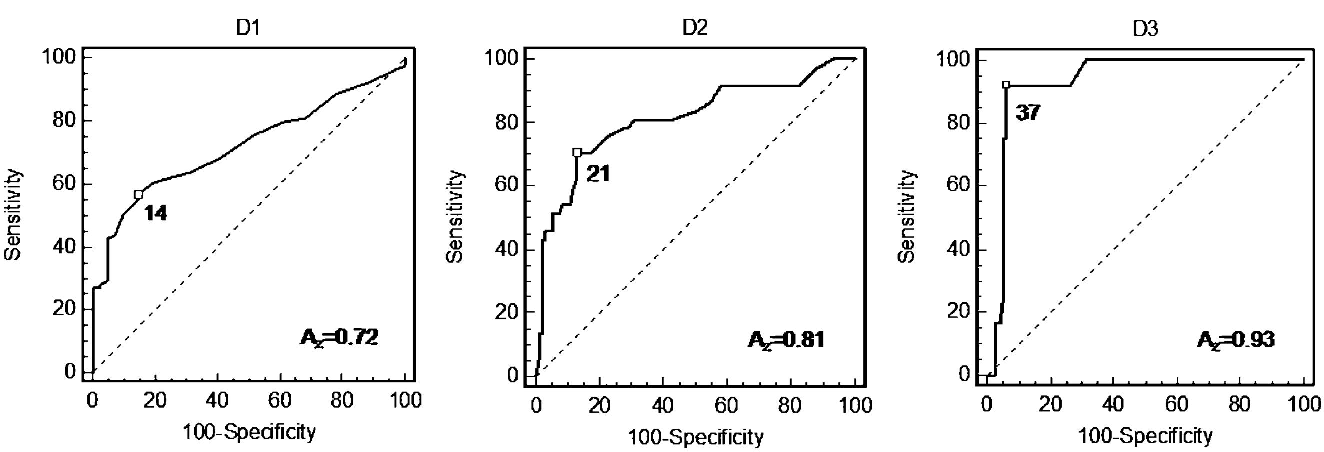

Fig. 1 ROC curves for the LF device at different thresholds (D_1, D_2 and D_3)

Table 2 Optimal cut-off limits of the LF device to detect in vivo occlusal caries lesion

New cut-off limits	Clinical lesion depth
0–14	Sound
15–21	Enamel lesions
22–37	Caries lesion in the outer half of the dentin
>38	Caries lesion in the inner half of the dentin

LF performance is dependent on the cut-off limits. Different cut-off limits are proposed by the manufacturer and by in vitro and in vivo studies, which may explain the diversity in results found throughout the literature, as there is great variation regarding adopted cut-off limits [15], confounding the clinicians in deciding the best treatment in daily practice [14]. In most cases the values determined through in vitro investigations were lower than values obtained in clinical studies [1, 24], so the use of cut-off limits obtained in in vitro studies cannot be extrapolated to the clinical situation. Also, some authors have shown that the storage solutions for teeth conservation, such as buffered formalin, chloramines and thymol-saturated saline solution, may influence LF measurements [10, 25]. However, the difference in cut-off limits observed in our study is probably related to the clinical conditions.

Besides the differences in cut-off limits of the LF device, other factors can affect the readings, which may compromise its performance and induce under- or over-treatment. It is known that the presence of bacterial plaque, stains, calculus, hypomineralization, restorative material and residual material such as pastes, powders or gels from the cleaning procedures may emit some fluorescence and lead to false-positive results [1, 7, 9, 10, 14, 19, 26]. In our clinical study, factors such as calculus, plaque and extrinsic stains in the fissures were controlled to provide reliability of the results, but it cannot be excluded that these factors are completely eliminated under clinical conditions [14].

The great difficulty in evaluating a detection method in a clinical study is that there is not a histological “gold standard” (due to ethical reasons) and the lesion’s depth may be questionable [7, 21]. In our study validation ratings were obtained only in carious sites with operative intervention indicated by visual and radiographic examinations. Preparation of cavities followed the philosophy of minimally invasive dentistry [27]; fissure opening revealed that lesion depth was commonly deeper than that revealed by visual and radiographic examinations [14]. It was possible only to distinguish superficial from deep dentin caries lesions, since this differentiation in enamel is very difficult under clinical conditions [1]. Sites detected as sound or as enamel caries could not be validated by invasive measures on ethical grounds. To overcome this problem “construct validity” could be used [28], which is associated with caries activity. In our study, the non-validated sound sites were included to achieve superior data for the performance of the method, as suggested by Heinrich-Weltzien et al. [14].

Optimal cut-off limits were obtained in our study by our determining the maximum sum of specificity and sensitivity values as a function of various maximum readings of the LF device (Table 2). This procedure was used because few cut-off limits exist for the application of an LF device on patients. For this reason the LF readings were not used to decide if a tooth had to be drilled [1]. The area under the ROC curve (Fig. 1) showed that the A_z value at D_3 (0.93) was higher than at D_2 (0.81) and at D_1 (0.72). Heirinch-Weltzien et al. [14] found high A_z values for D_2 (0.90) and D_3 (0.83) in a clinical situation. However, Verdonschot et al. [29] showed a lower value (0.61).

Some studies have shown that the LF device seems to be unsuitable for the initial detection of caries lesions [9, 30] but is more effective in recognizing caries lesions in dentin [1, 13–15, 18, 31]. Considering only dentin lesions (D_2 threshold) sensitivity was similar (0.70–0.81) for LF cut-off limits tested and specificity was higher for Lussi et al. [1] cut-off limits (0.86) and the new one (0.87), with no statistical differences between them. Rocha et al. [15] showed similar results for dentin caries detection with an LF device (sensitivity was 0.73 and specificity was 0.95); however, Heinrich-Weltzien et al. [14] showed higher values for sensitivity (0.95) and lower values for specificity (0.58). In our study, the optimal cut-off limits for dentin caries detection (>21) agree with the results of other

Table 3 Sensitivity, specificity and accuracy for LF cut-off limits

LF cut-off Limits	Sensitivity		Specificity		Accuracy	
	D_2	D_3	D_2	D_3	D_2	D_3
Lussi et al. [1]	0.70^a	0.92^a	0.86^a	0.88^a	0.81^a	0.88^a
KaVo [22]	0.81^a	0.92^a	0.57^b	0.76^b	0.64^b	0.77^b
New cut-off	0.70^a	0.92^a	0.87^a	0.94^c	0.82^a	0.94^c

D_2: 0–1=sound, 2–3=decayed
D_3: 0–2=sound, 3=decayed
Different superscript letters show differences in statistical significance within the same column ($P<0.05$)

clinical studies [1, 14]. As a consequence, this new approach provides more confidence in monitoring enamel lesions and in indicating the appropriate preventive or operative treatment.

Visual examination was found not to be a good method to detect deep dentinal caries, as reported in other studies [17, 32]. When traditional diagnostic methods are applied during clinical practice, many caries lesions are not detected or are wrongly diagnosed as caries of the enamel, allowing underlying dentinal lesions to progress unchecked [21]. For the detection of deep dentin lesions, the best LF performance was determined for cut-off limits >37. LF showed excellent sensibility and specificity for the D_3 threshold at all cut-off limits. Krause et al. [33], in a clinical study comparing the LF device and the LF pen, showed a sensitivity of 0.92, specificity of 0.53, and optimal cut-off of 36 to detect deep dentin caries for the LF device. Heinrich-Weltzien et al. [14] reported a similar cut-off limit (>37) and high values for sensitivity (0.84) and lower values for specificity (0.70). However, Anttonen et al. [13] showed high values of sensitivity (0.92) and specificity (0.82), and, at an LF value of approximately 30, an operative intervention should be considered.

Our study has demonstrated that visual examination provides low sensitivity for D_2 and D_3 thresholds; however, the LF device showed good to excellent sensitivity, especially when the cut-off limits proposed by Lussi et al. [1] and the new one were used. Most of the authors recommend using the LF device as a useful adjunct in the decision-making process in cases of doubt after visual examination [1, 14, 15, 32–35].

In conclusion, this study demonstrated that the LF device provided good ability to detect dentin caries lesions. Furthermore, the new cut-off limits, as well as the values proposed by Lussi et al. [1], could be suggested for the in vivo detection of occlusal caries, but these limits are not fixed and must be carefully interpreted. Measurements with the LF device should be considered as a second opinion only, since the nature of the subject's tooth may still remain unclear in a clinical situation. Further in vivo studies using deciduous and permanent teeth should be made.

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