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Detection of Approximal Caries with a New Laser Fluorescence Device

A. Lussi[a] A. Hack[b] I. Hug[a] H. Heckenberger[b] B. Megert[a] H. Stich[a]

[a]Department of Operative, Preventive and Paediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland; [b]KaVo Dental GmbH, Biberach, Germany

Key Words

Approximal caries · Bitewing radiography · Caries detection · DIAGNOdent · DIAGNOdent pen · Laser fluorescence

Abstract

The laser device DIAGNOdent developed for the detection of occlusal caries has limited value on approximal surfaces. The aim of this study was to develop and to test a new laser fluorescence (LF) device for the detection of approximal caries. Light with a wavelength of 655 nm was transported to the approximal surface using two different sapphire fibre tips. Seventy-five teeth were selected from a pool of extracted permanent human molars, frozen at –20°C until use. Before being measured, they were defrosted, cleaned and calculus was removed with a scaler. The molars were set in blocks simulating the contact area of adults. Bitewing radiographs were obtained using Kodak Insight films. After two independent assessments with the new LF device, the teeth were histologically prepared, and assessed for caries extension. Using the laser, specificity values for D_1 threshold (outer half of enamel), D_2 threshold (inner half of enamel), D_3 threshold (dentine) ranged between 0.81 and 0.93, sensitivity between 0.84 and 0.92 with no difference between the two tips. Bitewing radiography showed an inferior performance compared to LF ($p < 0.05$). Intraexaminer reproducibility was high (kappa > 0.74). The new LF system might be a useful additional tool in detecting approximal caries. Because of its good reproducibility, it could be used to monitor caries regression or progression on approximal surfaces.

The diagnosis of dental caries, including its detection, is difficult. Clinical methods have been improved and devices were introduced in the last years designed to support dentists in the diagnostic process [Ekstrand, 2004; Wenzel, 2004]. It is possible to detect caries on occlusal surfaces by detecting the emitted fluorescence after application of pulsed red light [laser fluorescence (LF)]. Several studies have investigated a device (DIAGNOdent, KaVo, Biberach, Germany) based on this principle on occlusal and smooth surface caries [reviewed by Bader and Shugars, 2004]. There were some attempts to use the device for approximal surfaces. Some potential was found to use it on this site if an occlusal cavity was present [Iwami et al., 2003]. Direct detection on approximal surfaces of molars or premolars was not possible as there was no device available equipped with a tip able to penetrate the proximal space.

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Prof. Dr. A. Lussi
Klinik für Zahnerhaltung
Freiburgstrasse 7
CH–3010 Bern (Switzerland)
Tel. +41 31 632 25 10, Fax +41 31 632 98 75, E-Mail adrian.lussi@zmk.unibe.ch

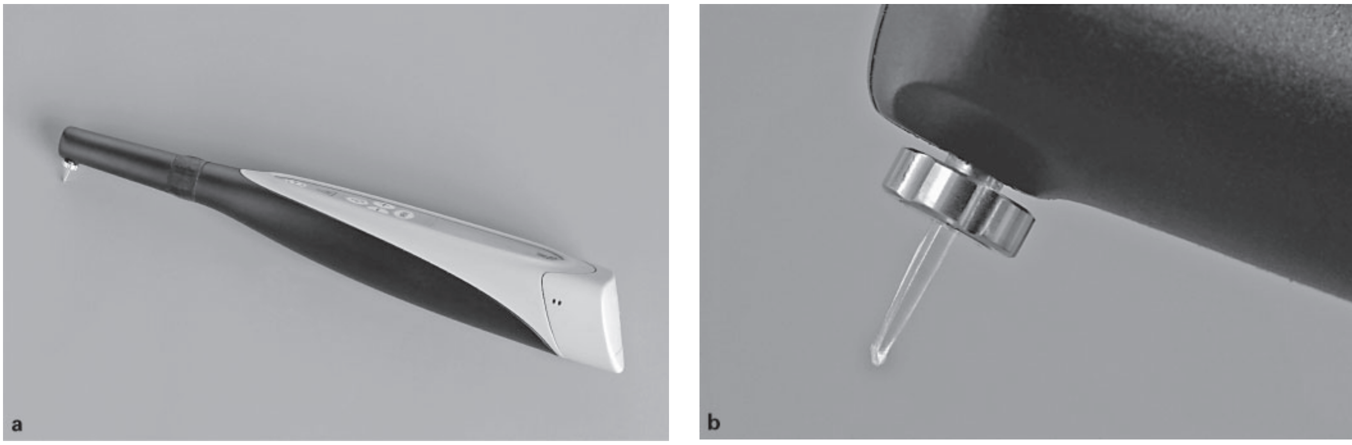

Fig. 1. **a** LFpen with the tip for measurement of the fluorescence on approximal surfaces. **b** Close-up of the tip and the knob for turning it around.

The aim of this study was to develop and test a new laser device with the ability to measure fluorescence on approximal surfaces.

Materials and Methods

Description of the LF Device

The mode of function of the commercially available LF system (LFpen; DIAGNOdent pen, KaVo, Biberach, Germany; fig. 1, 2) used in this study is based on the fact that the caries-induced changes in teeth lead to increased fluorescence at specific excitation wavelengths [Sundström et. al., 1985]. As with the first LF system [Lussi et al., 1999], the new device emits red light with a wavelength of 655 nm. A filter blocking light below 665 nm eliminates reflected light and ambient light. A photodetector (fig. 2, No. 1) measures the amount of fluorescent light passing through the filter and a digital display shows both a real-time and a maximum value. To enable the user to place the probe on mesial and distal surfaces at the facial and oral sides of front and posterior teeth, the tip must be rotatable around its long axis. A knob (fig. 1, 2) allows to turn around the tip and a red point on it indicates the light direction. For the probe tip a wedge-shaped (WDG) solid single sapphire fibre (fig. 2, No. 4, 8) was chosen, as this allowed the end of the tip to be formed with a prismatic shape (fig. 2, No. 7). This surface served as a deflector directing the beam of excitation and detection laterally to the longitudinal axis of the tip (fig. 2, No. 9). Inside the solid fibre tip the excitation *and* fluorescence followed the same optical path of propagation in opposite directions. The cylindrical shape at the other end of the tip allowed coupling of the light in and out of the probe tip, in a way which enabled the user to rotate the tip without changing the conditions for optical transmission (first interface; fig. 2, No. 10).

A fibre bundle (fig. 2, No. 3) consisting of a large quantity of 40-μm single fibres was used to transmit the light around the tight bend which was needed to keep the height of the instrument small enough to access the oral cavity. At the second interface (fig. 2, No. 11), the beam propagating from the fibre bundle was split into two paths. One path transferred the excitation light through a single fibre. The other path was composed of a set of 9 single detection fibres (fig. 2, No. 2). The excitation light (fig. 2, No. 5), transmitted through the separate solid single (excitation) fibre, was coupled to a laser diode (fig. 2, No. 6) by means of a focusing lens. At the interface to the fibre bundle, these fibres were placed circumferentially around the central excitation fibre. They were glued together and guided the fluorescence to the photodetector (fig. 2, No. 1). To separate the fluorescence light from the excitation light, a fluorescence filter was placed in the optical path in front of the photodetector.

Set-Up

From a pool of extracted permanent human molars, frozen at –20°C until use, 75 molars (with 150 approximal surfaces) with non-cavitated surfaces were selected. Preliminary experiments showed that storage under this condition does not change red fluorescence significantly [Francescut et al., in press]. All teeth had been extracted by dental practitioners in Switzerland (no water fluoridation, 250 ppm F^- in table salt). Prior to the extraction, the adult patients were informed about the use of their teeth for research purposes and consent was obtained. After the teeth had been defrosted, they were cleaned in total for 15 s with water and then for 10 s with Prophyflex and sodium bicarbonate (KaVo). Calculus on approximal surfaces was removed with a scaler. Photographs of the occlusal and approximal surfaces were taken (magnification ×2.8) to identify the sites to be examined and later histologically prepared. The tooth under study was then placed in-between two teeth mannequin. The roots were embedded in composite to arrange these three teeth in a manner that simulated contact points of adult teeth. Soft tissue was not simulated. Before being measured, the whole block was stored under 100% humidity.

Dental bitewing radiographs were taken using Kodak Insight films (22 × 35 mm, Kodak, Rochester, Minn., USA). The X-ray machine (HDX Dental EZ, USA) was set to 65 kV and 7 mA and an exposure time of 0.14 s was used.

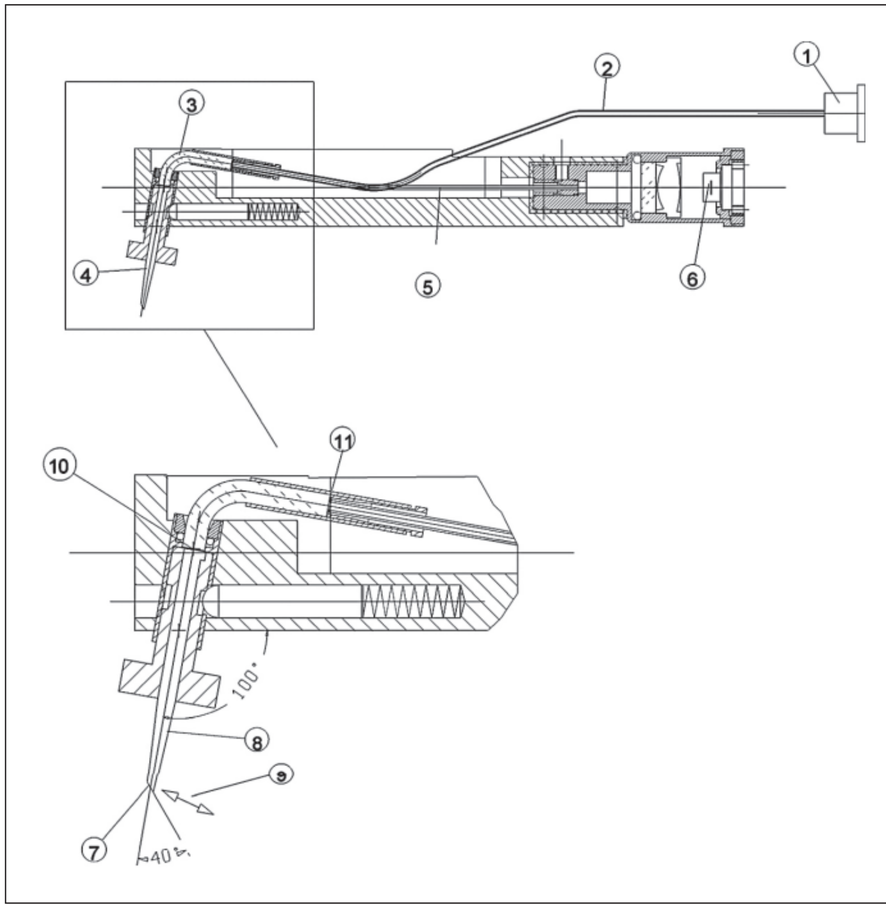

Fig. 2. Sectional view of the LFpen for the detection of approximal caries: (1) photodetector, (2) detection fibre, (3) fibre bundle, (4) solid fibre, (5) excitation fibre, (6) laser diode, (7) prism, (8) approximal tip, (9) direction of the light, (10) first interface, (11 second interface.

Assessments with the New LF Device and Bitewing Radiography

The measurements with the LFpen were carried out as follows: first, the device was calibrated for every tooth using a ceramic reference. The fluorescence of a sound spot on the coronal part of the facial surface (zero value) was recorded. For the measurement, the tip of the device was moved from the facial side towards the other side underneath the contact area. The peak value was registered. The procedure was then repeated from the oral side. For each of the two tips, the higher peak value of the two measurements of an approximal site was taken for further analysis. For histological analysis, the spot with the higher peak value was marked on the photograph. Two sapphire fibre tips were used with the following dimensions: thickness: 0.4 mm; width: 1.1 mm (WDG) and 0.7 mm (tapered wedge-shaped, TWDG). To determine reproducibility, the measurements including the calibration procedure and measurement of the zero value were repeated by the same person and on the same day.

The bitewing radiographs were examined by 5 experienced dentists on a backlit screen using a dental X-ray viewer (X-Scope magnification ×2, Jordi, Münchenstein, Switzerland) to determine whether the surfaces under study showed: no radiolucency (D_0), radiolucency in the outer (D_1), inner half of enamel (D_2) or in dentine (D_3, D_4).

Validation

After the assessment of the teeth, they were ground longitudinally on a Knuth-Rotor polishing machine with silicon carbide paper of grain size 60 μm under constant tap water cooling. Progression of the grinding process was repeatedly checked under the microscope (magnification ×3.2). When the periphery of the test site was reached, papers of grain size 30, 18 and 10 μm were used. The surface was coloured with saturated rhodamine B (Fluka, Buchs, Switzerland) and the teeth were photographed (magnification ×3.2, ×6.4).

Statistical Analyses

For LFpen, as no interpretation of the scale was available, the cut-off limits were determined in a way that enabled highest sum of specificity and sensitivity [Lussi et al., 2001]. Specificity, sensitivity and likelihood ratios (LR^+) were calculated at the D_1, D_2 and D_3 levels for LF using the average value of the two (independent) measurements per surface. For bitewing radiography, the mean sensitivity, specificity and LR^+ of the participating dentists were calculated. Summarising the information obtained about sensitivity and specificity in one number, the LR^+ expresses how likely a positive test result is to come from teeth with approximal caries (at D_1–D_3 levels) as from teeth without caries. Tests results with higher LR^+ are better discriminators of disease than those with lower values [Sackett et al., 1991].

Comparison of the different methods applied on the same teeth was made using the McNemar χ^2 test. For multiple comparisons, the p values were corrected by the Bonferroni adjustment procedure. The level of significance was set at $p \leq 0.05$. Cohen's unweighted kappa values were determined using the established cut-off levels for different caries states (SPSS 11.0, Chicago, Ill., USA). Kappa values above 0.75 denote excellent agreement [Fleiss, 1981]. Further, the intra-examiner reliability was assessed using the method described by Bland and Altman [1986]. The difference between the first and second measurements was plotted against their mean and the limits of agreement (mean difference ± 2 SD) were calculated [Bland and Altman, 1986].

Results

The histological examination of the 150 experimental sites revealed that 61 sites were caries free (D_0), 20 sites had caries extending up to halfway through the enamel (D_1), 32 sites had caries in the inner half of enamel (D_2) and 37 sites had caries in dentine (D_3, D_4).

The optimal cut-off limits for both tips of the laser device are shown in table 1. Specificity values ranged between 0.81 and 0.93, sensitivity between 0.84 and 0.92 using the LFpen (table 2). The McNemar χ^2 square test showed that there were no statistically significant differences between the two tips. Bitewing radiography showed overall a significantly lower performance ($p < 0.05$). The likelihood ratios for bitewing radiography were between 2.0 (D_1) and 4.2 (D_3), while for LFpen they were between 4.8 (D_3) and 13.3 (D_1).

The calculated kappa values (0.74 for WDG, 0.82 for TWDG) indicated a high reproducibility for both configurations. The averaged difference was –0.11 for WDG and –0.32 for TWDG. The limits of agreement were +16.4 and –16.6 for WDG and +12.9 and –13.5 for TWDG (fig. 3).

Table 1. Optimal cut-off values of the two tips

Histology	Wedge-shaped	Tapered wedge-shaped
D_0	0–6	0–9
D_1	6.1–9	9.1–13
D_2	9.1–15	13.1–19
D_3, D_4	>15	>22

Discussion

The present investigation has shown that the new LF device is capable of detecting decay on approximal surfaces with good accuracy. The original DIAGNOdent could not differentiate between sound occlusal surfaces and those with lesions in the outer half of enamel. The reason why this was possible on approximal surfaces is not clear but could be as follows. (1) The teeth in the present study were not stored in a solution and therefore the fluorescing molecules were not washed out. (2) The plaque composition on approximal surfaces is different from occlusal surfaces which could have some influence on the fluorescing molecules. When using the instrument, it is important to apply it on the oral and facial side of an approximal surface and to move it towards the other side underneath the contact point. This allows the dentist to search for the spot with the highest fluorescence. The good intra-examiner reproducibility should allow the device to be used for longitudinal monitoring of caries and, thus, also for assessing the outcome of preventive interventions. Its potential utility is to facilitate prevention-based management of dental caries, not merely as a device to aid in the location of dentinal lesions requiring fillings.

Table 2. Specificities, sensitivities and likelihood ratios for the detection of approximal caries

	Specificity			Sensitivity			Likelihood ratio		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
Bitewing radiography	0.67	0.81	0.89	0.68	0.46	0.45	2.0	2.4	4.2
DIAGNOdent *pen* (WDG)	0.92	0.89	0.82	0.88	0.87	0.89	10.8	7.9	5.1
DIAGNOdent *pen* (TWDG)	0.93	0.89	0.81	0.87	0.84	0.92	13.3	7.6	4.8

D_1: D_0 = sound, D_1–D_3 = decayed.
D_2: D_0, D_1 = sound, D_2, D_3 = decayed.
D_3: D_0–D_2 = sound, D_3 = decayed.

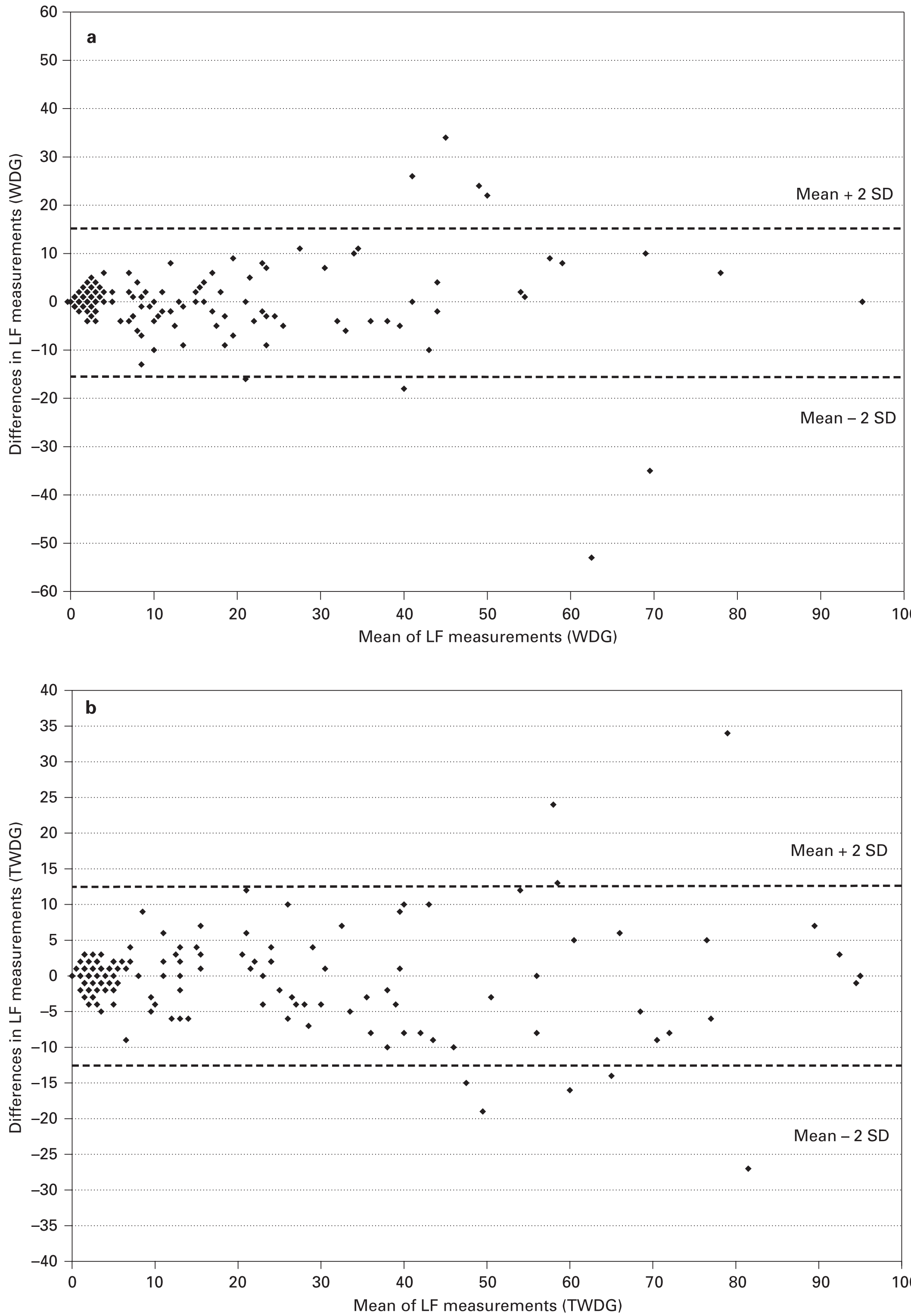

Fig. 3. The difference between fluorescence values of the first and second measurement plotted against their mean. Dashed lines = Mean difference ± 2 SD. **a** WDG tip. **b** TWDG tip.

Approximal caries lesions have traditionally been diagnosed by clinical inspection in combination with radiography. It is agreed in the literature that radiography is a more sensitive diagnostic method than clinical inspection for detecting approximal lesions in dentine [Wenzel, 2004]. However, there is some hesitation of the public and profession towards the unavoidable hazards of ionizing radiation. The advantage of the laser-based system could probably be a decrease of the amount of bitewing radiographs taken and the ability to use LF measurements more frequently at times between taking bitewing radiographs for monitoring caries regression or progression.

It is known from experience with the original DIAGNOdent that deposits like plaque or fluorescing dental materials, staining, calculus could give false-positive readings. Thorough cleaning is a prerequisite for every examiner for accurate inspection which must precede the use of LF. In our sample, the approximal surface quite often had spots of calculus, which would have given false positives if they had not been removed before.

The tips of the original DIAGNOdent designed for detection of occlusal caries were unable to penetrate far enough into the proximal space or to deflect the light laterally. The possibility of rotation around the long axis of the tip was a prerequisite to use it on mesial and distal approximal surfaces. Therefore, a new optical system for the probe had to be designed to enable the user to access the contact area close enough to capture fluorescence emerging from a carious approximal surface. A prismatic shape of the probe tip had the advantage to allow access to the approximal contact and to direct the excitation light laterally to the long axis of the tip. A red point on the knob indicated the light direction. The use of a single fibre allowed to shape the tip of the optical probe with a prismatic form at which the light is deflected by total reflection. Shaping the fibre bundle of the original DIAGNOdent accordingly would not deflect the beam in the desired manner as neighbouring fibres would absorb the light. Experiments with different angulations of the prism between 40° and 45° determined the appropriate angulation of 40° [unpubl. data] (fig. 2).

Both tips had a minimal thickness of 0.4 mm. Therefore, in vivo tight approximal contact areas are a problem which was not simulated in the present set-up. When tight contact points are present, separation of the teeth would increase accessibility. Detection of secondary caries in the approximal area should be easily possible as the margins of the restorations are often in an area with enough space between teeth. For both purposes, soft tissue will be touched during LF measurements. This should not be a problem as blood does not seem to interfere with them. Preliminary experiments showed no influence of the carious status of the adjacent tooth surface on the LF measurements. However, more investigations are needed to assess not only the influence of the caries status but also of fluorescing adjacent dental materials. An advantage of the new device is the possibility to use differently shaped tips for other purposes such as detection of occlusal caries, detection of caries remnants in a cavity or remnants of calculus in a periodontal pocket.

Earlier experiments in our laboratory showed that the fluorescence values and hence the cut-off values decreased when the teeth were stored in thymol, chloramine or formalin but remained stable when they were frozen during storage and were defrosted for fluorescence measurements [Francescut et al., in press]. This would mean that the cut-off assessed under a set-up as in our experiments could better resemble the in vivo situation. Nevertheless, caution is indicated before extrapolating these cut-off points into the clinical situation. Furthermore, the cut-off values of the original DIAGNOdent [Lussi et al., 2001] as well as of this LF device are not a fixed border but rather a range of LF values. The cut-off values found were based on histological evaluation where small penetration of the lesion into the dentine was assessed. Histological involvement of dentine should not, in any case, indicate immediate operative intervention. The decision triggering restorative treatment is dependent upon a range of other variables, such as the patient's case history, fluoride and dietary status, as well as perceived caries activity and the status of the surface.

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