

Comparison of two laser fluorescence devices for the detection of occlusal caries *in vivo*

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Laser fluorescence measurements have been shown to be well suited for caries diagnosis. The aim of this study was to compare two laser fluorescence devices and to correlate the respective values with the visual and radiographic assessment and with the extent of the carious lesion. Ninety-four clinically non-cavitated occlusal carious lesions in the premolars and molars of 82 patients were examined. Laser fluorescence values on the surface were measured with a conventional laser fluorescence system and a novel laser fluorescence pen device. When operative intervention at a site was indicated, the extent of caries was determined after its removal. Readings obtained with both systems were significantly different with an interdevice factor of 0.64. Sensitivity and specificity for operative care were 92.6% and 53.7%, respectively, for the conventional, and 88.9% and 53.7%, respectively, for the pen device. For both devices, a correlation between laser fluorescence values and the visual and radiographic assessment and with the extent of the lesion was shown. The study indicates that the novel laser fluorescence device seems to be suitable for occlusal caries diagnosis. However, proposed guidelines for the clinical use of laser fluorescence readings of the conventional device cannot be transferred to the novel pen system.

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Since the proportion of occlusal caries lesions in the prevalence of caries has increased (1), the importance of early occlusal caries diagnosis has grown (2). The commonly used diagnostic methods for fissure caries detection exhibit high specificity but low sensitivity (1, 3). To improve the accuracy of non-cavitated occlusal caries diagnosis, methods based on laser fluorescence have been developed and tested. The phenomenon of dental hard tissue fluorescence was first described more than 90 yr ago (4). On the basis of investigations that showed stronger fluorescence of carious lesions compared with healthy regions (5), a laser fluorescence device for caries detection (Diagnodent) was developed. With an excitation wavelength of 655 nm, the total intensity of the resulting fluorescence light correlates with the existence of carious lesions (6). The enhanced fluorescence radiation probably results from porphyrins and other chromophores (7, 8). Working in accordance with this principle, this laser fluorescence device can improve the diagnosis of so-called 'hidden caries'. Specifically, occlusal caries lesions in permanent and deciduous teeth under a clinically intact tooth surface can be detected. The Diagnodent device is easy to handle in general practice and the measurements offer the dentist the possibility of non-invasive caries detection. Several *in vitro* and *in vivo* studies have extensively investigated the performance of this laser fluorescence device for occlusal caries

detection (2, 9–13) and for assessment of complete caries removal (14).

Recently, a new laser fluorescence device was introduced, which allows both occlusal and approximal caries detection (15–17). Moreover, the manufacturer tried to build a hand-size version of the classical device. On the basis of the conventional Diagnodent device, new tips had to be developed as a result of the different architecture of the new system. Until now, this device has not been evaluated in clinical *in vivo* studies.

Hence, the aim of the present study was to compare the two laser fluorescence devices for caries diagnosis on occlusal surfaces *in vivo*, evaluating both sensitivity and specificity. We evaluated the hypothesis that the readings of the two diagnostic systems under study are closely related. Additionally, fluorescence values should be correlated to the visual and radiographic assessment and with the extent of the carious lesions. Guidelines available for the conventional device should be compared with the outcomes of the new system. Furthermore, the influence of the calibration mode of the measurement devices on laser fluorescence readings should be assessed.

Material and methods

After professional cleaning of the occlusal surfaces using a rotating soft rubber cup and plain water spray, clinical

Table 1
Criteria used for visual and radiographic examination (18)

Score	Visual	Radiographic
0	No or slight change in enamel after prolonged air-drying (> 5 s)	No radiolucency visible
1	Opacity or discoloration hardly visible on the wet enamel, but distinctly visible after air drying	Radiolucency visible in enamel
2	Opacity or discoloration in enamel distinctly visible without air drying	Radiolucency visible in dentine, but restricted to the outer third of dentine
3	Localized enamel breakdown in opaque or discolored enamel and/or greyish discoloration from the underlying dentine	Radiolucency extending to the middle third of dentine
4	Cavitation in opaque or discolored enamel exposing dentine	Radiolucency in the pulpal third of dentine

assessment was performed after briefly drying the teeth with air pressure. Cotton rolls were placed and, subsequently, visual inspection was performed with the aid of a light reflector using visual and radiographic criteria (18) (Table 1). Radiographic examination was performed of the evaluation of recent bitewing radiographs using an In Exam apparatus (60 kV, 07 mA, 0.27 s; KaVo, Biberach, Germany) with bitewing positioners (KerrHawe, Bioggio, Schweiz) and insight radiographic films (Kodak, Stuttgart, Germany). The radiographic appearance was evaluated on a lightening screen with a black viewing box to cut out extraneous light (Table 1).

In this study, only teeth with either non-cavitated occlusal carious lesions requiring operative intervention (score 3) or teeth where no or preventive treatment was indicated by visual examination and/or bitewing radiographs (scores 0, 1, or 2) were selected. Teeth with occlusal restorations, fissure sealants, fissures with obvious stains and calculus, hypoplastic tips, an advanced degree of fluorosis or frank occlusal cavitations (score 4) were excluded. According to these criteria, a total of 94 non-cavitated occlusal carious lesions in premolars and molars in 82 patients (48 female, 34 male) were included in this study. The patients' mean age was 36 ± 8 yr. All patients were informed about the study in advance and had given their informed consent to participate. The study was conducted in full accordance with declared ethical principles (Helsinki Declaration II) and had been approved by the local Ethics Committee.

Laser fluorescence examination and treatment procedures

Laser fluorescence assessment of the occlusal surfaces was performed using the conventional system and a new laser fluorescence system (Diagnodent and Diagnodent pen, respectively; KaVo). A comprehensive description of the physics of both devices has been described in detail previously (11,15,16). Measurements were taken under cotton roll isolation and after tooth drying with air pressure, after standard calibration using an appropriate ceramic touchstone according to the manufacturer's instructions. The indicated sites were measured by placing the probe tip perpendicular to the occlusal surface and by making a

rotational movement to ensure that fluorescence from the slopes of the fissure walls, where the carious process often begins, was registered. In addition, measurements were made after individual calibration: the fluorescence of a sound spot on the smooth enamel surface of the respective tooth was measured in order to provide a baseline value, according to the manufacturer's instructions. The maximum laser fluorescence reading on each measurement point was recorded. For each site, three measurements were performed and averaged for statistical purposes. The intervention cut-off for operative treatment was set at score 3 for visual and radiographic examination as therefore an advanced dentinal involvement of the carious lesion could be expected. When operative intervention at a site was performed, local anesthesia was given if required. Operative treatment was performed by a second investigator. Enamel margins were removed with diamond burs in a high-speed handpiece. Caries was excavated with a conventional steel round bur at a speed of 700 r.p.m. without water cooling. The endpoint of complete caries removal of the air-dried cavities was determined using a sharp explorer to differentiate carious from sound dentine (19); cavity preparation was considered complete when dentine was hard to a dental probe and the probe was capable of inducing a sharp sound. The extent of a carious lesion was classified as follows: superficial dentinal caries (D3) or advanced dentinal caries (D4) (20). Cavity extension between D3 and D4 lesions was differentiated by assessing the additional cavity depths after removal of the overlying enamel by comparing the clinical situation after caries removal with the dentine-enamel junction and average values for dentine thickness. A calibrated periodontal probe was used to evaluate the cavity depths. When the extension in dentine was more than 1 mm, the cavity was regarded as an advanced dentinal lesion. All teeth under study that were treated operatively were restored with an appropriate composite resin employing an adhesive bonding technique.

Statistical analysis

For statistical analysis, the normal distribution of the laser fluorescence values was analyzed with the Shapiro-Wilk test. As not all values were normally distributed, differences between the values with respect to the fluorescence devices and the calibration procedures were analyzed pairwise by means of a non-parametric test (Wilcoxon). Assessing the correlation between laser fluorescence values and the scores/extent of carious lesions, cross tabulation tables were computed and the non-parametric correlation coefficient eta was calculated, as nominal readings were compared with interval values. Diagnostic performance for occlusal caries detection was evaluated assessing the parameters sensitivity and specificity for score 3 lesions by calculating the respective receiver operating characteristic (ROC) curve. Cut-off limits were determined by performing Youden's index (21) for the highest sum of sensitivity and specificity, allowing the calculation of an interdevice factor. The significance level was set at $P < 0.05$. All calculations were performed with the statistical program SPSS 14.0 (SPSS, Chicago, IL, USA).

Results

In total, 55 premolars and 39 molars with macroscopically non-cavitated occlusal surfaces were investigated.

Table 2

Assessment (score 0–3) and validation (score 3) of occlusal surfaces

Occlusal surfaces assessed by different methods (n = 46, score 0–2)	
Lesions detected by clinical inspections only	44
Lesions detected radiographically only	0
Lesions detected by clinical inspection and radiography	2
Occlusal dentine lesions assessed by different methods (n = 48, score 3)	
Lesions detected by clinical inspections only	8
Lesions detected radiographically only	1
Lesions detected by clinical inspection and radiography	39
Validation of occlusal dentine lesions (score 3, n = 48)	
Superficial dentinal lesions	27
Deep dentinal lesions	21

Overall, 21 first, 18 second, and 0 third molars were included. After visual examination, 20 teeth were scored as 0, 26 teeth were scored as 1 or 2, and 48 teeth were scored as 3, whereas 27 teeth revealed superficial, and 21 teeth advanced, dentinal caries after operative care (Table 2). Disregarding the visual and/or radiographic criteria or depth of carious lesions, the overall laser fluorescence values measured with both systems were significantly different ($P < 0.05$, Wilcoxon, Fig. 1). For both devices, laser fluorescence readings of the occlusal reading point after standard calibration were significantly higher than values obtained after individual calibration ($P < 0.05$, Wilcoxon, Fig. 1), with a median difference of 5.5 units (laser fluorescence values [U]). Considering the different Ekstrand criteria and the caries extent, lower laser fluorescence values were obtained for teeth with a score of 0 and higher readings were observed for teeth with scores of 1 and 2 and dentinal carious lesions (Fig. 2). All respective eta-values were ≥ 0.81 , indicating a correlation between laser fluorescence values and the extent of caries. Sensitivity, specificity, cut-off

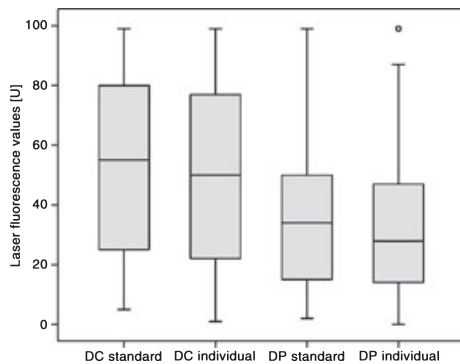


Fig. 1. Box plots for overall laser fluorescence values [U] of the conventional (DC) and the new Diagnodent (DP) instruments after standard and individual calibration (n = 94). Statistically significant differences were observed between the devices and the calibration procedures ($P < 0.05$, Wilcoxon). Box plots show median, first and third quartiles, and minimum and maximum values (whiskers). Outliers are marked as data points.

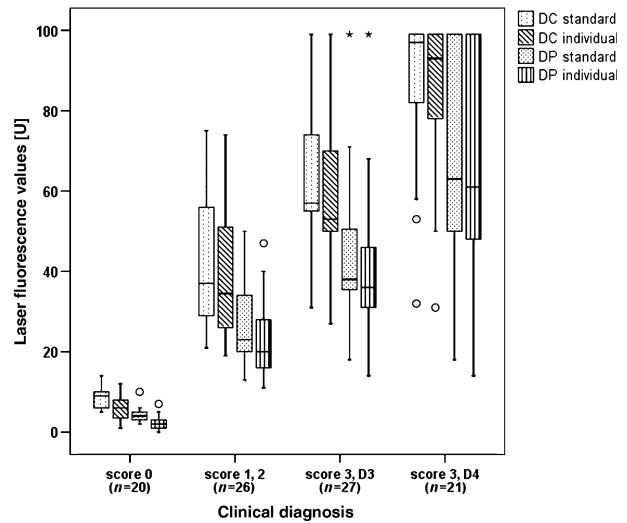


Fig. 2. Box plots for laser fluorescence values [U] depending on the visual assessment (score 0–2) and clinical caries extent after operative intervention (score 3) (n = 94). Readings of both systems correlate with the visual observation and with the extent of the carious lesion ($\eta \geq 0.81$). Box plots show median, first and third quartiles, and minimum and maximum values (whiskers). Outliers are marked as data points and asterisks.

Table 3

Performance of the diagnostic devices in diagnosing occlusal caries lesions for score 3 lesions

	Sensitivity (%)	Specificity (%)	Cut-off value	Az
Diagnodent	92.6	53.7	36	0.69
Diagnodent Pen	88.9	53.7	23	0.67

values, and Az values (area under the ROC curve) are given in Table 3. The interdevice comparison revealed that the difference between the readings of the pen and the conventional device was 0.64.

Discussion

The conventional laser fluorescence device (Diagnodent) lacks an efficient working tip for approximal caries detection. As a result, the manufacturer tried to combine the development of a hand-size detection system with an interproximal working tip. Unfortunately, our own unpublished data and clinical observations showed that the values obtained with both devices are not exactly the same. Thus, it is important to assess the new system's characteristics and compare the results with the findings of the conventional device. Therefore, one aim of the present study was to compare the outcomes of the two systems for occlusal caries detection. Data of the present *in vivo* study showed that the fluorescence values obtained from both devices were not the same. The fluorescence values obtained using the new laser device were significantly lower than those obtained using the

conventional system. Possible reasons for this finding could be the different diameters of the tips and the different optic pathways for the excitation light and the emitted fluorescence light. In contrast to the conventional system, inside the solid fiber tip of the new device the excitation and fluorescence light followed the same optical path in opposite directions. Hence, the intensity of light reaching the tooth might be reduced and the resultant fluorescent light might also be reduced in intensity on its way back to the laser fluorescence device. The data of the present study are in contrast to a recently published *in vitro* study comparing the old and the new laser fluorescence device by histological examination of teeth that showed no statistically significant difference between the systems (15). However, calculated optimal cut-off levels for different caries status tended to lower values for the new device compared with the old one (15). Concerning the calibration procedure, the results of the present study showed that median laser fluorescence values obtained with the standard calibrated laser fluorescence system were approximately 5 units higher than those obtained after individual calibration. This is in accordance with a study evaluating the influence of the calibration mode on laser fluorescence caries detection with the conventional device (22): it was demonstrated that following standard calibration, values were also approximately 5 units higher than those measured after individual calibration. In the present study, higher values for standard calibration were also shown for the new device within the same range of difference. As the new device is based on the same physical principle, it is likely that this difference could also be expected for the new device.

Several studies have proposed guidelines for the clinical use of laser fluorescence values. According to LUSI *et al.* (12), values from 0 to 13 indicate that no active care is necessary, values from 14 to 20 indicate that preventive care is advised, and values from 21 to 29 indicate that preventive or operative care is required, depending on the patient's individual caries risk. For values higher than 29, operative care is advised. In another *in vivo* study, preventive care is advised when values of 10 or higher are noted, and a value of 30 was confirmed as a borderline reading for operative intervention (10). The recommendations of both studies are based on values obtained after individual calibration of the conventional system. Laser fluorescence values for high sensitivity and specificity, as calculated in the present study, are not contradictory to the findings of the studies described above: the readings obtained using the conventional device correspond to the range of values previously described in the guidelines. As a result of the high variation of laser fluorescence values for different depths of clinical caries measured in the present study for both systems, the intensity of fluorescence light might not indicate the exact extent of the carious decay. This is in accordance with previous studies (10, 23–25) and underlines the fact that recommended cut-off values for the clinical use of the conventional Diagnodent device should not be considered as exact threshold readings. In fact, these values should be used as adjunctive information for a dentist's treatment decision.

Consequently, the conventional Diagnodent should not be used as a clinician's primary diagnostic method (26). Our study assessed 94 teeth, but the results of sensitivity of 92.6% lies within the range of the outcomes of other reports that evaluated fewer or more teeth (9, 12, 27, 28). The specificity value of 53.7% for the conventional device is lower than in the above-mentioned studies, and the specificity value varied more among these studies than the sensitivity value.

Comparing the present results of the novel pen device with those of the recently published *in vitro* study (15), the sensitivity was nearly the same. The sensitivity value of the present study, of 88.9%, is similar to the range of 78–91% reported in the *in vitro* study. However, the specificity value of the present study (53.7%) is lower than the reported range of 69–79%. The *in vitro* calculated cut-off value of 17–19 for the pen device is slightly lower than the cut-off value of 23 evaluated in the present study.

In the present study, the endpoint of complete caries removal of cavities was determined by tactile and auditory means. The hardness and the color of dentine are presently the main parameters used by clinicians to differentiate between infected and non-infected dentine during excavation (19, 29, 30). Whereas a significant correlation has been found between dentine hardness and level of bacterial infection, the same is not evident for tissue color, so it may not be necessary to continue preparation until the dentine is stain free (19).

In the present study, differentiation between D3 and D4 lesions was determined by assessing the clinical situation with respect to the dentine–enamel junction. Considering average values (31), an extension of ≈ 1 mm into dentine seemed to be suitable for clinical differentiation between superficial and advanced lesions.

Overall, teeth should be cleaned and dried to optimize conditions for regular visual inspection, which should be the first diagnostic step. Thorough cleaning is a prerequisite for accurate caries detection because drying makes decalcifications visible. Several reports assessing the conventional fluorescence device pointed out that plaque, toothpastes, prophylaxis pastes, and stains (e.g. brownish pigments) could give false-positive readings (12, 32–34). Therefore, in the present study, professional cleaning of tooth surfaces was performed using a rubber cup and plain water spray, as this cleaning procedure is recommended prior to laser fluorescence measurements in teeth with visible plaque and in cases where laser fluorescence readings approach the threshold level for operative intervention (35). However, even though we excluded teeth with visibly stained fissures, in other teeth an exogenous stain in the depth of a fissure might have contributed to a potential source of error in laser fluorescence measurements.

To avoid any personal bias, both in the selection of teeth and in the determination of the presence of caries, two investigators were involved in the present study: one operator focussed on tooth selection, caries excavation, and assessment of the depth of the cavities; and the other performed laser fluorescence measurements with the two devices under study.

As the detection of very early lesions is currently the main use of the Diagnodent device in clinical dentistry, our study is limited by not validating such lesions by operative intervention, as it would be clearly unethical to do this on Ekstrand scores 1 and 2. Validation of the caries extent is therefore limited to score 3 lesions that can already be detected visually or radiographically.

Within the limits of the present study, it may be concluded that the new laser fluorescence device seems to be suitable for occlusal caries diagnosis. However, proposed guidelines for the clinical use of laser fluorescence readings of the conventional fluorescence device cannot be transferred to the Diagnodent pen. When performing measurements with the new pen device for caries diagnosis, lower values have to be expected than for the conventional system. The present study showed that an interdevice factor of ≈ 0.6 has to be considered when comparing the values of the two systems under study. Further studies are necessary to evaluate other aspects of caries detection using laser fluorescence measurements of the new pen device. In particular, the possibility of approximal caries detection should be evaluated under clinical conditions.

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