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ORIGINAL ARTICLE

Performance of light-emitting diode device in detecting occlusal caries in the primary molars

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Abstract

This in vitro study aimed to compare the performance of a light-emitting diode (LED) device (Midwest Caries I.D.: MID), International Caries Detection and Assessment System (ICDAS) visual criteria, and fluorescence-based devices (DIAGNOdent: LF; DIAGNOdent pen: LFpen; and Quantitative Light-induced Fluorescence: QLF) in detecting occlusal caries in the primary molars. Eighty-eight primary molars with sound occlusal surfaces or carious lesions at different stages were assessed twice, with a 1-week interval in between, by one examiner using all three methods. Subsequently, the teeth were sectioned and lesion depth was verified using stereomicroscopy as a gold standard. Sensitivity, specificity, and accuracy were calculated at D_1 (all carious lesions—enamel and dentin) and D_3 (dentin lesions) thresholds. Correlation with histological analysis was evaluated using Spearman's rank correlation coefficients (rho). Weighted Kappa and intraclass-correlation (ICC) coefficients were calculated to assess intra-examiner reproducibility. At D_1 threshold, ICDAS and LFpen showed higher sensitivity than the other methods, whereas ICDAS, LF, and QLF showed higher specificity ($p < 0.05$), and MID showed lower accuracy. At D_3 threshold, ICDAS, LFpen, and QLF showed higher sensitivity than MID, whereas ICDAS, LF, and MID showed higher specificity ($p < 0.05$). All methods, except MID, showed statistically similar accuracy values ($p < 0.05$). Correlations with histopathological analysis varied from 0.15 (MID) to 0.57 (ICDAS). Intra-examiner reproducibility varied from 0.30 (MID) to 0.92 (ICDAS, LF, and QLF). The MID device exhibited a poor performance in detecting occlusal carious lesions in the primary molars, and ICDAS visual criteria exhibited greater accuracy than LF, LFpen, and QLF devices.

Keywords Caries detection · Primary teeth · Occlusal surfaces · Fluorescence

Introduction

The detection of non-cavitated carious lesions on the occlusal surfaces is a challenge in the field of dentistry due to the complex morphology of the fissure system, as well as the potential for surface remineralization associated with the use of fluoride, which allows the dentin carious lesion to progress under an intact macroscopic surface. [1, 2] Traditionally, radiographic and visual examinations are used for the detection of caries. However, these methods have high specificity and low sensitivity of detection, are subjective, and dependent on the examiners' experience. In this context, the International Caries Detection and Assessment System (ICDAS) criteria developed to standardize classification of the different stages of the carious lesion demonstrated good reproducibility and accuracy in the detection of cavitated and non-cavitated occlusal caries lesions in the permanent [1–4] and primary teeth [5–7].

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Early detection of caries is important to support less invasive treatments [8], and several marketed devices aim to decrease subjectivity while improving diagnostic accuracy. Fluorescence laser devices such as DIAGNOdent 2095 (LF, KaVo, Biberach, Germany) and DIAGNOdent 2190 – DIAGNOdent pen (LFpen, KaVo, Biberach, Germany) have shown divergent results in the detection of caries in the primary teeth [9–13]. Nonetheless, a systematic review of literature indicated that these devices are more accurate in detecting advanced dentin caries in both the permanent and primary teeth [14]. In both devices, bacterial porphyrins and other chromophores present in caries lesions emit greater fluorescence than sound tissues when stimulated by a red visible light laser with a wavelength of 655 nm. A filter blocking light below 665 nm eliminates reflected and ambient light; a photodetector measures the amount of fluorescent light passing through the filter, and a digital display shows both a real-time (moment) and a maximum (peak) value. In the LFpen device, the excitation and emission of fluorescence follow the same solid fiber tip, but in opposite directions, in contrast to the LF device, which has different fibers for light excitation and emission. Changes in fluorescence intensity are numerically quantified and translated to values ranging from 0 to 99, according to the lesion's depth [4, 8, 9].

QLF (quantitative light-induced fluorescence) is a caries lesion detection system based on autofluorescence in the red and green spectra used for quantifying mineral loss [8, 15, 16]. The QLF device emits a blue light with a wavelength of 405 nm to measure the difference of the back-scattered fluorescence between healthy and demineralized enamel. The reemitted fluorescence is collected with a micro-CCD-video camera equipped with a yellow high-pass filter (wavelength > 540 nm) to exclude any excitation or ambient light from reaching the detector. The presence of an area of demineralized enamel results in reduced fluorescence. Finally, a specific software is used to display, store, and analyze the images. This software uses the pixel values of the sound enamel to reconstruct the surface of the tooth, and subtracts pixels which are identified as a lesion. This is controlled by a threshold of fluorescence loss that is generally set to 5%. Once the pixels have been designated as "sound" or "lesion," the software calculates the average loss of green fluorescence observed in initial enamel carious lesions, and the device translates this fluorescence into quantitative values ([A] lesion area in mm^2, [ΔF] fluorescence loss in %, and [ΔQ] the fluorescence loss integrated over the lesion area in mm^2*%) [8, 15]. QLF has been used to detect and monitor initial caries on the smooth surfaces [17]; moreover, some studies have reported its' performance to detect occurrence on the occlusal surfaces [18]. However, only one study has evaluated the accuracy of QLF in the detection of occlusal caries in the primary teeth [19], and another evaluated the association of QLF quantitative measures with caries activity [20].

Another device for the detection of caries is based on light-emitting diode (LED) technology (Midwest Caries I.D. DENTSPLY Professional, York, PA, USA). The portable device transmits diode soft light between 635 and 880 nm wavelength and analyzes the reflectance and refraction of light emitted from the tooth surface, which is captured by an optical fiber and converted into electrical signals for analysis. The microprocessor of the device has an in-built computer-based algorithm that identifies different optical signatures based on the changes in translucency and opacity between the sound and demineralized teeth [21]. According to the manufacturer, when there is a change in the optical translucency and opacity of the dental tissues, the emitted green light changes to red and an audible signal can be heard (slow, moderate, or fast beeping) [21, 22]. Nevertheless, few studies have evaluated its performance in permanent teeth [22–27], whereas its performance on primary teeth has not been reported.

The present study aimed to compare the in vitro performance of the LED-based device (Midwest Caries I.D.: MID), International Caries Detection and Assessment System (ICDAS) visual criteria, and fluorescence-based devices (DIAGNOdent: LF; DIAGNOdent pen: LFpen; and Quantitative Light-induced Fluorescence: QLF) on the detection of occlusal caries lesions in the primary teeth, with histological validation. The null hypothesis of the study is that there are no significant differences between methods for the detection of occlusal caries in the primary teeth.

Materials and methods

The Ethics Committee Research of Araraquara School of Dentistry, Univ. Estadual Paulista approved the study (IRB#48/08).

Sample selection

Eighty-eight primary molars (46 first molars, and 42 s molars) recently extracted for purpose other than study, with varying conditions from sound to that of different stages of carious lesion, were stored at − 20 °C until further analysis. A previous study has shown that this storage method is important for laboratorial studies, since it was not associated with any change in the fluorescence values [28]. The patient's guardians were informed about the use of their teeth for research purpose and their consent was obtained. The primary teeth that presented fissure sealant, restoration, enamel hypoplasia, and hypomineralization were excluded.

After defrosting for 3 h, the teeth were carefully cleaned for 10 s using tap water and a toothbrush; in addition, sodium bicarbonate powder was used (Profi III Bios®, Dabi Atlante, Ribeirão Preto, São Paulo, Brazil) for 10 s. The teeth were rinsed using three-in-one syringe for 10 s to remove any remnants inside the fissure that could influence the laser fluorescence readings [29].

The occlusal surfaces were photographed at × 6.25 magnification (EOS Rebel XTi, Canon, Lake Success, New York, EUA). An experienced researcher (A.G.F.Z.) who did not participate in the examination selected one site on the occlusal surface of each tooth. One trained and experienced examiner (M.B.D.) assessed the teeth twice at 1-week interval under guidance of black and white photographs printed on draft-quality paper. Specific test sites were marked with a dot to allow precise assessment of the same area [3]. This examiner evaluated the teeth using ICDAS, LF, LFpen, MID, and QLF devices.

To standardize the examinations, the teeth were mounted individually on a dental model with sticky wax in a phantom head at the same position. During the measurements, the teeth were stored under relative humidity of 100%.

Visual examination (ICDAS)

Visual inspection was conducted using ICDAS criteria. The selected sites were examined using direct visualization under light illumination and use of three-in-one air syringe, with World Health Organization (WHO) probe. The teeth were assessed moist and subsequently after drying for 5 s.

The ICDAS criteria was coded as follows: Zero, sound tooth surfaces, no evidence of caries after prolonged air drying (5 s); 1, first visual change in the enamel, opacity or discoloration (white or brown) visible at the entrance to the pit or fissure after prolonged air drying; 2, distinct visual change in the enamel, opacity, or discoloration distinctly visible at the entrance to the pit and fissure when wet; 3, localized enamel breakdown due to the presence of caries with no visible dentin or underlying shadow, opacity, or discoloration wider than the natural fissure/fossa, when wet and after prolonged air drying; 4, underlying dark shadow from the dentin with or without localized enamel breakdown; 5, presence of distinct cavity with visible dentin, visual evidence of demineralization and the dentin exposed; and 6, extensive distinct cavity formation with visible dentin and involvement of more than half of the surface [30].

Laser fluorescence (LF and LFpen)

Fluorescence-based methods were conducted using DIAGNOdent (LF) and DIAGNOdent pen (LFpen). For the measurements, tip A in the LF device and cylindrical-sapphire fiber tip in the LFpen were used. The device was calibrated for each tooth using a ceramic standard in accordance with the manufacturer's instructions at the smooth sound site of each tooth. After drying the tooth for 3 s with three-in-one air syringe, the device tip was rotated on its long axis at the selected site and the peak value was recorded [19].

Light-induced fluorescence (QLF)

Examination of the tooth was conducted using QLF device (QLF Inspektor Pro; Inspektor Research System, Amsterdam, Netherlands) under exposure to 290 to 450 nm blue-violet light. Extracted teeth were mounted individually on a dental model, and images were acquired using QLF in a dark room after drying the surface with a cotton roll.

The images were analyzed using proprietary software (Inspektor Pro Software, Inspektor Research Systems, Amsterdam, Netherlands) on a computer monitor located in the dark room in order to reduce external light, at QLF threshold of − 5%. Subsequently, for evaluation, the selected occlusal site was manually demarcated by the examiner, and a sound-surface area was defined as the reference for measurements; and the parameter ΔF (% of green fluorescence radiance loss) was recorded [16].

Light-emitting diode (MID)

Examination using MID device was conducted according to the manufacturer's instructions with device calibration for each tooth using a ceramic standard. The teeth were kept moist, and the tip was rotated on its long axis at the selected site without pressure.

The MID device change of LED from green to red with concurrent audible signal was used to confirm the presence of demineralization. The largest measurement was recorded at each occlusal site based on the scores suggested by the manufacturer: Zero, green light/no beeping noise (no demineralization); 1, red light, slow beeping noise (demineralization at the enamel); 2, red light, moderate beeping noise (demineralization at the amelodentinal junction); and 3, red light, fast beeping noise (demineralization at the dentin) [26].

Histological analysis

After completion of the evaluations, the teeth were longitudinally sectioned near the periphery of the center of the selected sites using a sectioning machine with water-cooled diamond disk (Isomet 1000, Buehler, Lake Bluff, IL, EUA). Subsequently, the tooth slice was polished using a grinder polisher machine (Ecomet, Buehler, Lake Bluff, IL, EUA), with sandpapers of grain size 320, under stereomicroscopy (× 10 magnification) until the periphery of the site was reached; thereafter, water slicks of decreasing granulation of 600 and 1200 were used until reaching the site to be analyzed.

Histological analysis of the tooth surfaces was performed independently by two experienced senior researchers using a stereomicroscope at × 10 magnification (Olympus SZ40, Olympus Inc., Melville, NY, EUA) according to the extent of caries lesion in the enamel and dentin. In case of any discrepancy, an agreement was reached through consensus. The sites were scored based on extension of the caries according to method of Ekstrand et al. [31]: Zero, absence of enamel demineralization or narrow surface zone of opacity; 1, enamel demineralization limited to outer 50% of the enamel layer; 2, presence of demineralization between 50% of the enamel and outer third of the dentin; 3, presence of demineralization at middle third of the dentin; and 4, presence of demineralization at inner third of the dentin.

Statistical analysis

The data were tabulated, and all analyses were performed using statistical MedCalc for Windows 13.1.2.0 software (MedCalc software bvba, Ostend, Belgium), with level of significance set at $p < 0.05$.

Inter- and intra-examiner reproducibility were calculated using Kappa Cohen coefficient for categorical data (ICDAS and MID), and intraclass correlation coefficient (ICC) for numerical data (LF, LFpen, and QLF).

The best cutoff points (highest sum of the specificity and sensitivity rates) were determined by means of the ROC (receiver operating characteristics) curve for devices including LF, LFpen, and QLF at two thresholds: D_1 (enamel and dentin lesions; score 0 = sound versus scores 1–4 = caries lesions) and D_3 (dentin lesions; scores 0–2 = sound versus scores 3–4 = caries lesions). Subsequently, using these cut-off points, the sensitivity (the proportion of disease cases that were classified as positive [disease present]), specificity (the proportion of healthy cases that were classified as negative [disease absent]), and accuracy (the total percentage of correctly assessed diseased and non-diseased cases) values for each method at each diagnostic threshold were calculated, considering D_1 (all carious lesions – enamel and dentin) and D_3 (dentin lesions) thresholds. Comparisons among the methods were performed using McNemar's test. The correlation between the methods and histological scores was determined using Spearman's correlation coefficient (rho).

Results

In the present study, of the 88 occlusal sites assessed, histological analysis revealed that 22 were sound (score 0), 11 had enamel demineralization limited to outer 50% of the enamel layer (score 1), 48 had demineralization between 50% of the enamel and 1/3rd of the dentin (score 2), four had demineralization involving middle third of the dentin (score 3), and three had demineralization involving inner third of the dentin (score 4).

Tables 1 and 2 show the cut-off limits, sensitivity, specificity, and accuracy values at D_1 and D_3 thresholds for all methods, respectively. At D_1 diagnostic threshold, ICDAS and LFpen showed higher sensitivity values, whereas ICDAS, LF, and QLF presented higher specificity values ($p < 0.05$). In terms of accuracy, ICDAS showed the higher value and MID showed the lowest value ($p < 0.05$), indicative of imbalance between the sensitivity and specificity values. At D_3 diagnostic threshold, ICDAS, LFpen, and QLF presented higher sensitivity values than MID, whereas ICDAS, LF, and MID presented higher specificity values ($p < 0.05$). In terms of accuracy, ICDAS, LF, MID, and QLF presented statistically similar values ($p < 0.05$). Table 3 shows Spearman's correlation coefficient between the methods and histological analysis. All methods presented significant positive correlation with the histological analysis, with ICDAS showing the highest correlation, and MID, the lowest correlation. Table 4 shows the intra-examiner reproducibility for all methods. Weighted Kappa and ICC values varied from 0.30 (MID) to 0.92 (ICDAS, LF, and QLF), indicating that MID had the lowest intra-examiner reproducibility.

Table 5 provides a summary of the methods used in regard to ease of use, sensitivity, specificity, accuracy, and reproducibility in detecting occlusal caries lesions in primary molars. ICDAS visual criteria was shown to be a simple-to-use method that displayed higher specificity, sensitivity, accuracy, and reproducibility compared to the other methods.

Table 1 Sensitivity (Se), specificity (Sp), and accuracy (Ac) values for all methods at D_1 threshold

Methods	Cut-off points	Se	Sp	Ac
ICDAS	> 0	0.86^{A}	0.70^{A}	0.82^{A}
LF	> 4	0.68^{B}	0.64^{A}	0.67^{B}
LFpen	> 3	0.81^{A}	0.48^{B}	0.73^{B}
MID	> 0	0.71^{B}	0.30^{B}	0.61^{C}
QLF (ΔF%)	> 7.4	0.68^{B}	0.80^{A}	0.71^{B}

Superscript letters indicate statistically significant differences between the methods considering the same column (McNemar test; $p < 0.05$)

Discussion

To the best of our knowledge, this is the first study to evaluate the performance of MID device for the detection of occlusal

Table 2 Sensitivity (Se), specificity (Sp), and accuracy (Ac) values for all methods at D_3 threshold

Methods	Cut-off points	Se	Sp	Ac
ICDAS	> 2	0.71^{A}	0.92^{A}	0.90^{A}
LF	> 23	0.93^{A}	0.92^{A}	0.92^{A}
LFpen	> 19	0.93^{A}	0.83^{B}	0.84^{B}
MID	> 1	0.43^{B}	0.93^{A}	$0.89^{A,B}$
QLF (ΔF%)	> 13.8	0.93^{A}	$0.87^{A,B}$	$0.88^{A,B}$

Superscript letters indicate statistically significant differences between the methods considering the same column (McNemar test; $p < 0.05$)

Table 3 Spearman ranking correlation coefficients (rho) between the methods and histological analysis

Methods	rho	p value
ICDAS	0.57	< 0.0001*
LF	0.53	< 0.0001*
LFpen	0.44	< 0.0001*
MID	0.15	0.0451*
QLF (ΔF%)	0.53	< 0.0001*

*Variables statistically associated ($p < 0.05$)

caries in the primary molars. Few studies investigating the performance of this device demonstrated poor in vivo and in vitro performance to detect approximal and occlusal caries lesions in the permanent molars [22–27]. Based on the results of the present study, the null hypothesis of absence of differences among the methods in detecting caries lesions on the occlusal surfaces of the primary molars was rejected.

MID presented low performance and correlation with the histological analysis in the detection of occlusal caries lesions in the primary molars at both diagnostic thresholds. The unsatisfactory performance of MID device may be attributed to subjectivity in relation to the sound signal emitted during the measurements including low, moderate, and high frequencies [27]. In addition, studies on the in vitro permanent teeth reported that MID presented poor correlation [23, 26, 27], excepting studies by Rodrigues et al. [22], and Van Hilsen and Jones [25] that reported moderate correlation. The present study suggested that MID was not reliable in determining sound dental structure based on the low specificity value obtained at D_1 diagnostic threshold, resulting in overdiagnosis (false-positive result), corroborating the report of Patel et al. [26] in the permanent teeth. It should be mentioned that the MID device might fail to detect early-stage caries lesions (sensitivity of 0.71), leaving the site susceptible to further caries progression, as mentioned previously by Patel et al. [26]. Although the manufacturer does not recommend MID device for use in detecting caries lesions in the primary teeth, the results observed in the present investigation were similar to those obtained in studies including the permanent teeth. Moreover, the manufacturer does not recommend the device for use in other clinical situations, such as caries lesions

Table 4 Weighted Kappa and intra-class correlation (ICC) coefficients (95% CI - confidence interval) for intra-examiner reproducibility for all methods

Methods	Weighted Kappa (95% CI)	ICC (95% CI)
ICDAS	0.92 (0.88–0.95)	–
LF	–	0.92 (0.88–0.94)
LFpen	–	0.77 (0.66–0.88)
MID	0.30 (0.15–0.45)	–
QLF (ΔF%)	–	0.92 (0.88–0.95)

around the restorations, buccal and lingual smooth surfaces of the anterior and posterior permanent teeth, surfaces with dental calculus, pigmentation and biofilm, and dried teeth. Thus, the device has limitations for use in daily clinical practice, regardless of the dental structure to be evaluated.

In the present study, the results obtained using ICDAS visual criteria showed good performance in terms of the sensitivity, specificity, and accuracy for both the enamel and dentin (D_1 threshold) and the dentin (D_3 threshold) lesions alone, corroborating the results from previous studies [5, 6, 9, 32, 33]. In addition, significant positive correlation with the histological analysis was reported by other authors [5–7, 9, 32]. These results confirm the conclusions supported by a systematic review of the literature that visual examination with validated visual indices has good accuracy and high specificity and, thus, may be recommended for use in clinical practice without the need for adjunct methods [34]. Moreover, ICDAS visual criteria is suitable for assessing and monitoring the progression of caries lesions and allows the assessment of lesion activity concurrently with lesion detection, which is essential for diagnosis and an appropriate clinical decision-making process [30].

LF and LFpen laser fluorescence devices presented better performance in the detection of caries lesions in the dentin, corroborating previous reports [6, 9, 32, 35]. Braga et al. [36] reported that these devices showed good correlation with the depth of caries lesion, but not with the amount of mineral loss. This fact was attributed to the presence of bacterial metabolites/porphyrins in the emission of fluorescence by the demineralized dental tissue [8]. At D_1 threshold, the finding that LFpen had high sensitivity of detection may be attributed to the higher number of teeth with lesions in the enamel observed through histological analysis, in agreement with Kavvadia et al. [37]. Most studies using these fluorescence-based methods were performed on the smooth and occlusal surfaces, especially in the permanent teeth [14, 17]. Regarding the correlation with histological analysis, LFpen presented higher correlation than LF, as verified by Souza et al. [6]. A systematic review of the literature showed that these devices were more accurate in the detection of advanced dentin lesions in the primary and permanent teeth [14], whereas a meta-analysis demonstrated the capability of laser fluorescence to detect occlusal caries lesions in the enamel and dentin in the in vitro permanent teeth [38]. It should be mentioned that laser fluorescence devices present an increased likelihood of false-positive diagnoses which limit their usefulness as principal diagnostic tools. Thus, these methods have significant disadvantages for use in clinical trials, specifically to monitor caries lesions, as increases in tooth staining over time might be interpreted as lesion progression when, in fact, they reflect the opposite [15].

With regard to QLF device, the present study showed good specificity at D_1 threshold and good performance in terms of

Table 5 Summary results of the methods in regard to ease of use, sensitivity, specificity, accuracy, and reproducibility in detecting occlusal caries lesions in primary molars

Methods	Ease of use	Sensitivity	Specificity	Accuracy	Reproducibility
ICDAS	Simple-to-use	High	High	High	High
LF	Time-consuming	Moderate	Moderate	Moderate	High
LFpen	Time-consuming	High	Moderate	Moderate	High
MID	Time-consuming	Low	Low	Moderate	Moderate
QLF	Time-consuming	Moderate	High	Moderate	High

the sensitivity, specificity, and accuracy values at D_3 threshold, corroborating the studies by Ferreira-Zandoná et al. [39] and Jallad et al. [16]. Studies using QLF indicated good correlation between the mineral loss and organic content of the caries lesion [15, 40], as observed in the present study. A study evaluating the performance of QLF in the detection of occlusal caries lesions in the primary teeth in vivo showed comparable results to those using LFpen and visual examination through ICDAS criteria [19]; however, few studies evaluating its performance on the occlusal surfaces in the permanent teeth reported controversial results [41–43], which makes it difficult to compare the results. The QLF method allows for the longitudinal examination of lesions as it employs a video repositioning system that enables the precise geometry of the original image to be replicated on subsequent visits. Once an image of a tooth has been captured, lesions must be analyzed to produce a quantitative assessment of the de-mineralization status of the tooth [15].

Intra-examiner reproducibility values were higher for ICDAS, LF, and QLF, while MID presented lower value. Reports in the literature have indicated good reproducibility of the results obtained using ICDAS visual criteria in the primary teeth [5, 6, 9, 32], QLF [16], and LF [6, 9]. However, previous studies evaluating the performance of MID device to detect caries lesions on the occlusal and approximal surfaces of the permanent teeth reported higher intra- and inter-examiner reproducibility values [22, 23, 25, 27].

With regard to limitations of the present study, of note, the different histological levels of caries lesions of the sample showed non-homogeneous distribution. However, it is difficult to obtain exfoliated and/or extracted primary teeth for use in in vitro studies.

Thus, MID device showed poor performance in this in vitro study, and the visual method using ICDAS visual criteria presented better performance when compared to LF, LFpen, and QLF in the detection of occlusal caries lesions in the primary molars. Methods using fluorescence-based and light-based devices are time-consuming and do not improve the diagnostic outcome; meticulous visual examination may be recommended as the method of choice in actual dental practice. Moreover, adjunct fluorescence-based methods should be used with caution; and clinical studies assessing the performance of these methods on both the primary and permanent teeth are required.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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