

Quantitative light-induced fluorescence (QLF) in relation to other technologies and conventional methods for detecting occlusal caries in permanent teeth

Antônio Carlos Pereira¹, Hafsteinn Eggertsson², Carlos González-Cabezas³,
Domenick T. Zero², George J. Eckert⁴, Fábio Luiz Mialhe¹

¹Department of Community Dentistry, Piracicaba Dental School, University of Campinas, SP, Brazil

²Indiana University School of Dentistry, Indianapolis, IN, USA

³University of Michigan School of Dentistry, Ann Arbor, MI, USA

⁴Indiana University School of Medicine, Indianapolis, IN, USA

Abstract

Aim: The aim of this *in vitro* study was to compare the reproducibility and accuracy of quantitative light-induced fluorescence (QLF) in relation to other technologies and conventional methods for detecting occlusal carious lesions. **Methods:** Ninety-six extracted permanent molar teeth were selected. Three examiners carried out examinations using Visual examination (VI), bitewing radiographs (RX), QLF, electrical conductance measurement (ECM), and DIAGNOdent. Twenty-five percent of the teeth were re-examined for repeatability. Stereomicroscopic examination was used as the gold standard. **Results:** Intra- and inter-examiner agreement ranged from 0.43 to 0.89. Areas under ROC curves were 0.82, 0.54, 0.84, 0.79 and 0.88, respectively, for VI, RX, QLF, ECM and DIAGNOdent examinations, with RX significantly lower than the other methods. No significant statistical difference was found when comparing the areas under ROC curve of visual inspection and QLF. **Conclusions:** Although QLF and other technologies for early caries detection may offer some advantages, this study did not find significant improvement in occlusal caries detection when compared to visual examination.

Keywords: dental caries, detection, diagnosis, pits and fissures, quantitative light-induced fluorescence, visual scoring of caries, radiograph, fluorescence, accuracy, ECM.

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Correspondence to:

Antonio Carlos Pereira
Faculdade de Odontologia de Piracicaba
FOP/UNICAMP
Departamento de Odontologia Social
Av. Limeira 901 - Areão - 13414-903
Piracicaba, SP, Brazil
Phone: +55 10 2106 5209
Fax: +55 19 2106 5218
E-mail: apereira@fop.unicamp.br

Introduction

Over the past 40 years there have been changes in the epidemiological pattern of dental caries around the world. These changes have been characterized by a reduction in prevalence and severity of carious lesions¹⁻². The reduction has been surface dependent, and the occlusal surfaces of teeth are the sites most frequently affected by dental caries¹⁻². The reduction in caries progression has resulted in changes in the morphology and pattern of lesions, making it more difficult for the clinician to detect and assess the extent of the lesion³.

Table 1: Criteria for visual examination

Score	Criteria
0	No or slight change in enamel translucency after prolonged air drying (>5s)
1	Opacity or discoloration hardly visible on the wet surface, but distinctly visible after air drying
2	Opacity or discoloration distinctly visible without air drying
3	Localized enamel breakdown in opaque or discolored enamel and/or grayish discolored from underlying dentin
4	Cavitation in opaque or discolored enamel exposing the dentin beneath

Detection of carious lesions in their earliest stages has important implications for preventing their progression before cavitation occurs. Unfortunately, traditional diagnostic systems for detecting caries lesions, such as visual inspection and radiography, have limited accuracy and sensitivity when diagnosing occlusal caries at the pre-cavitated level³⁻⁴. To improve the accuracy of diagnosis, non-invasive instrument-based techniques have been developed for detecting and quantifying demineralization⁵⁻⁷. These techniques include methods based on electrical conductance measurement and laser- or light-induced fluorescence properties associated with demineralized dental tissues. At the same time, proposals have been put forward for improvement in the visual examination, which include the detection of caries lesions in pre-cavitated stages⁷⁻⁹.

However, in relation to light-induced fluorescence (QLF), few studies have been published evaluating the diagnostic performance of the method on occlusal surfaces and comparing it with traditional and other techniques for caries detections⁸⁻⁹. Therefore, the aim of this study was to evaluate *in vitro* the performance of QLF for detecting occlusal caries and compare the results with visual examination criteria adopted by Ekstrand⁶⁻⁷, and with other technologies in permanent molars without cavitation.

Material and methods

The study was approved by the Research Ethics Committee of the Piracicaba Dental School, University of Campinas, registration number 027/2004. Ninety-six extracted permanent molar teeth exhibiting complete root formation were selected from an institutional teeth depository. The occlusal surfaces were visually diagnosed for caries and ranged from sound to varying degrees of fissure discoloration and possible microscopic breakdown of the surface structure (extractions especially for orthodontic reason). None of the teeth showed macroscopic signs of cavity formation. The teeth were stored in 0.1% thymol solution for less than 3 months from the time of extraction. Teeth with dental fluorosis, tetracycline stain, hypoplasia or dental restorations were excluded. The teeth were cleaned with a prophylaxis brush using pumice slurry, rinsed with a 3-way syringe, and after the ECM examination, mounted in blocks in sets of 3 teeth. The occlusal surfaces were photographed ($\times 4$ magnification), and one site on each tooth was selected and marked on the photograph for identification during examinations. The teeth were stored under refrigeration in de-ionized water in individual plastic containers.

Three examiners participated in this study. All the examiners

underwent a training session, which consisted of two-hours of theoretical training and four-hours of practice on extracted teeth. Additionally, a pilot study was conducted, using 9 supplementary teeth.

Examinations

Visual Examination

Visual examination was carried out using only a dental operating light and air-drying up to 5 s. No explorer was used during the examination. Each surface was scored using the criteria described by Ekstrand et al.⁷, as presented in Table 1.

Radiographic Examination

The teeth were radiographed under standardized conditions and the exposures were made using a Trophy General Electric GE 1000 Intraoral x-ray machine, operating at 70 kVp and 8 mA. The blocks of teeth were placed in a holder, specially designed to provide standardized projection geometry during exposure. The focus-film distance was 21 cm and a 15-mm-thick soft tissue equivalent material was placed between the cone end and the blocks of teeth. The classification criteria for radiographic examination are shown in Table 2.

Table 2: Criteria for radiographic examination

Score	Criteria
0	No caries
1	Radiolucency extending to the outer ½ of the enamel
2	Radiolucency extending to the inner ½ of the enamel
3	Radiolucency extending to the outer ½ of the dentin
4	Radiolucency extending to the inner ½ of the dentin

Quantitative Light-induced Fluorescence (QLF)

Images of occlusal surfaces of tooth specimens were captured using a portable intra-oral camera device connected to a computer (QLF, Inspektor Research Systems BV, Amsterdam, The Netherlands). Each occlusal surface was illuminated with 13 mW/cm² of the violet-blue light (wave length: 290-450 nm) and the images were captured through a yellow 520 nm high-pass filter using a custom-made software (QLF, Inspektor Research Systems BV). The images were scored subjectively from the stored images displayed on a CRT monitor. The scoring criteria are shown in Table 3.

Electrical Conductance Measurement (ECM)

Electrical conductance method was performed using the Electronic Caries Monitor III (ECM III, LODE, Groningen,

Table 3: Criteria for QLF examination

Score	Criteria
0	No change in enamel fluorescence
1	Slight change in enamel fluorescence
2	Fluorescence loss distinctly visible without enamel broken,
3	Fluorescence loss distinctly visible with enamel broken
4	Fluorescence loss distinctly visible with cavitation

The Netherlands). The ECM examination had to be done before mounting to allow for a reference electrode to be attached to the root complex for measurement. Before each measurement the occlusal surface of the tooth was moistened with de-ionized water then gently air-dried and a toothpaste gel was syringed into the fissure system as a conducting medium. The reference electrode was attached to the root and the measurement electrode probe placed in contact with the fissure enamel at the site identified in the photograph, activating the co-axial air flow (7.5 L/min) until stable readings were obtained. ECM readings ranged from 0.00 indicating low conductance, to 99.99 being the highest measurable conductance. A score of 15 or lower was considered to indicate the presence of caries. Each site was examined three times, and the average of these readings was considered as a definitive score.

Laser Fluorescent (LF) Examination

Laser fluorescence measurements were made using the DIAGNOdent device (Kavo, Biberach, Germany). The device was calibrated before use on the standardized porcelain chip provided by the manufacturer. Using probe tip A, the machine was then calibrated against a sound area on each tooth separately, by holding the tip against a sound smooth surface and pressing the ring button until calibration was completed. The conical probe tip was then positioned perpendicularly over each selected site and slightly rotated around its long axis. Each site was measured 3 times using the above-mentioned procedures, and the average of these readings (0-99 range) was considered as a definitive score.

Histological Validation

After all assessments were completed, the teeth were removed from the blocks, and approximately 150 to 200- μ m-thick buccolingual sections made using a Silverstone-Taylor microtome (Silverstone-Taylor, Scientific Fabrications Co., Lafayette, CO, USA), by cutting through the pre-selected site in the occlusal surface. The histologic examination was done with a stereomicroscope at $\times 40$ magnification. Both sides of each tooth section and the more severe side scored for the specimen. Three examiners underwent a training session, which consisted of 2 h of theoretical training and 4 h of practice on extracted teeth. Additionally, a pilot study was conducted, using nine supplementary teeth. All examiners were university teachers who had graduated more than 10 yr previously, had experience in clinical teaching, and had up to 4 yr of experience in clinical practice¹⁰. Caries was defined as being present when demineralization was observed, seen

as white or discolored (yellow/brown) area. The histological criteria for caries lesion depth are presented in Table 4.

Table 4: Criteria for histological validation

Score	Criteria
0	No caries
1	Demineralization extending to the outer ½ of the enamel
2	Demineralization extending to the inner ½ of the enamel
3	Demineralization extending to the outer ½ of the dentin
4	Demineralization extending to the outer ½ of the dentin

Statistical Analysis

To assess the intra-examiner agreement, 25 teeth were re-examined. Intra- and inter-examiner reproducibility for the ordinal visual, radiographic and QLF scores were assessed using weighted kappa statistics¹¹. Intra- and inter-examiner reproducibility for ECM and DIAGNOdent were assessed using intraclass correlation coefficients (ICC)¹². In order to compare the sensitivity, specificity, accuracy, and area under the ROC curve (AUC) between methods, a bootstrap sampling procedure was used. A bootstrap sample was obtained by randomly selecting specimens with replacement, preserving the percentages of true positives and true negatives in the sample distribution. The estimates were obtained for each of the 1000 bootstrap samples for each method, and the difference between methods was calculated. Bootstrap sampling allows p-values and confidence intervals to be generated for the differences between methods¹⁰. The sensitivity, specificity, and accuracy were calculated for the D1 diagnostic threshold (histology score ≥ 1) with the cut-off > 0 ratings for visual and cut-off ≥ 2 for QLF measurements. For ECM site measurements, the cut-off for all lesions was < 15 and for DIAGNOdent, the cut-off limits for all lesions were values ≥ 5 , adopted by Lussi et al.¹³ Area under the ROC curve, an indicator of overall diagnostic performance which does not require cut-offs for the diagnostic methods, was computed using the c-statistic from logistic regression models for each examiner and for each method. SPSS and SAS statistical software packages were used for statistical analysis.

Results

The histological examination revealed that 41 sites (43%) were sound; 31 (32%) had demineralization in enamel and 24 (25%) had demineralization extending into dentin.

Table 5 shows weighted kappa values for intra- and inter-examiner reproducibility for the visual examination, radiography, and QLF ranked scoring systems. Weighted kappas for intra-examiner repeatability ranged from 0.58 to 0.89 and QLF presented the best results for examiner 2. In relation to inter-examiner reproducibility, QLF presented better results than visual and radiography methods.

Table 6 presents the values of intraclass correlation coefficients for intra- and inter-examiner reproducibility for DIAGNOdent and ECM diagnostic methods. Intra-examiner

Table 5: Weighted Kappa values of intra- and inter-examiner reproducibility for visual, radiography and QLF for examiners.

Score method	Intra-examiner reproducibility			Inter-examiner reproducibility		
	exam 1	exam 2	exam 3	exam 1-2	exam 1-3	exam 2-3
Visual	0.78	0.84	0.89	0.64	0.49	0.43
Radiography	0.58	0.80	0.75	0.58	0.57	0.54
QLF	0.79	0.87	0.77	0.86	0.54	0.50

Table 6: Intraclass correlation coefficients for intra- and inter-examiner reproducibility for ECM and DIAGNOdent diagnostic methods.

Method	Intra-examiner reproducibility			Interexaminer reproducibility
	exam 1	exam 2	exam 3	exam 1, 2, 3
ECM	0.40	0.81	0.95	0.69
DIAGNOdent	0.66	0.69	0.93	0.83

agreement for both ECM and DIAGNOdent varied widely among examiners, with ICCs ranging from 0.40 to 0.95, but it was clearly higher for one of the examiners (range: 0.93-0.95). Inter-examiner agreement was higher for DIAGNOdent (ICC=0.83) than for ECM (ICC=0.69).

The performance of each diagnostic method in terms of sensitivity, specificity, accuracy and the area under the ROC-curve (Az) are shown in Table 7. LF presented the best sensitivity but the worst specificity values. DIAGNOdent had a higher Az, accuracy, and sensitivity than ECM; higher accuracy than QLF, and higher specificity than visual. QLF presented the best sensitivity but the worse specificity values.

The radiographic method was significantly worse than any of the other methods for Az, accuracy, and sensitivity while it had higher specificity than the visual and QLF methods.

Table 7: The performance of each diagnostic method at D1 diagnostic threshold assessed by all examiners expressed in terms of sensitivity, specificity, accuracy and the average area under the ROC-curve (Az).

Detection method	Sensitivity	Specificity	Accuracy	Az
Visual inspection	0.81 ^b	0.72 ^b	0.77 ^{ab}	0.82 ^{ab}
Radiography	0.20 ^d	0.88 ^a	0.49 ^c	0.54 ^c
QLF	0.96 ^a	0.38 ^c	0.72 ^b	0.84 ^{ab}
ECM	0.62 ^c	0.80 ^{ab}	0.70 ^b	0.79 ^b
DIAGNOdent	0.78 ^b	0.91 ^a	0.83 ^a	0.88 ^a

Different superscript letters indicate statistically significant differences among detection methods ($p < 0.05$).

Discussion

In the present study, the traditional visual diagnosis of occlusal caries presented high sensitivity (0.81) and specificity (0.72) values. These findings are similar to those obtained by other studies^{3,6-7,14-16}, that showed high sensitivity values (0.80-0.98) and moderate to high specificity values (0.38-0.98) at D1 and D2 diagnostic thresholds. The visual criteria used in the present and in these studies were those proposed by Ekstrand et al.⁶ The better performance of the

visual inspection compared with other methods assessed in this study, should also be compared with the traditional visual examination, as none of the teeth in the study had macroscopic cavitation, and therefore would have been called sound. It should also be born in mind that the majority of teeth had narrow and deep fissures typical of third molars. Some authors have demonstrated that in teeth with narrow fissures, the overall sensitivity, specificity and the percentage of correctly diagnosed teeth decreased 30% on average, in comparison with those that had wide fissures¹⁴.

Studies comparing the areas under ROC curve for QLF and visual inspection have shown conflicting results. Some authors affirm that visual inspection is as good as QLF when the dentist is instructed to detect the early signs of caries, and have not found significant differences in the areas under ROC curve between the methods¹⁷⁻¹⁸.

On the other hand, QLF has been found to detect more non-cavitated caries lesions than visual inspection using the criteria of Ekstrand⁸. However, due to its time-consuming image processing and analysis and higher cost, authors questioned the practicality of QLF for regular use in the dental office at the present stage. Furthermore, it has been suggested that the use of QLF technology must be combined with visual clinical examination since QLF detects any hypocalcified area, including developmental defects and dental fluorosis¹⁷.

The poor performance of bitewing radiography in the present study may be attributed to several reasons: the majority of the studies evaluating the performance of radiographic methods in detecting occlusal caries lesions serially sectioned the teeth in the buccolingual direction, the probability of a carious lesions being found is greater and the diagnostic performance of the method would potentially be better^{6-7,10,19}.

Several in vivo and in vitro studies have demonstrated that QLF presented better repeatability and reproducibility values for the quantification of smooth-surface caries than in pit and fissures ones²⁰⁻²². However, it is interesting to note that studies have found higher levels of intra/inter-examiner reliability for QLF when detection of occlusal caries lesions was done through quantitative analysis using the QLF analysis

software than when using qualitative interpretation of the images, as was the case of the criteria utilized in the present study^{8-9,23}. These differences could also be attributed to the threshold value chosen for a caries lesion to be considered absent or present. A review of the effectiveness of QLF to detect occlusal caries lesions showed that intra and inter-examiner reproducibility values were above of 0.90 when the evaluations were based on D3 diagnostic threshold²⁴.

In the present study, the criteria used for QLF demonstrated a good performance in detecting occlusal caries lesions, represented by the area under ROC curve (Az) and no significant statistical difference in Az was found with visual inspection and DIAGNOdent. DIAGNOdent showed the highest accuracy at D1 diagnostic threshold (0.83), which in agreement with the published literature^{13,19,25}.

Strong positive correlation between the histological examination and DIAGNOdent was observed, although it was lower than those obtained by other authors^{16,19,26}. The performance of this method could be dependent on the cut-off points used, as a probable source of variation, which could explain the different results in the performance of this method. Here, the cut-off chosen was a value of 5 which is lower than the recommended value of 15 for clinically detected early lesions. This correction is to compensate for the fluorescence decrease that occurs in teeth stored in different media, including the solution used for tooth storage in this study²⁷.

An important difference between QLF and the other methods evaluated was its lower specificity, which could lead to more false-positive diagnosis and consequently over-treatments. Low specificity values for QLF have been reported previously^{18,28}.

The sensitivity and specificity values for ECM found in the present study were lower than those found by other studies^{6,15-16,29}. However, the estimated area under the ROC curve for occlusal caries detection agreed with the data presented by other authors^{16,29-30}. Only a moderate correlation was found between depth of the lesions and the numerical ECM reading. These results were in agreement with those obtained by Ricketts et al.³⁰⁻³¹ but were lower than data presented in other studies⁶⁻⁷. This could be attributed to the differences in the histological scores used.

Although QLF, ECM and DIAGNOdent provide an appealing high-tech approach in the dental office, the present results do not suggest they are a significant improvement over a well-trained eye using the new visual criteria. Therefore, although the advantages of QLF, ECM and DIAGNOdent provide quantitative information, allowing the progression or arrest of carious lesions to be monitored in the course of time, the effectiveness of these emerging technologies only for detecting occlusal enamel and dentinal lesions in comparison with traditional methods is questionable. However, the higher specificity values found by some of these technologies indicated that those diagnostic methods were more accurate than the visual method for detecting sound surfaces. Considering the decrease in the prevalence of caries in many populations around the world, these methods could

be used as adjuncts in sites where there is clinical uncertainty, thereby decreasing the probability of over-treatment. While QLF and ECM methods have several advantages, they are expensive, and a less expensive device, such as DIAGNOdent, would probably find greater acceptance by clinicians. Further studies should focus on the applicability and effectiveness of new visual methods, using different classification criteria, and the combination of these with emerging technologies.

In conclusion, although QLF and other technologies for early caries detection present some advantages, this study did not find significant improvement in occlusal caries detection when compared to visual examination system.

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