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ORIGINAL ARTICLE

Caries detection under composite restorations by laser fluorescence and digital radiography

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Abstract
Objectives The objective of this study is to assess the potential of DIAGNOdent readings in detecting carious lesions under composite resin restorations in comparison with digital radiography.
Materials and methods One hundred extracted third molars were visually selected: 50 with and 50 without carious lesions. Class I occlusal cavities were prepared. In the carious group, caries were left on the floor of cavities before composite resin restoration. The occlusal surface relevant to the caries position in the carious group and a counterfeit point in the non-carious group were marked for DIAGNOdent reading. Teeth were fixed in a plaster box. Digital radiographs were taken and examined by four observers. Definitive diagnosis of caries was based on a histological assessment. Diagnostic accuracy for each method was expressed by the area under the receiver operating characteristic (ROC) curve. Differences between the areas under the ROC curves were assessed using the McNemar test.
Results The respective sensitivity (95 % confidence interval (%CI)) and specificity (95 %CI) of DIAGNOdent were 0.74 (0.66–0.83) and 0.84 (0.76–0.92). The respective average diagnostic performance values for digital radiographs assessed by four observers were 0.54 (0.36–0.72) and 0.77 (0.65–0.86). The respective ROC values for DIAGNOdent and digital radiographs based on four observers were 0.79 and 0.65. Cohen's kappa statistic revealed a moderate to substantial agreement among interobserver reliabilities (k=0.60–0.77).
Conclusions There were no statistically significant differences between DIAGNOdent and digital radiographs for the detection of dental caries under composite restoration (p value>0.05).
Clinical relevance DIAGNOdent was developed to detect caries on occlusal surfaces and was tested for caries adjacent to filling materials. This study demonstrated the use of DIAGNOdent in detecting caries under old composite restorations.

Keywords Caries detection · Laser fluorescence · Digital radiography · Accuracy · Reliability · Reproducibility

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Introduction

Carious lesions under filling materials are difficult to diagnose because we cannot see through the tooth substance and filling materials. Radiographs are therefore needed to assess demineralization under tooth restorations. Currently, digital radiography, which includes computer technology in the capture, display, enhancement, and storage of radiographic images, is considered equivalent to dental film for the detection of dental caries [1, 2]. However, manipulated digital radiographic images, which are the main advantage of digital radiography over radiographic films, may not improve the visibility of these dental caries [3]. In addition, the interpretation of digital radiographic images is based on the education level and experience of the observer [4] as well as other factors which affect an observer's performance [5].

The laser fluorescence-based instrument (DIAGNOdent) is a device measuring the fluorescence difference between the sound dental tissue and carious lesions. It examines tooth substances, either sound or carious lesions, and displays the results, according to histological findings, in numeric values, which can reduce human error. DIAGNOdent has been accepted for its reproducibility [6, 7] and sensitivity over conventional radiography [7] in primary occlusal caries in vitro and in vivo [8–11]. The investigation of a laser fluorescence effect to detect dental caries under a dental material has not yet been reported. Some studies evaluated secondary caries

adjacent to amalgam fillings [12] or composite resin restorations [13, 14], but not under a restorative material. This is probably because the interaction of fluorescence and composite resin has not been fully understood. Recently, laser fluorescence reading affected by dental materials has been reported in an in vitro study [15], which showed that the fluorescence value of the composite resin did not exceed the value used for caries detection; if the fluorescence value of restorative materials was higher than that for enamel caries, it could possibly result in a false-positive diagnosis.

The aims of this study were to assess if the laser fluorescent device (DIAGNOdent) could detect dental caries under a posterior composite resin filling material in an in vitro study and to compare its diagnostic performance with digital radiographic images.

Materials and methods

Tooth preparation

A total of 100 extracted human third molars, which were stored in thymol-saturated saline solution, were used in this study; 50 teeth with no visible carious lesions and 50 teeth with carious lesions on the occlusal surfaces were chosen. No patient identifiers or clinical information were available for any of the teeth. Class I cavity preparations were made as uniformly as possible. The pulpal floor extended at least 2 mm from the outer surface into the dentine. The occlusal width was approximately 2 mm through the groove. The marginal ridge width was 2 mm. A straight diamond fissure bur (FG 109 010 Diamond, Horico, Berlin, Germany)—in a high-speed handpiece with water spray as coolant—was used to cut the tooth substance. The carious lesions at the pulpal floor and axial wall were left. Teeth were scanned and recorded in a computer for future reference. The site of each carious lesion was marked on the occlusal surfaces (Fig. 1a). The same procedures were used for the non-carious teeth in order to blind the observers during DIAGNOdent measurement (Fig. 1b). The cavity was filled with composite resin (Z100TM, 3 M, St. Paul, MN, USA) without etching and bonding. The ethics committee at Khon Kaen University approved the study as it conformed to the Helsinki Declaration (HE450807).

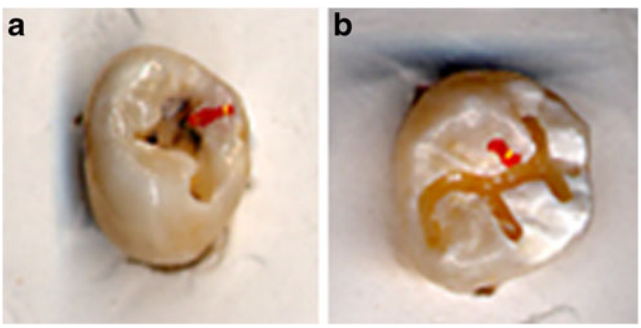

Fig. 1 Tooth preparation **a** with carious lesion site and **b** with non-carious site

Radiographic procedure

Each tooth was fixed in a plaster block. All direct digital radiographic images of the teeth were acquired using a charge-coupled device sensor (RVG UI sensor, Trophy, Beaubourg, France). Images of each tooth were obtained in the faciolingual view using a parallel technique. A digital X-ray unit (Novelix, Trophy, Beaubourg, France) with round collimation was operated at 60 kVp and 10 mA with a 0.08-s exposure time. The respective source-to-object distance and object-to-image receptor distance were 24 and 1 cm.

Image evaluation

Digital radiographic images were displayed using the Trophy Windows Imaging Software (RVG, Trophy, Beaubourg, France) on a 19-in SVGA monitor with a 1,024×768-pixel (256 gray levels) resolution (Laser-Computers, Dublin, Ireland) and stored in TIF format. All images were converted using sharpness function mode and examined by four sixth-year dental students who had no knowledge of the distribution of the simulated secondary carious lesions. Observers were informed of the design and the purpose of the experiment. Time for observation was not limited. Caries were defined when the observer found a radiolucent area under the composite resin, and no caries were defined when no radiolucent area could be detected. The same procedure of radiographic evaluation was repeated after 1 month to assess for intra-observer reliability.

DIAGNOdent readings

Teeth were cleaned. The occlusal surface was cleaned two times—first by fine pumice slurry and second by an air polisher (PROPHYflex 2 with #2012 powder, Kavo Dental, Biberach, Germany)—before being examined by DIAGNOdent.

DIAGNOdent (KaVo Dental, Biberach, Germany) with a conical fiber-optic tip (Tip A), in accordance with the manufacturer's instructions, was used. The assessment of a tooth with the laser fluorescence system was conducted as follows: after calibration with a ceramic standard, the fluorescence of a sound spot on the smooth surface of the tooth was measured in order to provide a baseline value for that tooth by a single observer. The observer had no prior knowledge of the distribution of the carious site. The time for measurements was not restricted. DIAGNOdent tip was measured at a marked point, which was labeled on all of the teeth as carious or non-carious. In order to get the maximum extension of

caries, the instrument was tilted around the measuring site as per manufacturer's recommendation and recorded in three locations per site directly on the tooth/restoration margin 1 mm from the margin on the tooth structure and 1 mm from the margin on the restoration [13]. The readings were done twice in a different order to reduce reading-order bias; they were then averaged and interpreted as sound or carious. The criterion for DIAGNOdent interpretation is as follows: it is sound from 0 to 14 and carious from 14 to 99.

Gold standard

For validation, all of the teeth were vertically cut at the marker point of the carious site, dividing the tooth into half sections using the ISOMET 4000 Precision Saw (Buehler Ltd., Lake Bluff, IL, USA) and dyed with caries detector. Each section was examined under a stereomicroscope (×10) (Nikon, Tokyo, Japan). All of the sections were examined carefully by two observers working together to assess the carious lesions. The results of the histological sections were as follows: there were 65 sound teeth (65 %) and 35 with residual caries (35 %).

Statistical analysis

The diagnostic test (sensitivity, specificity, predictive values, and likelihood ratio) with 95 % confidence interval (%CI) and the area of the receiver operating characteristic (ROC) curve were calculated for each modality. Differences between the areas under the ROC curves were assessed using the McNemar test at a significance level of 5 %.The degree of intra- and interobserver reliability was assessed using the kappa index. Statistical evaluations were performed using Stata 7.0 (Intercooled Stata 7.0, StataCorp LP, College Station, TX, USA)

Results

The numbers of carious teeth detected by DIAGNOdent and by the four observers on digital radiographs are shown in Tables 1 and 2, respectively. From these tables, the accuracy of DIAGNOdent in classifying teeth as carious or sound was higher (81 %) than that of the digital radiographs (65–73 %). The sensitivity (95 %CI), specificity (95 %CI), positive predictive value (95 %CI), negative predictive value (95 %CI), positive likelihood ratio (95 %CI), and negative likelihood ratio (95 %CI) of DIAGNOdent compared with those of the digital radiographic images are presented in Table 3. The probabilities of correctly detecting carious lesions and correctly detecting sound teeth by DIAGNOdent were 74 and 84 %, respectively, which are higher than those of digital radiography (sensitivity=54 % and specificity=77 %, respectively). Because of its higher sensitivity, the false-negative rate of DIAGNOdent would be less than that of digital radiography. Meanwhile, when the specificity of DIAGNOdent was higher, the false-positive rate was lower. The diagnostic performance of digital radiographs by each observer is shown in Table 4. The fourth observer showed the highest sensitivity (66 %) and the lowest specificity (68 %) in detecting carious lesions in digital radiographic images. The respective ROC for DIAGNOdent and digital radiographs based on the four observers was 0.79 and 0.65. There was no statistically significant difference between DIAGNOdent and digital radiography in detecting residual caries under composite resin restorations (p value=0.417).

The intra-observer reliability for digital radiography in observers 1–4 was 0.83, 0.64, 0.78, and 0.80, respectively. Three observers (observers 2, 3, and 4) showed a substantial agreement, and the other (observer 1) had almost a perfect agreement [16]. The kappa statistic showed moderate to substantial agreement for the interobserver reliability (k= 0.60–0.77) for the digital radiographic image interpretation. The kappa statistic was interpreted as per Landis and Koch [16], i.e., >0.80 is very good or almost perfect, 0.61–0.80 is good or substantial, 0.41–0.60 is moderate, 0.21–0.40 is fair, and <0.20 is poor agreement.

Table 1 The accurate number of carious teeth detected by DIAGNOdent

Method		Gold standard		Total
		Carious	Sound	
DIAGNOdent reading	Carious	26	10	36
	Sound	9	55	64
Total		35	65	100

Table 2 The accurate number of caries detection by four observers using the sharpness function of digital radiography

Image interpretation		Gold standard	
		Caries	Sound
Observer 1	Caries	16	16
	Sound	19	49
Observer 2	Caries	16	11
	Sound	19	54
Observer 3	Caries	20	12
	Sound	15	53
Observer 4	Caries	23	21
	Sound	12	44

Table 3 Sensitivity, specificity, predictive value and likelihood ratio for DIAGNOdent and digital radiography (by the four observers)

	DIAGNOdent (95 %CI)	Average diagnostic values of digital radiography (95 %CI)
Sensitivity	0.74 (0.66–0.83)	0.54 (0.36–0.72)
Specificity	0.84 (0.76–0.92)	0.77 (0.65–0.86)
Positive predictive value	0.72 (0.63–0.81)	0.56 (0.38–0.73)
Negative predictive value	0.85 (0.79–0.93)	0.75 (0.63–0.85)
Positive likelihood ratio	4.83 (2.72–8.89)	2.32 (1.35–3.98)
Negative likelihood ratio	0.30 (0.17–0.50)	0.60 (0.39–0.84)

Discussion

The contribution of fluorescence difference techniques to detect carious lesions under composite filling materials in carious teeth is not established. The present study indicates the potential of DIAGNOdent for detecting carious lesions under a composite filling material with higher sensitivity and specificity than digital radiography. Notwithstanding, there was no significant difference between the methods.

In comparing the two methods, DIAGNOdent showed higher values for all diagnostic tests, except in the negative likelihood ratio. This implies that DIAGNOdent has greater potential over digital radiography in identifying dental caries. The ROC curve, which represents the relationship between the ability to correctly identify carious teeth and the false-positive fraction, had a value of 0.79 for DIAGNOdent, which was interpreted as fair according to Hanley et al. [17]. In comparison, it was 0.65 for digital radiography, which represents poor accuracy, implying limitations in the perception of the human eyes.

Since positive and negative predictive values are sensitive to the prevalence of disease, a good test should have a high predictive value irrespective of the prevalence of disease. In this study, DIAGNOdent had higher positive and negative predictive values. This means that if the prevalence of the caries is high, then the predictive value of a carious lesion will also be high. DIAGNOdent had a higher positive likelihood ratio value, indicating high sensitivity and a low false-positive rate, whereas the low negative likelihood ratio suggests that DIAGNOdent has a low false-negative rate and high specificity.

The potential of rays from the laser fluorescence device to pass through composite resin was reported in the experimental study [15]. The results showed that baseline fluorescence values for composite resin were not higher than those for caries. Therefore, our study implemented this finding to a clinically relevant situation by examining the fluorescence value of composite restorations within tooth structures. As we did not use bonding agents in our experiment, we could not evaluate whether or not they impeded fluorescence readings [18]. Although restorations without bonding agents may not occur in a clinical situation, we anticipate that this finding might nevertheless be useful in tooth restorations with wear, which show filling material leakage, either through the dentine–adhesive interface or by porosity in the adhesive and composite layers.

DIAGNOdent has very high reproducibility [6, 19] which is superior to that of conventional methods (visual and bitewing examination) [14]. DIAGNOdent readings are repeatable irrespective of the number of readings [20] with no difference between dentists and students [21]. In the current study, we had high intra- and inter-examiner reproducibility for digital radiography and an average value for DIAGNOdent readings [13].

The performance of DIAGNOdent in clinical practice may be premature, even though it was shown to be effective in studies in vitro, for the following reasons. There are differences in the clinical and laboratory situations, such as salivary flow, temperature, stains on teeth, or restorations, which may impact the results. It has been suggested that polishing dental fillings prior to DIAGNOdent measurements might correct some limitations [15]. One in vitro

Table 4 Sensitivity, specificity, predictive value and likelihood ratio of digital radiographs for each observer

Observer	Sensitivity (95 %CI)	Specificity (95 %CI)	Positive PV (95 %CI)	Negative PV (95 %CI)	Positive LR (95 % CI)	Negative LR (95 %CI)
1	0.45 (0.36–0.55)	0.75 (0.67–0.84)	0.50 (0.40–0.60)	0.72 (0.63–0.81)	1.86 (1.07–3.22)	0.72 (0.49–0.97)
2	0.46 (0.36–0.55)	0.83 (0.76–0.90)	0.59 (0.60–0.69)	0.74 (0.65–0.73)	2.71 (1.42–5.14)	0.65 (0.45–0.86)
3	0.57 (0.47–0.67)	0.82 (0.74–0.89)	0.63 (0.53–0.72)	0.78 (0.80–0.86)	3.09 (1.74–5.57)	0.52 (0.34–0.74)
4	0.66 (0.56–0.75)	0.68 (0.59–0.77)	0.52 (0.42–0.62)	0.79 (0.81–0.87)	2.03 (1.32–3.12)	0.50 (0.30–0.78)

PV predictive value, *LR* likelihood ratio

study showed that tooth storing solutions can influence the fluorescence yield [22]. In our study, the use of thymol-saturated saline storage may have had an influence on the response of the infrared laser fluorescence so that the results may not be extrapolated to the in vivo situation.

To obtain the best diagnostic value from both methods in clinical practice, one must recognize the factors which can affect the results obtained. Digital radiography is used when occult caries are suspected. Digital radiography has the advantage of presenting the site of the carious lesion and the potential for image manipulation, which may offer better visibility [23, 24]. However, it does not increase diagnostic accuracy [25]. Although the present study used the sharpness function for digital radiographic images, which has been tested to improve dental caries diagnosis [24], its sensitivity was lower than that of DIAGNOdent. It is certain that many factors, such as observer performance, the lesion size [26, 27], the location of carious lesion [28], and the exposure factor [29], affect radiographic interpretation. Differences in radiopacity values between materials indicate that the problems in interpretation may occur in the clinical situation [28, 30], but porosity in composite resin restorations may also cause false-positive findings.

Our study supports the use of DIAGNOdent to detect caries under composite restorations and is consistent with the findings from the study conducted by Lennon [31], which showed greater sensitivity of DIAGNOdent than visual tactile examination and caries-detector dye in detecting residual caries at the open cavity floor [31]. Some studies [32] that reported the sensitivity of DIAGNOdent in residual caries detection did not recommend its use. Klause et al. [33] indicated a limitation of DIAGNOdent when assessing residual caries close to the dental pulp. This implies that many factors affect fluorescence values in clinical practice and, therefore, should be further studied.

However, there are major difficulties in validating the diagnosis of dental caries in clinical practice when caries are present beneath the filling. Based on the findings of the current in vitro study (in which validated caries diagnosis under the restoration was possible), DIAGNOdent can be considered as an auxiliary method for the detection of dental caries under composite restorations even though its effectiveness in clinical situations is yet to be established.

Conclusions

The performance of a laser fluorescent device (DIAGNOdent) was not significantly different from that of digital radiographic images in detecting in vitro dental caries under a posterior composite resin filling material.

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

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