Comparison between a laser fluorescence device and visual examination in the detection of occlusal caries in children

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Abstract
Occlusal surfaces of molars are especially susceptible to the development of caries due to the features, such as pits and deep fissures, of their anatomical structure.

**Aim:** To evaluate the efficiency of DIAGNOdent laser fluorescence measurements in comparison with visual examination for occlusal caries detection for first permanent molars in children.

**Methods:** The study involved 156 permanent molar teeth in 40 children aged 7–12 years. A relatively new technology, the fluorescence laser DIAGNOdent pen, was used for detecting and diagnosing caries on the occlusal surfaces of molars. The visual examination of fissures was based on the Ekstrand classification system.

**Results:** The results showed a strong relationship between examination with the DIAGNOdent and visual inspection. DIAGNOdent's sensitivity and specificity were 97% and 52%, respectively, indicating that the laser fluorescence DIAGNOdent pen is a reproducible and accurate diagnostic tool that may be very helpful in conjunction with visual examination in the detection of occlusal caries in permanent molars in children.

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1. Introduction

The occlusal surfaces of molars are especially susceptible to the development of caries due to their anatomical structure, which contains pits and deep fissures (Weerheijm and Gruythuysen, 1992). In industrialized nations, the caries prevalence rate has decreased and the occlusal surface of the tooth has become the most affected surface (Newbrun, 1993). The majority of caries lesions in the school-aged population is concentrated on the masticatory surfaces of the first permanent molars, followed by approximal surfaces on posterior teeth (Batchelor and Sheiham, 2004).

Caries diagnosis requires a thorough dental examination and close attention to the clinical evidence. Nevertheless, many studies have demonstrated that diagnosing occlusal caries without cavities is difficult, and that both false-positive and false-negative findings occur frequently (Horowitz, 2004; Badger et al., 2002; Sheehy et al., 2001). Accordingly, as a visual exam is a subjunctive method, it is difficult to diagnose occlusal caries using only this method (Lussi, 1991; Lussi, 1993).

Complementary tools, such as the laser fluorescence system DIAGNOdent, may be used in order to avoid the occurrence of false-positive and false-negative findings. Furthermore, it is very important to know the degree of carious demineralized occlusal surfaces susceptible to remineralizing treatment, the
There are a number of relatively new detection technologies commercially available to help in the early detection of carious lesions (Young, 2002). One such device is DIAGNODent, which involves fluorescence measurements performed by a laser device. Development of the DIAGNODent came about thanks to the work of Hibst and Gall who showed in 1998 that exposing a tooth surface to red light (638–655 nm) helps to differentiate between sound and carious tissues. This is because the fluorescence intensity caused by excitation in caries lesions exceeds that of healthy tissues. Red emission light, in addition to infrared fluorescence excitation, is less well absorbed and scattered by enamel than light of shorter wavelengths. Red light penetrates deeper into the tissue, enabling fluorescence detection even from carious dentine under visibly sound enamel (Hibst and Gall, 1998). Two laser fluorescence-based devices are available: the DIAGNODent 2095 and the DIAGNODent pen 2190 (Rodrigues et al., 2011).

When the laser irradiates the tooth, the light is absorbed by organic and inorganic substances present in the dental tissues, as well as by metabolites from oral bacteria (Hibst and Paulus, 2000). These metabolites may be porphyrins that are produced by several types of oral bacteria. Studies using chromatography have found that porphyrins showed some fluorescence after excitation by red light (Lussi et al., 2004).

Decalcified areas in the enamel and dentin structure stimulate fluorescent light of a different wavelength. The resulting fluorescence is evaluated by the appropriate electronic system in the DIAGNODent unit, measured by a photodiode and converted into digital values that appear on a screen. Fluorescence intensity values, from 0 to 99, are transformed into an acoustic signal. DIAGNODent readings between zero and 14 indicate a healthy occlusal surface, readings between 15 and 20 indicate the presence of enamel caries, and readings of 21 or more indicate the presence of dentinal caries (DIAGNODent, KaVo, Biberach, Germany).

According to a relatively recent systematic review (Bader and Shugars, 2004), further assessment of the laser device in clinical applications is needed, especially with regard to anatomical factors that interfere with the laser fluorescence device’s ability to assess occlusal caries. Accordingly, DIAGNODent readings should not be relied on when making diagnostic decisions (Markowitz et al., 2012).

Few studies have been performed to compare the results of clinical examination with those obtained through the use of the DIAGNODent for the diagnosis of children’s permanent molars. For this reason, the decision was made to study the validity of this instrument by measuring the fluorescence of occlusal surfaces and to compare the results with the results of a visual examination of first permanent molars in children.

### 1.1. The aim of the study

To evaluate the efficiency of laser fluorescence measurements, obtained using the DIAGNODent pen, by comparing with visual measurement for the detection of occlusal caries for first permanent molars in a convenience sample of boys and girls aged 7 through 12 years who sought dental care at the pediatric clinic of Damascus University.

### 2. Materials and methods

#### 2.1. Study sample

The study involved 156 first permanent molars from 40 patients aged 7 to 12 years, who were referred for treatment at the Pediatric Department of Damascus University. Ethical approval was given by the Ethics Committee of the Faculty of Dental Surgery in Damascus University.

The mean patient age was 9.5 ± 1.8 years, with 21 male and 19 female subjects. The study used first permanent molars with and without carious lesions. In order to be included in the study, patients had to have at least one permanent molar that met the following criteria: be fully erupted (surface free from any gingival tissues) and have no restoration on the occlusal surface; not be sealed; and have no hypoplastic surfaces, pathological abrasions or other structural defects. Excluded from the sample were the molars of children who had systemic diseases that could interfere with the diagnostic process such as temporomandibular joint defects that limit the child’s ability to open his or her mouth and other syndromes that made it impossible for the child to cooperate. There were 79 upper molars and 77 lower molars.

Histological validation was not possible in this clinical study. The gold standards were visual examination and DIAGNODent® manufacturer’s criteria.

#### 2.2. Assessment parameters

##### 2.2.1. Visual clinical examination

Visual examination was always carried out first in order to eliminate the possibility of the laser fluorescence system producing bias in the visual scores obtained. One dentist visually examined all the teeth in the study. Visual clinical examination was performed without probing with patients positioned in a dental chair and with the aid of a light reflector, air/water spray and plane buccal mirror. No prior professional cleaning was carried out and no magnifying device was used. After drying the tooth surface for 3 to 5 s, the visual inspection was performed. The criteria used to record the visual appearance of teeth were based on Ekstrand’s ranked system (Ekstrand et al., 1997) and are shown in Table 1.

##### 2.2.2. Laser fluorescence examination

Scanning with the laser fluorescence system (DIAGNODent LF Pen, KaVo, Biberach, Germany) was performed after the initial visual dental examination. The examiner was trained to use the laser equipment following the manufacturer instructions. No professional cleaning was done. The occlusal surface was briefly air-dried using a 3-in-1 air syringe for 10 s. Care was taken to tilt the instrument around the measuring site to ensure that the tip picked up fluorescence from the slopes of the fissure walls. The DIAGNODent device currently available on the market is equipped with two diagnostic tips: a cone-shaped “A” tip designed for fissures and a broad “B” tip for smooth, buccal and lingual surfaces of teeth. Probe tip A (narrow) was then tracked across the occlusal fissure and a peak reading recorded. The probe tip was positioned on this spot and rotated around its vertical axis until the highest value was found, which could range from 0 (sound) to 99 (caries). The peak value (maximum fluorescence) readings were then
recorded according to the DIAGNOdent manufacturer’s criteria: 0–14 = no caries; 15–20 = enamel caries; >21 = dentinal caries (Table 2). Then the preventive or operative treatment was performed at the Department of Pediatric Dentistry at the Faculty of Dental Surgery at Damascus University as follows: 0–14 = no caries and no care advised; 15–20 = enamel caries and preventive care advised; >21 = dentinal caries and preventive or operative treatment advised, depending on patient’s caries risk; and >30 = operative treatment required (Table 7).

### 2.3. Statistical analysis

Visual examinations of fissures by Ekstrand’s scoring system were compared with maximal laser measurements according to the DIAGNOdent manufacturer’s criteria, as shown in Table 2. The obtained results were analyzed statistically using SPSS Version 13 statistical software. The inter-rater reliability was tested using kappa values, in addition to determination of the odd ratios, sensitivity, specificity, receiver operating characteristic (ROC) curves for the laser fluorescence system, and the value of the area under curve (AUC). The kappa statistic is used for comparing two raters when the raters have a different range of scores. Sensitivity and specificity are terms used to describe the value of tests. The subsequent formulae were used to determine the following values based on true-positives, false-positives, true-negatives, and false-negatives.

\[
\text{Sensitivity} = \frac{a}{a + c}, \quad \text{Specificity} = \frac{d}{b + d}, \quad \text{Positive Predictive Value} = \frac{a}{a + b}, \quad \text{Negative Predictive Value} = \frac{d}{c + d}
\]

### 3. Results

#### 3.1. Results of visual evaluation

Table 3 lists the results of the visual evaluation: 23 (14.7%) teeth scored 0, 52 (33.0%) scored 1, 35 (22.4%) scored 2, 36 (23.1%) scored 3, and 10 (6.4%) scored 4.

#### 3.2. Results of laser fluorescence evaluation

The laser fluorescence evaluation results are detailed in Table 4. Briefly, 16 (10.2%) molars had a score of 0, 39 (25.0%) had a score of 1, and 111 (71.1%) had a score of 2.

### 3.3. Interpretation of results and statistical analyses

#### 3.3.1. The level of concordance in frequencies of caries presence between clinical examination and the DIAGNOdent pen

The results of the definition of the clinical presence of caries in the laser fluorescence DIAGNOdent pen system in relation to the presence of caries in the visual examination are shown in Table 5. There were 16 teeth with a DIAGNOdent score of 0, corresponding to a visual caries score of: 12 with score 0, 4 with score 1, and 0 with score 2, 3, and 4. For a DIAGNOdent score of 1, there were 39 teeth with the following visual caries scores: 10 with score 0, 27 with score 1, 2 with score 2, and 0 with score 3 and 4. For a DIAGNOdent score of 2, there were 111 teeth with visual caries scores of: 1 with score 0, 21 with score 1, 33 with score 2, 36 with score 3, and 10 with score 4.

### Table 1

<table>
<thead>
<tr>
<th>Score</th>
<th>Criteria</th>
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<tbody>
<tr>
<td>0</td>
<td>No or slight change in enamel translucency after prolonged air-drying (5 s).</td>
</tr>
<tr>
<td>1</td>
<td>Opacity or discoloration hardly visible without drying, but distinctly visible after air-drying.</td>
</tr>
<tr>
<td>2</td>
<td>Opacity or discoloration distinctly visible even without air-drying.</td>
</tr>
<tr>
<td>3</td>
<td>Localized enamel breakdown in opaque or discolored enamel and/ or grayish discoloration from the underlying dentin.</td>
</tr>
<tr>
<td>4</td>
<td>Cavitation in opaque or discolored enamel exposing to dentin beneath.</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Score</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–14</td>
<td>No caries</td>
</tr>
<tr>
<td>15–20</td>
<td>Enamel caries</td>
</tr>
<tr>
<td>21–99</td>
<td>Dentinal caries</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Score</th>
<th>Criteria</th>
<th>No. molars</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No or slight change in enamel translucency after prolonged air-drying (5 s).</td>
<td>23</td>
<td>14.7</td>
</tr>
<tr>
<td>1</td>
<td>Opacity or discoloration hardly visible without drying, but distinctly visible after air-drying.</td>
<td>52</td>
<td>33</td>
</tr>
<tr>
<td>2</td>
<td>Opacity or discoloration distinctly visible even without air-drying.</td>
<td>35</td>
<td>22.4</td>
</tr>
<tr>
<td>3</td>
<td>Localized enamel breakdown in opaque or discolored enamel and/ or grayish discoloration from the underlying dentin.</td>
<td>36</td>
<td>23.1</td>
</tr>
<tr>
<td>4</td>
<td>Cavitation in opaque or discolored enamel exposing to dentin beneath.</td>
<td>10</td>
<td>6.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>156</td>
<td>100</td>
</tr>
</tbody>
</table>
3.3.2. Kappa value
The kappa value was 0.94, which as shown in Table 6, lies in the 0.81–1.00 band and is considered almost perfect (Landis and Koch, 1977). The results showed a better relationship between visual inspection and examination with DIAGNOdent, meaning that DIAGNOdent is a diagnostic modality in the present study with respect to operative intervention.

3.3.3. Sensitivity and specificity
The positive and negative odds ratios were 82.73 and 7.7, respectively. The positive and negative predictive values were 7.1 and 2.6, respectively. The limitation was that the sensitivity and specificity of the laser fluorescence system were 0.97 and 0.52, respectively.

3.3.4. ROC curves and the value of the AUC
To determine the laser fluorescence pen’s diagnostic precision, an ROC curve was traced. The AUC value of the ROC curve for the laser fluorescence system for permanent molars was 0.924 (Fig. 1).

4. Discussion
Not only is the occlusal surface the area that is most susceptible to dental caries, it is also the most difficult surface for the reliable detection of caries (Pinheiro et al., 2008). For this reason, several investigators have attempted to discover a method capable of assisting the clinical examination in diagnosing occlusal caries.

Among the methods reviewed, the laser fluorescence of the DIAGNOdent pen appliance (KAVO, Biberach, Germany) has shown the greatest promise. The caries-detection capability of the DIAGNOdent has been tested on occlusal surfaces in numerous studies (Lussi et al., 1999, 2001; Shi et al., 2000; Attrill and Ashley, 2001; El-Housseiny and Jamjoum, 2001; Heinrich-Weltzien et al., 2003; Anttonen et al., 2003; Córtes et al., 2003; Lussi and Francescut, 2003), and its performance has been compared with that of visual inspection, histology, radiography, and quantitative light-induced fluorescence.

This study evaluated the clinical applicability of the DIAGNOdent laser device as a complementary tool in the visual exploration of the occlusal surfaces of permanent first molars. The criteria adopted in this study to determine the validity of the DIAGNOdent was published by Ekstrand et al. (1997), which classified the integrity of the occlusal surface according to its histological validation. However, histological validation was not possible in this clinical study and thus we used the gold standard, visual examination, which is essential for confirmation of the laser device’s diagnosis, similar to other authors (Heinrich-Weltzien et al., 2003; Sheehy et al., 2001).

The DIAGNOdent evaluation criteria in this study used were those defined previously by the manufacturer. In addition, several authors (Rocha et al., 2003; Alwas-Danowska et al., 2002; Lussi et al., 1999; Heinrich-Weltzien et al., 2003;
Konig et al., 1993) used the same criteria as those used in other in vivo studies (Cortés et al., 2003; Seremidi et al., 2011).

This study included 156 first permanent molars from 40 patients aged from 7 to 12 years old. The mean patient age was 9.5 ± 1.8 years, with 21 male and 19 female. This study, like others (Huth et al., 2008; Toraman Alkurt et al., 2008), detected caries in the occlusal surface of first permanent molars. The study of Tomasi et al. (2005) also included 237 first permanent molars, not sealed and non-cavitated due to caries, in 84 children aged 6–7 years (mean age 6.74 ± 0.63). The study of Sheehy et al. (2001) included 170 first permanent molars and compared the DIAGNOdent with a visual caries-scoring system (Ekstrand et al., 1997).

4.1. The kappa value

The kappa coefficient, which is very important for assessing the reproducibility of a method, was employed to measure the agreement between the categorical data. In the present study, the kappa value was 0.94 indicating good repeatability for both the laser fluorescence device and visual examination (Landis and Koch, 1977). The reported kappa value in similar comparative studies in the literature varies widely: it was 0.98 in the study of Lussi et al. (1999), 0.89 in the study of Sheehy et al. (2001), 0.93 in the categorical data study of Lussi et al. (2001), 0.85 in the study of Anttonen and Vuokko (2007), 0.88 in the study of Heinrich-Weltzien et al., 2003, 0.816 in the study of Zaidi et al. (2010), but just 0.231 in the study of Duruturk et al. (2011), revealing “poor” statistical agreement between the two diagnostic methods. This may be because the method is correct for the early caries lesions in newly erupted first permanent molars only. All these studies of the occlusal surface were in vivo and these figures represented good to excellent agreement. Nonetheless, reproducibility is not always important, because a test may be reproducible, but inaccurate. Accordingly, the sensitivity and specificity tests are vital for assessing the worth of a diagnostic method.

4.2. Sensitivity and specificity

In this study, the sensitivity and specificity of the laser fluorescence system were 97% and 52%, respectively. Various in vivo studies have evaluated DIAGNOdent’s sensitivity and specificity (Barbariá et al., 2008; Sheehy et al., 2001). Although most sensitivity values tended to be high, they varied widely, from 0.19 to 1.0. Specificity values exhibited a similar pattern, ranging from 0.52 to 1.0 (Bader and Shugars, 2004). The sensitivity value obtained in this study was 97%, which was 17% higher than that obtained by Verdonschot et al. (2002), 40% higher than that of Barbariá et al. (2008), 81% higher than that of Angnes et al. (2005), and 92% higher than that obtained by Sheehy et al. (2001).

The sensitivity and specificity of the DIAGNOdent experimental method in the study of Lussi et al. (2001) were 92% and 86%, respectively, when carious dentin was the cut-off point; when carious enamel was the threshold, the sensitivity was about 96%. In the literature, varying sensitivities and specificities have been reported: 93% sensitivity and 75% specificity in the study of Costa et al. (2008), 89.9% sensitivity and 53.7% specificity that of Krause et al. (2007), 92% sensitivity and 82% specificity in that of Anttonen and Vuokko (2007), 44% specificity in that of Chu et al. (2009), and 62% sensitivity and 87% specificity in the study of Rodrigues et al. (2011). These differences may be due to the fact that some of the studies excluded lesions with cavities, thereby increasing the percentage of healthy teeth and caries limited to enamel.

4.3. AUC

The AUC value for the ROC curve for the laser fluorescence system was 0.924, which is similar to the 0.92 obtained by Reis et al. (2006), but higher than obtained by Huth et al. (2008), the 0.72 obtained by Barbariá et al. (2008), and the 0.6 obtained by Angnes et al. (2005). Thus, as the AUC in this study for first permanent molars was close to 1, these results make it possible to state that the laser device is a highly precise tool for the diagnosis of occlusal caries in permanent molars.

5. Conclusions

From the results of this study we believe that the DIAGNOdent pen is a reproducible and accurate diagnostic tool that may be valuable as an adjunct to visual examination for occlusal caries detection in first permanent molars in children.

5.1. Clinical Implications

In daily practice, dentists can consider the laser fluorescence system a complementary tool in the visual exploration of occlusal surfaces of first permanent molars. On the other hand, this procedure avoided the problem of false negative findings, which are common in clinical studies with respect to ethical aspects.

Although the evidence recommends the use of laser fluorescence as a diagnostic adjunct, further in vivo studies are required, preferably comparing laser fluorescence (LF) to a combination of visual examination (VE) and radiographic examination (RE).

Future studies should also include all types of teeth tested under varying conditions found in the oral cavity (restorations, sealants, staining, calculus and plaque).

Larger sample sizes from varying age groups and diverse ethnicities will also help strengthen the results, and provide greater confidence when applying the findings to clinical practice (Aversa et al., 2008).

References


