Visual Examination, Fluorescence-Aided Caries Excavation (FACE) Technology, Bitewing X-Ray Radiography in the Detection of Occlusal Caries in First Permanent Molars in Children

Sigalit Blumer*/ Johnny Kharouba**/ Lazar Kats*** / Dora Schachter****/ Hanaa Azem*****

Objectives: *To compare the effectiveness of visual examination, radiographic examination and fluorescence-aided caries excavation (FACE) in detecting occlusal caries in first permanent molars in 150 children aged 6-14 years with intact occlusal surface with caries lesions without cavitation, or with darkened or deep fissures that had no clear diagnosis.* ***Study design:*** *Two dentists independently performed a visual oral examination, FACE and bitewing radiography. The inter-rater reliability of each detection method was determined and their specificity and sensitivity.* ***Results:*** *All caries detection methods showed high inter-rater reliability with absolute agreement between raters above 90%. Most caries lesions were detected by visual (75.8%) and FACE (79.1%), while only 28.8% of lesions were detected by radiography. Detection by visual examination was strongly correlated with detection by FACE (X^2=37.9, Phi=0.498, p<0.001). A lower, yet statistically significant, correlation was found between visual examination and X-ray radiography (X^2=5.53, Phi=0.190, p<0.001). FACE had higher sensitivity (87%) and specificity (65%) for detecting occlusal caries in comparison with radiography (60% specificity and 55% sensitivity).* ***Conclusion:*** *Although visual examination remains the best method to detect occlusal caries in young permanent molars in children, FACE is an effective and accurate diagnostic tool that may aid in detection and treatment decisions.*

Keywords: *caries detection, first permanent molars, occlusal caries fluorescence-aided caries excavation.*

INTRODUCTION

Despite a significant decline in the prevalence of caries since the mid-1970s,[1-3] dental caries remains one of the most prevalent chronic diseases; it is estimated that more than 530 million children worldwide are affected by caries of primary teeth and 2.3 billion people have caries of permanent teeth.[4]

The macro morphology of the occlusal surface, specifically the groove fossa system, together with a relatively long eruption period with reduced mechanical oral function favors bacteria adherence.[5] Several studies have demonstrated that the occlusal surface of the first permanent molars is the dentition site most frequently affected by dental caries,[6-10] and that the highest caries incidence was observed in the first molars followed by the second molars.[11-14] A high incidence of occlusal caries in these teeth was observed during the process of eruption,[10,15,16] immediately after eruption,[10,15,17] and 1-3 years after eruption.[8,10,17] A Danish study has shown that although the occlusal surfaces constitute less than 15% of all dentition surfaces, half of caries experience in 18-year-olds is located occlusally.[18]

Fissure morphology and the pattern of lesion development contribute to the difficulty of occlusal caries detection.[19] Fissure anatomy comprises shallow fossae with a little narrowing towards the base (i.e. a "U" or "V" shape);[19] However occlusal fissures have a different anatomy whereby the base is located below a narrowing that is frequently closed off by organic material debris.[20] When

From the Maurice and Gabriela Goldschleger School of Dental Medicine, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel.
*Sigalit Blumer, DMD, Head of the Department of Pediatric Dentistry.
**Johnny Kharouba, DMD, Department of Pediatric Dentistry.
***Lazar Kats, DMD, the Department of Oral Pathology, Oral Medicine and Maxillofacial Radiology.
****Dora Schachter, DMD, the Department of Pediatric Dentistry.
*****Hanaa Azem, DMD, the Department of Pediatric Dentistry.

Corresponding author:
Sigalit Blumer, Department of Paediatric Dentistry, The Maurice and Gabriela Goldschleger School of Dental Medicine, the Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel.
Phone: +972-3-6409254
Fax: +972-3-6409250
E-mail : blumer@012.net.il

bacteria gain access to the microenvironment developed below this narrowing, a caries lesion may develop at the base of the fissure without being detected, since the enamel remains clinically intact. Current preventive methods cannot prevent this process.

The initial stages of caries present as a white spot lesion (WSL) due to the changed visual characteristics of the enamel due to less mineral being present. However, the visual diagnostic process of the occlusal surfaces may be impaired by various factors, such as the presence of dental plaque, non-standardized examination process (poor light, presence of saliva, difficult access, etc.), and the presence of other enamel defects on the surface (dental fluorosis, hypoplasia, molar incisor hypomineralization). Another challenge in visual diagnosis of occlusal surfaces is related to the frequent application of topical fluoride, which is essential for reducing caries lesions and slowing their progression. Fluoride has been associated with the occurrence of "hidden caries" lesions.[21] In such cases, dentinal lesions progress under a clinically intact surface, leading to difficulties in visual diagnosis.[22]

Early detection and diagnosis of non-cavitated lesions are important for preventing caries progression. Moreover, as progression of non-cavitated lesions is slower than that of cavitated ones, preventive treatment may be used to stop progression.[23]

Methods for caries detection and diagnosis usually rely on subjective interpretation of location, surface texture and color using a dental probe or explorer and bitewing radiographs.[24] The procedure involves the visual identification of demineralized areas (typically white spots) or suspicious pits or fissures. These methods usually detect caries lesions only when about one-third or more of the thickness of enamel is involved; i.e., when caries is relatively advanced.[25] Tactile detection depends on the use of the dental explorer to determine the presence of a loss of continuity or breaks in the enamel and assess the softness or resilience of the enamel. The typical use of the dental explorer to probe the suspicious areas often results in the rupture of the surface layer covering early lesions, and may produce small enamel defects that may offer a point of entry for bacterial activity, or can preclude remineralization or noninvasive treatment by causing non-cavitated lesions to become cavitated.[26] The use of such instruments on occlusal surfaces contaminated by bacteria may transmit bacteria to other previously uncontaminated surfaces. Furthermore, the dental explorer may stick into the pit or fissure because of the morphology of the occlusal surface rather than because of the presence of dental caries. Therefore, the conventional use of tactile evaluation with an explorer leads to over-diagnoses and the need for intervention. Consequently, the use of the dental explorer to probe enamel is no longer recommended. Instead, it is recommended to use a ball-ended probe to judiciously remove plaque and debris to permit visual inspection of pits and fissures.[27]

Radiography is also limited in its ability to detect occlusal carious lesions, especially in their early stages[28,29] because the lesion in a pit or fissure is obscured by dense, sound enamel.[30] When an occlusal lesion is detected on a bitewing radiograph, the lesion may have already reached the middle third of dentine and hence is beyond the scope of remineralization interventions.[28] Moreover, radiography cannot distinguish between active and arrested lesions and sometimes between non-cavitated and cavitated lesions.[31] Another concern is the standardization of the image acquisition process, as the intraoral positioning of the film/sensor varies.[32]

Hence, visual examination and radiography rely on subjective interpretation and are insensitive to early caries detection. It is widely recognized that the current methods cannot detect caries lesions until a relatively advanced stage, involving as much as one-third or more of the thickness of enamel. False positive diagnoses may lead to unnecessary invasive treatments.[33] An ideal method for caries detection should offer high specificity, sensitivity, and reproducibility. Moreover, quantitative methods may be more useful for improving reliability.

The disadvantages of conventional caries detection methods and the need for additional detection methods have led to the development of non-invasive optical methods for caries diagnosis that may allow better identification and recognition of lesions compared to the conventional visual examination. These include fiber-optic transillumination, light scattering, laser or light-emitting diode (LED) and fluorescence-aided caries excavation (FACE).[34]

Technologies based on light or laser-induced fluorescence, such as FACE, use the characteristic orange-red autofluorescence emitted by bacterial metabolic products (porphyrins and metalloporphyrins) when illuminated by light or laser, as a marker for infected tissues.[35-39] Porphyrins and metalloporphyrins typically have absorption maxima between 398 and 421 nm and emission maxima between 530 and 633 nm.[40] Spectrographic studies have shown that carious dentine fluoresces more intensely in the red portion of the visible spectrum than healthy dentine.[41,42] In contrast, unaffected dentin displays blue-violet light. One such device is the D-light Pro GC (GC Europe N. V. Leuven, Belgium) which uses LED at near ultraviolet wavelengths to visualize bacteria in plaque, fissures, infected dentin and the presence of micro-leakage.

The aim of the present study was to compare the effectiveness of visual examination, radiographic examination and FACE (using the D-light Pro GC) in detecting occlusal caries in first permanent molars in children.

MATERIALS AND METHODS

Children aged 6-14 years who were referred for treatment at the Pediatric Dentistry Department at Tel Aviv University's Faculty of Medicine were included in the study if they had first permanent molars with intact occlusal surface, with caries lesions without cavitation (white spots), or with darkened or deep fissures that had no clear diagnosis. Children were excluded from participation if they had teeth with caries lesions presenting a collapse of the enamel occlusal surface, restored or sealed teeth. Teeth that were diagnosed with occlusal caries by X-ray imaging were also excluded.

The study was approved by Tel Aviv University's Ethics and Research Committee. All participants provided informed consent prior to participation in this study.

Sample size calculation

Sample size was calculated using the G-power software version 3.1 under the following assumptions: power of 80%, type I error (alpha) of 5%. The main hypothesis of the study was that radiographic examination and D-Light Pro GC would show a statistically significant difference in their ability to detect occlusal caries in first permanent molars in children, using visual examination as the gold standard. Based on previous studies,[43,44] we used size effect as the correlation between detection derived from visual examination and detection by radiographic examination or D-Light Pro GC. We assumed a correlation effect of r=0.35 between the gold standard and the other examination methods. Hence, the minimum sample size needed was 49 for each method, that is a total of 147 first permanent molars.

Assessments and data collection

Before the assessment of the cases in the study, all study dentists participated in a calibration session in which the scales used in the study were explained.

To eliminate the possibility of bias in visual scores, half of the patients (n=75) were first examined visually followed by examination with FACE, and the rest of the patients were first examined with FACE followed by a visual examination. All examinations were performed by two dentists, with each dentist performing an independent evaluation.

Visual examination

Before the visual examination the tested pits and fissures were cleaned by ball-ended probe and cotton rolls to judiciously remove plaque and debris. The teeth were examined before drying, then the teeth were dried for 5 seconds and examined again without probing with the aid of a light reflector, air/water spray and plane buccal mirror while patients were positioned in a dental chair. No prior professional cleaning was carried out prior to the visual exam and no magnifying device was used. The visual appearance of the teeth was rated according to Ekstrand's scoring system (0 = no or slight change in enamel translucency after prolonged air- drying (5 s); 1 = opacity or discoloration hardly visible without drying, but visible after air-drying; 2 = opacity or discoloration visible even without air-drying; 3 = localized enamel breakdown in opaque or discolored enamel and/or grayish discoloration from the underlying dentin and 4 = Cavitation in opaque or discolored enamel exposing to dentin).[45]

Fluorescence-aided caries excavation (FACE)

FACE was performed using the D-Light Pro (GC). The dentist was trained to use the equipment according to the manufacturer's instructions. No professional cleaning was done prior to FACE; however the tested pits and fissures were cleaned by ball-ended probe and cotton rolls to judiciously remove plaque and debris. The occlusal surface was air-dried for 5 seconds using a 3-in-1 air syringe. Cotton rolls were used if the patient presented excessive salivation. The Dt function of the device was used for 60 seconds on the suspected occlusal surface, with the tip positioned on the vertical axis of the explored occlusal surface. The red reflection of the pit or fissure was used as an indicator for the presence of a dental caries lesion.

Radiographic examination

Bitewing radiographs were taken immediately after the visual examination as part of the routine examination according to the American Academy of Pediatric Dentistry (AAPD) Guideline on caries risk assessment.[46] The teeth were radiographed per standard intra-oral photostimulable phosphor (PSP) imaging plates held in bitewing film holders and mounted such that the occlusal plane of each tooth was parallel to the x-ray beam and perpendicular to the film or imaging plate. Exposure was taken from the buccal aspect using ScanX Duo (Air Techniques, Inc.). Films were processed automatically and evaluated independently by two examiners. Bitewing radiographs of the selected teeth were scored according to the modified criteria suggested by Ekstrand *et al* (R0 = No radiolucency visible; R1 = Radiolucency visible in enamel; R2 = Radiolucency visible in dentin, but restricted to the outer one third of dentin; and R3 = Radiolucency extending to the middle one third of dentin).[45]

Statistical analysis

Data were analyzed using SPSS version 25 (IBM Corporation). Categorical variables were summarized by number and percentage and continuous variables were summarized by median, average and standard deviation. The distribution of continuous variables was tested using the Shapiro-Wilk test, and the appropriate statistical tests were chosen according to the test results.

The inter-rater reliability of each detection method was determined using kappa values, odds ratio, sensitivity, specificity, receiver operating characteristic (ROC) curves, and area under curve (AUC). If the evaluators had a different range of scores, the kappa statistic was used for comparing two raters.

Detection methods were compared using Chi-square procedures producing Phi correlations.

P values lower than 0.05 were considered significant.

RESULTS

A total of 153 observations were carried out in 150 children aged 6-14 years (mean, 9.8, standard deviation 2.1).

Assessment of inter-rater reliability

Inter-rater reliability was assessed using the Kappa measure for agreement between raters. Table 1 shows the rates of caries detection by each rater in each all methods.

All caries detection methods showed high inter-rater reliability with absolute agreement between raters above 90%. The inter-reliability (kappa) of visual examination, FACE and X-ray radiography was 0.665, 0.665 and 0.809, respectively ($p<0.001$ for the inter-rater reliability of each of the three detection methods). Absolute agreement between raters was 92%, 90.8% and 91.8% of total observations for visual examination, FACE and X-ray radiography, respectively. Aggregation of the ratings of both raters show that most caries lesions were detected by visual (75.8%) and FACE (79.1%), while only 28.8% of lesions were detected by X-ray radiography (Figure 1).

Detection methods were compared using Chi-square procedures producing Phi correlations. The results showed that detection by visual examination was strongly correlated with detection by FACE (X^2=37.9, Phi=0.498, $p<0.001$), that is, similar detection outcomes were obtained both by both visual examination and FACE. A lower, yet statistically significant, correlation was found between visual examination and X-ray radiography (X^2=5.53, Phi=0.190, $p<0.001$). Finally, FACE and X-ray radiography did not show a statistically significant correlation (X^2=3.40, Phi=0.149, $p=0.065$). These results indicate that visual examination and FACE show similar abilities in detecting caries.

Sensitivity and specificity of methods

To assess the sensitivity and specificity of the three methods, a ROC curve was computed (Figure 2). The threshold cutoff for ROC was determined as 1 for all methods (i.e., a value of 2 indicates a positive outcome of detecting caries). Both FACE and radiography

Figure 1. Extent of occlusal caries detection in permanent molars by examination methods. Bars represent the aggregated rate of caries detection in each method.

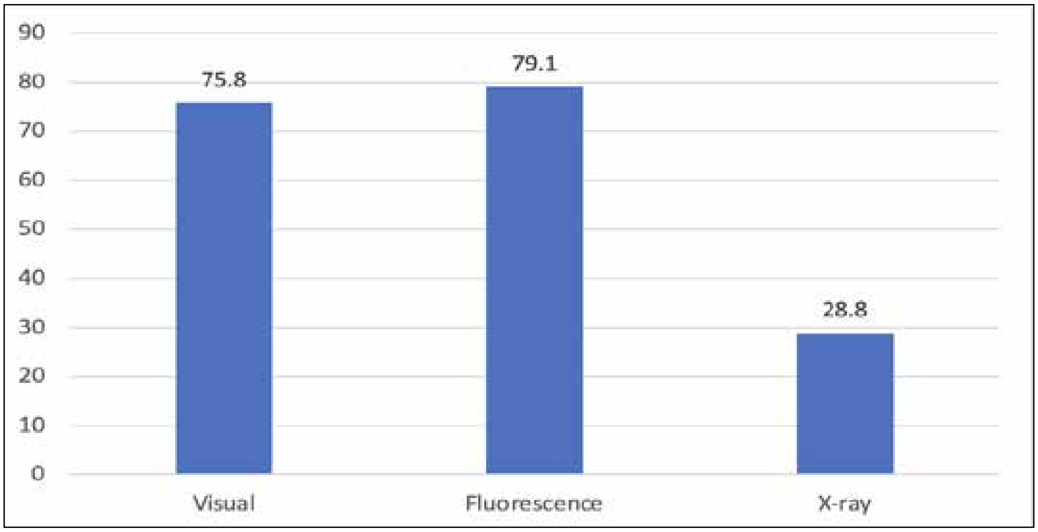

Figure 2. Receiver operating characteristics (ROC) curve for fluorescence and radiography compared to visual examination.

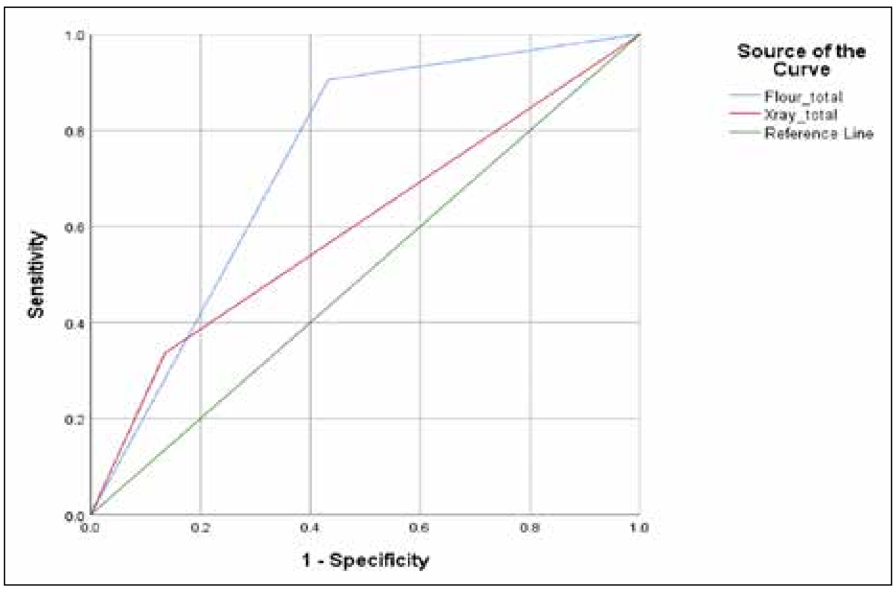

Table 1: Frequencies and rates of caries detection of each rater

	Visual		FACE		X-ray radiography	
Score*	**Rater 1 n (%)**	**Rater 2 n (%)**	**Rater 1 n (%)**	**Rater 2 n (%)**	**Rater 1 n (%)**	**Rater 2 n (%)**
0	16 (10.5)	17 (11.1)	25 (16.3)	25 (16.3)	103 (67)	104 (68)
1	16 (10.5)	16 (10.5)	128 (83.7)	128 (83.7)	1 (23)	37 (24.2)
2	121 (79.1)	120 (78.4)	NA	NA	15 (10)	12 (7.8)

FACE, fluorescence-aided caries excavation; NA, not applicable

*Visual examination score: 0 = no or slight change in enamel translucency after prolonged air- drying (5 s); 1 = opacity or discoloration hardly visible without drying, but visible after air-drying; 2 = opacity or discoloration visible even without air-drying.

FACE score: 0=no red light (no caries lesion detected) 1=red light (caries lesion detected)

X-ray radiography score: 0 = No radiolucency visible; 1 = Radiolucency visible in enamel; 2 = Radiolucency visible in dentin but restricted to the outer one third of dentin/Radiolucency extending to the middle one third of dentin.

were compared to visual examination as the gold standard. FACE has higher AUC of ROC curve (0.736, 95% CI [0.63,0.84]) in comparison with that of radiography (0.601, 95% CI [0.50,0.70]). Hence, FACE had higher sensitivity (87%) and specificity (65%) for detecting occlusal caries in comparison with radiography (60% specificity and 55% sensitivity).

DISCUSSION

To the best of our knowledge this is the first study that tested the method of D-Light Pro (FACE) in in the detection of occlusal caries in first permanent molars in children.

All caries detection methods evaluated in the study, namely, visual examination, FACE and X-ray radiography showed statistically significant, high inter-rater reliability in detection of occlusal caries in first permanent molars in children, with absolute agreement between raters above 90%. Similar detection outcomes were obtained by visual examination and FACE, with over 75% of caries cases detected by these 2 methods, while X-ray radiography enabled identification of less than 30% of occlusal caries.

Although visual examination remains the best method to detect occlusal caries in first permanent molars in children, this study shows that FACE can be used as an aid to confirm diagnosis because it allows to verify the visual diagnosis in confusing cases. It may especially help young clinicians with less clinical experience.

All caries detection methods are subject to errors. False positive diagnoses carry greater risk as they may lead to unnecessary invasive treatments.[33] An ideal method for caries detection should offer high specificity, sensitivity, and reproducibility. Moreover, quantitative methods may be more useful for improving reliability. In the present study, both FACE and visual examination showed fair sensitivity and specificity. Similarly to the mode of action of the device used in the present study, the DIAGNOdent device (Kavo,Biberach,Germany) uses laser light to induce autofluorescence of carious tissue. In a study that compared bitewing radiography, DIAGNOdent, and visual examination in diagnosing incipient occlusal caries of permanent first molars in children aged 7-13 years. The sensitivity of detecting caries that had extended into the enamel was 81.4%, 86.3%, and 81.4% for visual examination, DIAGNOdent and radiography, respectively. The specificity was 100%, 71.4%, and 100% for visual observation, DIAGNOdent and radiography, respectively.[47] These sensitivity and specificity of DIAGNOdent was similar to that observed with the D-Light Pro in the present study (87% and 65%, respectively), but the sensitivity and specificity of X-ray radiography was higher than those in the present study.

The D-Light Pro device is not invasive, safe to use, and convenient. Its handpiece is light and thin and can be manipulated just like a hand instrument, offering maximum comfort for both the child and clinician. However, assessments using the device may be confounded by plaque bacteria in inspected surfaces. For this reason, the teeth in the present study were cleaned before assessment. An additional limitation of the device, is that similar to the visual examination, the reflected color ranges from light to deep red. This color range may be subjective, yielding different results depending on the examiner, with variable sensitivity and specificity. False-positive results were reported by both examiners, probably due to color changes and deep fissures at the selected occlusal sites. It is important to emphasize that bright light in the surrounding can make it difficult to identify red fluorescing enamel. When using FACE in the present study the examiner had to turn away the light reflector while performing the FACE examination. In addition, the device does not provide the option for documenting long-term follow-up as the results cannot quantify changes of mineral content and lesion size by dose response. The use of the device is cost effective particularly because D-Light Pro is also a high-performance dual-wavelength curing light (700 and 1400 mW/cm^2).

CONCLUSIONS

Although visual examination remains the best method to detect occlusal caries in young permanent molars in children, FACE is an effective and accurate diagnostic tool that may aid in the detection and treatment decisions as an adjunct to the visual examination in everyday practice.

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