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Validity of caries detection on occlusal surfaces and treatment decisions based on results from multiple caries-detection methods

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The aim of this *in vitro* study was to evaluate whether having results available from multiple detection methods influences dentist's treatment decisions for incipient caries lesions on occlusal surfaces. The occlusal surface of 96 extracted permanent molars without frank cavitation was examined by three examiners initially by visual examination alone, following which they chose one of three treatment options: (i) no treatment, (ii) preventive or non-invasive treatment (sealants), and (iii) invasive treatment. Four weeks later the examiners again selected one of the three treatment options for the surfaces, but this time were able to refer to the results from additional caries-detection methods [bitewing radiographs, electric conductance measurement (ECM), quantitative light fluorescence (QLF), and DIAGNOdent] that had been performed in the interim time. Stereomicroscopy was used to evaluate sensitivity, specificity, accuracy, and area under the Receiver Operating Characteristic (ROC) curve (AUC) for the detection methods at the D1 diagnostic threshold. Slight improvement was obtained in the percentage of sites correctly diagnosed, and in the AUC, when referring to the results obtained from all detection methods compared with visual examination alone. However, a drastic effect on the selection of treatment options was observed by having results available from multiple methods, with the choice of invasive treatment increasing substantially. In conclusion, having data available from multiple methods did not improve the accuracy of examiners in detecting early occlusal caries lesions, but it had a great influence on the number of surfaces indicated for operative treatment. The potential decrease in overall specificity while using multiple methods of detection may be of concern in populations with a low prevalence of occlusal caries lesions.

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In order to improve the frequency of detection of caries lesions located on occlusal surfaces, various authors have recommended the combined use of visual examination and other diagnostic aids. The most widely used technique to improve detection beyond the naked eye, and the only one found in most dental offices, is radiographic examination (1–4). While bitewing radiographs are considered to be of great importance for detecting approximal caries, they have a lower ability to detect enamel caries in occlusal surfaces (1, 5, 6).

Since the early 1990s, several methods for the detection of occlusal caries have been introduced; some were only research tools, whereas others have been used in dental practice. These methods were introduced in an attempt to improve the reliability of occlusal caries detection beyond that of visual and radiographic methods (7–10), or to quantify the signal. These techniques include, among others, fiber-optic transillumination (FOTI), digital fiber-optic transilluminarion (DIFOTI), electrical conductance measurement (ECM), light-induced fluorescence (QLF), laser fluorescence (DIAGNOdent), and D-carie (11–15).

Studies comparing emerging technologies with conventional methods have shown mixed results. Initial reports are prone to emphasize the high sensitivity of new techniques, whereas subsequent reports often highlight the limitations, such as with ECM, FOTI, and DIAGNOdent (6, 16–19). Studies on QLF have also shown great potential to detect and measure early mineral loss (20, 21), whereas limited information on this is available for other methods.

It has been suggested that some types of detection aids may augment visual examination. Considering that no studies have investigated how data provided by multiple diagnostic methods would influence the perception of caries status and subsequent treatment-planning decisions, the aims of the present study were: (i) to investigate whether the combination of the data provided by various diagnostic methods could improve the performance of examiners in diagnosing occlusal caries in comparison with visual examination alone, and (ii) to investigate how data provided by these diagnostic methods influenced the treatment-planning decisions of the examiners.

Material and methods

The study was approved by the Research Ethics Committee of the Piracicaba Dental School, State University of Campinas, registration number 027/2004.

Sample teeth

Ninety-six extracted permanent molar teeth exhibiting complete root formation were selected. Teeth with dental fluorosis, tetracycline staining, hypoplasia or dental restorations were excluded. The occlusal surfaces ranged from sound to varying degrees of fissure discoloration and possible microscopic breakdown of the surface structure; however, none of the teeth showed macroscopic signs of cavity formation with exposure into dentin. The teeth were stored in 0.1% thymol solution for less than 3 months from the time of extraction. They were cleaned with a prophylaxis brush using pumice slurry and rinsed thoroughly with a three-way syringe. The most severely affected site on each tooth was selected for the study. The occlusal surfaces were photographed (4× magnification) and the site was marked on a black-and-white paper print-out for identification during examinations. Following the ECM examination (which required an exposed root for circuit purposes), the teeth were mounted in sets of three and stored under refrigeration in deionized water in individual containers.

Examiners

Three examiners examined the teeth using ECM, visual examination, bitewing radiographs, QLF, and laser fluorescence (LF). All 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 practice.

The examiners were asked to choose one of the following treatment options for the occlusal surface: (i) no treatment (leave, wait, and watch), (ii) non-invasive treatment (professionally applied topical fluorides, fissure sealing), or (iii) invasive treatment (including preventive resin, composite or amalgam restoration).

The examiners first performed the ECM after which the teeth were mounted in blocks. They then performed a visual examination and made a treatment decision during the same session. One week after the visual examination, radiographic, LF, and QLF examinations were conducted by the same three examiners. Four weeks following the initial visual examination/treatment decision, all examiners were requested to re-evaluate the designated examination sites, this time having available to them the results from the other detection methods, to make another decision regarding their recommended treatment.

Table 1

Criteria for visual examination

Score	Criteria
0	No or only a slight change in enamel translucency after prolonged air drying (> 5 s)
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 dentine
4	Cavitation in opaque or discolored enamel exposing the dentine beneath

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 predetermined site on the occlusal surfaces was scored using the criteria described by Ekstrand *et al.* (7), as presented in Table 1. The tooth selection included scores 0–3, but not score 4.

Radiographic examination

The teeth were radiographed under standardized conditions and the exposures were made using a Trophy General Electric GE 1000 Intra-oral X-ray machine (General Electric Company, Milwaukee, WI, USA), 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 fiberglass soft tissue equivalent material was placed between the cone end and the blocks of teeth. Kodak Ektaspeed (E-speed) films were used (Eastman Kodak, Rochester, NY, USA) and processed in an automatic film processor. The classification criteria for radiographic examinations are shown in Table 2.

Electrical conductance measurement

The ECM method was performed using the Electronic Caries Monitor III (ECM III; LODE, Groningen, the Netherlands). The ECM examination had to be carried out before mounting to permit a reference electrode to be attached to the root complex for measurement. Before each measurement the occlusal surface of the tooth was moistened with deionized water then gently air-dried and a small

Table 2

Criteria for radiographic examination

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

amount of toothpaste gel was syringed onto the probe tip as a conducting medium. The reference electrode was attached to the root, and the measurement electrode probe was placed in contact with the fissure enamel at the site identified in the photograph, activating the co-axial air flow (7.5 l min^{-1}) until stable readings were obtained. Electrical conductance measurement readings ranged from 0.00, indicating the highest measurable conductance, to 99.99, which was the lowest measurable conductance. A score of 15 or lower was considered to indicate the presence of caries. Each site was examined three times, with an intervening interval of at least 1 h to allow rehydration of the lesions, and the average of these readings was considered as a definitive score.

Laser fluorescence examination

Laser fluorescence measurements were made using the DIAGNOdent device (Kavo, Biberach, Germany). The device was calibrated before use with a porcelain standard provided by the manufacturer. The probe tip A was adjusted to each tooth separately by holding the tip against a sound smooth surface and pressing the ring button until calibration was complete. The tooth surface was dried, then the conical probe tip was positioned perpendicularly over each selected site, as indicated in the photographs, and rotated around its long axis. A score of 5 or higher was considered to indicate the presence of caries. Each site was measured three times using the above-mentioned procedures and the average of these readings (0–99 range) was considered as the definitive score.

Quantitative light-induced fluorescence

Images of occlusal surfaces of tooth specimens were captured using a portable intra-oral camera device connected to a computer (QLF; Inspektor Research Systems, Amsterdam, the Netherlands). Each occlusal surface was illuminated with 13 mW cm^{-2} of violet–blue light (wavelength: 290–450 nm, average 380 nm) from the camera handpiece and the images were captured using a camera fitted with a yellow 520-nm high-pass filter. The images were not analyzed, but were scored subjectively from the stored images displayed on a cathode ray tube (CRT) monitor. The scoring criteria were as follows: 0, no change in enamel fluorescence; 1, slight change in enamel fluorescence; 2, loss of fluorescence distinctly visible without broken enamel; 3, loss of fluorescence distinctly visible with enamel broken; and 4, loss of fluorescence distinctly visible with cavitation (22).

Histological validation

After all assessments were complete, the teeth were removed from the blocks and bucco-lingual sections, approximately 150–200-μm-thick, were made using a Silverstone-Taylor microtome (Silverstone-Taylor, Lafayette, CO, USA), through the preselected site in the occlusal surface. The histological examination was performed using a stereo-microscope at 40× magnification. Both sides of each tooth section were examined and the more severely affected side was scored for the specimen. Caries was defined as being present when demineralization was observed, seen as a white or discolored (yellow/brown) area. The histological criteria for the caries lesion depth were: 0, no caries; 1, demineralization extending to the outer half of the enamel; 2, demineralization extending to the inner half of the enamel; 3, demineralization extending to the outer half of the dentin; and 4, demineralization extending to the inner half of the dentin.

Statistical analyses

Sensitivity, specificity, accuracy, and the area under the Receiver Operating Characteristic (ROC) curve (AUC) using only the visual criteria as well as additional detection methods information were evaluated using the histology criteria at the D1 diagnostic threshold (a cut-off between 0 and 1 in the ordinal scale methods, a score of ≥ 5 for DIAGNOdent, and a score of $\leq$ 15 for ECM). An advantage of using ROC analysis is that it reflects the diagnostic performance more comprehensively than sensitivity and specificity, which are determined by only one cut-off point. In relation to treatment decisions, it was assumed that only when caries extended into dentine (D3 threshold) was it considered that the tooth needed operative treatment. If the tooth had no dentine caries or enamel caries, the tooth did not need restoration and recommendations to do nothing or to perform non-invasive treatments were considered to be the correct treatment decisions (23). In order to compare the sensitivity, specificity, accuracy, and 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 1,000 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 methods. Area under the ROC curve was computed using the c-statistic from logistic regression models for each examiner and for each method.

Results

Histological examination of the teeth revealed that 41 teeth (42.7%) were sound, 31 (32.3%) had

Table 3

The examiners' performance in detecting occlusal caries by visual examination, and by visual examination combined with bitewing radiography, quantitative light fluorescence (QLF), electric conductance measurement (ECM), and DIAGNOdent at the D1 diagnostic threshold, expressed in terms of sensitivity, specificity, accuracy, and area under the Receiver Operating Characteristic (ROC) curve (AUC)

Examiner	Sensitivity	Specificity	Accuracy (%)	AUC
Visual examination				
1	0.73	0.80	0.76	0.79
2	0.67	0.83	0.74	0.75
3	0.91	0.59	0.77	0.80
Mean	0.77†	0.73†	0.75†	0.78†
Combination of visual + other methods				
1	0.84	0.73	0.79	0.85
2	0.80	0.73	0.77	0.77
3	0.91	0.56	0.76	0.81
Mean	0.85‡	0.67‡	0.77†	0.81†

Different superscript symbols show statistical differences between diagnostic methods ($P < 0.05$).

Table 4

Number and type of treatments indicated by each examiner for occlusal surfaces, based on visual examination alone and on visual examination combined with other methods

	Visual			Visual + other methods			
Examiner	Nothing	Non-invasive treatment	Invasive treatment	Nothing	Non-invasive treatment	Invasive treatment	Weighted kappa
1	51	34	11	37	29	30	0.50
2	53	41	02	42	41	13	0.59
3	24	48	24	17	43	36	0.61

Weighted kappa agreement was calculated between the initial and the revised decisions.

demineralization in the enamel, and 24 (25.0%) had demineralization extending into the dentin. Table 3 presents the sensitivity, specificity, accuracy, and AUC for the visual examination by all three examiners and for the results obtained by combining all diagnostic methods at the D1 diagnostic threshold. The mean sensitivity of visual examination combined with the other methods was significantly higher than that of visual examination alone. Concurrent reduction in specificity was also statistically significant. However, no statistically significant improvement was obtained in the accuracy or in the AUC by combining all diagnostic methods, in comparison with visual examination only.

Table 4 shows the number and type of treatments indicated by each examiner for occlusal surfaces, based on the visual examination alone, as opposed to visual examination combined with other detection methods. The weighted kappa agreement between the initial and revised decisions is also shown. An increase was observed in the number of invasive treatments indicated for the occlusal surfaces when the examiners had assessed data from all methods combined, in comparison with treatments indicated after visual examination alone. This increase ranged from 11 to 20% of the teeth. A considerable difference in the number of calls for invasive treatment among the examiners was observed.

Table 5 shows the accuracy of treatment decisions proposed by the examiners from visual examination and from visual examination plus other detection methods, expressed in terms of AUC. No statistical differences were observed in AUCs between the visual examination alone and the combination of visual examination with other detection methods ($P > 0.60$).

Table 6 shows the relationship between the presence of caries, confirmed by the histological examination of teeth, and the treatment decisions based on visual examination alone and visual examination combined with other detection methods. The number of correct treatment decisions, based on the criteria adopted in the present study, was generally not affected by basing treatment decisions on all available methods. However, it was also observed that the number of overtreatments increased substantially when the examiners made their treatment decisions based on all available data.

Table 5

Accuracy of treatment decisions proposed by all examiners from visual examination and from visual examination plus other methods

	Examiner			
Method of examination	1	2	3	All
Accuracy of treatment decision (AUC)				
Visual	0.81	0.75	0.84	0.80
Combination of methods	0.83	0.75	0.84	0.81

AUC, area under ROC curve.

Discussion

This study supports the results of many previous investigations into the problem of occlusal caries and its management. Diagnosis and treatment decisions have become complex tasks, demanding that dentists have knowledge of the etiology, histopathological characteristics of lesions, and the effectiveness of preventive and restorative treatments (24). Indeed, treatment decisions should really be made on several factors: the first being the caries signs, the second what is going on in the rest of the dentition, the third being the patient factor, and the fourth being population factors. Only with integration of all those factors do dentists have the opportunity to make appropriate clinical treatment decisions.

It is obvious that the decision to restore an occlusal tooth surface should not be made solely on the basis of detecting disease by visual examination or with the help of other diagnostic methods, as observed in the present study. In making a decision to place a restoration, the dentist should assess the caries risk and activity of the individual patient, the tooth age and morphology, and rationally interpret the reading of any mechanical device (24–26). However, the development of reliable methods for caries detection has become of importance to help dentists to improve diagnostic performance and thus enhance their decision making as regards the treatment decisions (27).

For this study, no formal training or guidelines were provided for the examiners on how to make the treatment decisions. The difference in number of surfaces designated for invasive treatment is therefore reflected in differences in training, experience, culture, and personal preferences of the examiners, as is likely to be found in clinical practice. The examiners were not asked to indicate how much tooth structure they would prefer to remove in a restoration process, or which type of restorative material they would place, but such differences in preference for

Table 6

The relationship between the presence and depth of caries confirmed by the histological examination and treatment decision based on visual examination (VEI) and visual treatment combined with other methods (VEI + others)

Examiner	VEI (%)			VEI + others (%)		
	Undertreatment	Correct treatment	Overtreatment	Undertreatment	Correct treatment	Overtreatment
1	27 (28)	62 (65)	7 (7)	14 (15)	58 (60)	24 (25)
2	35 (36)	53 (55)	8 (8)	26 (27)	55 (57)	15 (16)
3	13 (14)	52 (54)	31 (32)	8 (8)	46 (48)	42 (44)

material and procedure may also impact the number of invasive treatment calls that are made.

No superiority of the combination of methods over clinical visual examination was observed in this study with regard to the diagnosis of occlusal caries. In relation to the DIAGNOdent device, several other studies have been unable to establish a significantly superior diagnostic advantage over a careful visual examination, for example, by using the criteria established by Ekstrand and collaborators (8, 11, 18, 26, 28, 29) or ICDAS (International Caries Detection and Assessment System). The lesions selected for this study ranged from the earliest stages to the beginning of breakdown of the surface; however, surfaces with cavitation extending into dentin were excluded. The resulting range of lesions may have affected the diagnostic yield differently for each method. Traditional visual methods using cavitation as a detection threshold are likely to have considered most of those surfaces as sound. The visual criteria in this study were those presented by Ekstrand and co-workers, which are similar for this range of lesions to the more recently adopted ICDAS-II criteria (codes 0–3). Teeth with hypoplasia, or obvious signs of fluorosis, were excluded for the sake of reducing confounding factors. However, it will be important to include those teeth in future studies because the differential diagnosis may be the single most important quality for new methods. The cut-off score for caries using the DIAGNOdent method is lower here than the clinically recommended cut-off score. This correction was to compensate for the fluorescence decrease that occurs when teeth are stored in thymol solution (30).

Various authors have suggested that if visual examination was followed by the use of an additional method, the accuracy of occlusal caries diagnosis would be improved (4, 8, 31). This theory is corroborated by data from studies that found an additional diagnostic yield from bitewing radiographs in the diagnosis of occlusal caries (1–4). Other studies indicated that detection technologies, as such ECM and DIAGNOdent, performed better in detecting early carious lesions in occlusal surfaces than traditional visual examination. By using visual criteria developed more recently this advantage of the detection technologies has greatly diminished; the detection methods mainly improve sensitivity, but by compromising on the specificity side of the equation. According to Lussi (32), when high values of both sensitivity and specificity cannot be achieved, the test providing high-specificity values is to be preferred. This study failed to find any improvement in the overall accuracy of the detection, although shifts in sensitivity and specificity reached statistical significance. Those shifts would lead to an increase in the number of false-positive diagnoses and may have affected the decision of the examiners towards invasive treatment.

In this study, it was also observed that there was only a slight improvement in the number of correctly diagnosed teeth and in the AUC by using all available data obtained from all methods. These results do not support the initial hypothesis that data from additional detection methods would improve the diagnosis of occlusal caries. The data were not analyzed to establish whether any one method or any particular combination of selected methods would be superior in supporting the visual examination. The path between the development of a new technology and the process of its appropriate application and adoption is not well known (6). Dentists decide whether and how they will use the data from new methods, often with limited clinical supporting evidence. Dentists are likely to give different weight to data from each diagnostic method, and which information they consider important to their diagnostic decision-making. In previous studies, dentists considered radiography to be of low value for detecting occlusal caries (33–35). However, if a lesion is found only on radiographs, the high specificity of radiographs is probably given a high priority in the decision-making process. It is possible that successful adaptation of new methods and their role in patient management will therefore rely more on high specificity.

Correctness of the treatment decision is always debatable because as soon as a lesion is removed the evidence is destroyed. Table 6 shows the correlation between the histological depth of the lesion (in enamel or dentin) with the decision of whether or not to intervene operatively. Although a common threshold for intervention for approximal lesions has been radiographic extension into dentin, this has been challenged. Here, the dentin extension is only used as a surrogate to validate the treatment decision call, while a clinical threshold of such decisions should be based on the breakdown of surfaces. Eventually, such treatment decisions need to withstand the scrutiny of studies on outcomes of patient management. Reports of successfully arresting or remineralizing dentinal lesions also need to be considered in such decision making. The issue of lesion activity was not assessed in this study, as such a decision depends on many clinical factors.

From the data presented in Table 4, it was observed that examiners showed a tendency towards more invasive treatment when more data were available. This occurred even though the examiners were well aware of the danger involved in the situation. Analysis of data in Table 6 showed that overtreatment increased when examiners used data from various diagnostic methods in an integrated way. The question thus arises: if research dentists, bearing in mind this potential danger, nevertheless fell into the trap, then how can practicing dentists be equipped to deal with the same tendency? Future studies should focus on defining and improving the diagnostic process resulting from data from diagnostic methods, under *in vivo* clinical conditions, and need to take into consideration variables of patient and dentist factors, with the aim of finding the best combination to assist dentists in their treatment decision-making. Table 6 also indicates that overtreatment existed at two levels, namely by applying non-invasive treatment to sound teeth and by applying invasive treatment to teeth with enamel lesions. The former is ''harmless'' although costly, and the second is disastrous.

In conclusion, having data available from multiple methods did not improve the accuracy of examiners in detecting early occlusal caries lesions, but it had a great influence on the number of surfaces indicated for operative treatment. The potential decrease in overall specificity while using multiple methods may be of concern in populations with a low prevalence of occlusal caries lesions.

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