©Operative Dentistry, 2011, **36-2,** 133-142

In Vitro Evaluation of ICDAS and Radiographic Examination of Occlusal Surfaces and Their Association With Treatment Decisions

MB Diniz • LM Lima • G Eckert
AG Ferreira Zandona • RCL Cordeiro • L Santos Pinto

Clinical Relevance

It has been suggested that occlusal caries detection has become more difficult due to the widespread use of fluoride, which slows down lesion progression and delays cavitation. The ability to detect caries lesions at an early stage has a significant impact on treatment decisions, improving the possibility for a successful preventive intervention. In this investigation, the authors found that the International Caries Detection and Assessment System associated with radiographic examination has the potential to support treatment decisions for occlusal surfaces.

SUMMARY

This *in vitro* study evaluated the performance of visual (International Caries Detection and Assessment System [ICDAS]) and radiographic (bitewing [BW]) examinations for occlusal caries detection and their associations with treatment decision (TD). Permanent teeth (n=104)

*Michele B. Diniz, DDS, MSD, PhD, Araraquara School of Dentistry, UNESP-Univ Estadual Paulista, Pediatric Dentistry, São Paulo, Brazil; assistant professor, School of Dentistry, Cruzeiro do Sul University, Pediatric Dentistry, São Paulo, Brazil

Luciana Monti Lima, DDS, MSD, PhD, Araraquara School of Dentistry, UNESP-Univ Estadual Paulista, Pediatric Dentistry, São Paulo, Brazil

George Eckert, MAS, Indiana University School of Medicine, Division of Biostatistics, Indianapolis, IN, USA

Andrea G. Ferreira Zandona, DDS, MSD, PhD, Indiana University School of Dentistry, Preventive and Community Dentistry, Indianapolis, IN, USA

Rita C. L. Cordeiro, DDS, MSD, PhD, associate professor, Araraquara School of Dentistry, UNESP-Univ Estadual Paulista, Pediatric Dentistry, São Paulo, Brazil

Lourdes Santos Pinto, DDS, MSD, PhD, associate professor, Araraquara School of Dentistry, UNESP-Univ Estadual Paulista, Pediatric Dentistry, São Paulo, Brazil

*Reprint request: Araraquara School of Dentistry, UNESP-Univ Estadual Paulista, Pediatric Dentistry, Rua Humaitá, 1680, Araraquara, São Paulo 14801–903, Brazil, e-mail: mibdiniz@hotmail.com

DOI: 10.2341/10-006-L

with occlusal surfaces varying from sound to cavitated were selected. Sites were identified from 10× occlusal surface photographs. Standardized bitewing (BW) radiographs were taken. Four dentists with at least five years of experience scored all teeth twice (one-week interval) for ICDAS (0–6), BW (0=sound, 1=caries restricted to enamel, 2=caries in outer third dentin, 3=caries in inner third dentin), and TD (0=no treatment, 1=sealant, 2=microabrasion and sealant, 3=round bur sealant, 4a=resin, 4b=amalgam). Histological validation was performed by observation under a light microscope, with lesions classified on a five-point scale. Intraexaminer and interexaminer repeatability were assessed using two-way tables and intraclass correlation coefficients (ICCs). Comparisons between percentage correct, specificity, sensitivity, and area under the receiver-operating characteristic (ROC) curve were performed using bootstrap analyses. ICCs for intraexaminer and interexaminer repeatability indicated good repeatability for each examiner, ranging from 0.78 to 0.88, and among examiners, ranging from 0.74 to 0.81. Correlation between ICDAS and TD was 0.85 and between BW and TD was 0.78. Correlation between the methods and histological scores was moderate (0.63 for ICDAS and 0.61 for BW). The area under the ROC curve was significantly greater for ICDAS than for BW ($p<0.0001$). ICDAS had significantly lower specificity than BW did ($p=0.0269$, 79% vs 94%); however, sensitivity was much higher for ICDAS than for BW ($p<0.0001$, 83% vs 44%). Data from this investigation suggested that the visual examination (ICDAS) showed better performance than radiographic examination for occlusal caries detection. The ICDAS was strongly associated with TD. Although the correlation between the ICDAS and BW was lower, it is still valuable in the clinical decision-making process.

INTRODUCTION

The widespread use of fluoride, among other factors, has slowed down dental caries lesion progression, delaying cavitation and making detection of occlusal caries more challenging.[1-3] Caries detection has a tremendous impact on treatment decision (TD) and is directly linked to the patient's dental management and treatment outcomes.[4-6] The dynamism and reversibility characteristics of noncavitated lesions have caused changes in treatment decision-making concepts.[7]

Although visual inspection and radiographic examination are the conventional methods used for caries detection,[8,9] some studies have shown considerable variation among clinicians in their diagnoses, restorative decisions, and treatment plans.[10-21] These differences occurred independently of the study conditions, such as *in vitro* studies, studies in clinical practice settings, or whether bitewing (BW) radiographs were evaluated.[11,22] The variation among dentists could be explained by deficiencies of adjunctive detection tests, due to incorrect or partial understanding of the test's parameters[4] or to variations in observers' clinical experiences and their professional preferences.[12]

Caries lesions are diagnosed clinically via subjective assessment of alterations in color, translucence, and dental hardness and/or roughness, depending on whether it is an enamel or dentin lesion.[23,24] Traditional visual caries examinations tend to have high specificity and low sensitivity.[25] Therefore, different criteria have been proposed to provide defined descriptors of different severity stages of caries lesions.[23,24,26]

One promising new visual criterion is the International Caries Detection and Assessment System (ICDAS), which was introduced for use in dental education, clinical practice, research, and epidemiology.[27] The ICDAS describes six stages of caries extension, varying from initial changes visible in enamel to frank cavitation in dentin.[26,28,29] Although some studies have shown good reproducibility and accuracy of the ICDAS for occlusal caries detection in permanent teeth,[26,29-34] there still is a need to study how it affects the treatment options for those surfaces. The literature has suggested that the ICDAS criteria have the potential to aid treatment planning.[35] Recently, Longbottom and others[36] introduced a guidance of caries-preventive treatment options for the different ICDAS scores. According to the authors, there is limited strong evidence supporting the use of specific techniques for secondary prevention to arrest and/or reverse the caries process after initiation of clinical signs for any caries lesion severity.[36]

Radiographic examination has shown greater detection sensitivity for approximal than occlusal surfaces, warranting its use when visual findings may be questionable.[37] According to the authors, clinical examination performed better than radiographic examination in noncavitated lesions, partic-

ularly on occlusal surfaces. They stress that radiographs are important for detecting caries lesions that remain undetected by visual examination, and if the lesions' depth could be assessed, it would enable a correlation between their severity and treatment choices. Dentists are influenced by different factors when making restorative decisions, such as the various degrees of a lesion's depth seen on BW radiographs[38,39] and observed in clinical examination. No study to date has looked at the impact of the use of ICDAS criteria in conjunction with radiographic examination in TDs. Thus, the aim of this *in vitro* study was to evaluate the performance of visual (ICDAS) and radiographic (BW) examinations for occlusal caries detection and their associations with the TD.

METHODS AND MATERIALS

For this Institutional Review Board–exempt study, 104 permanent human premolars and molars, without sealants or restorations, hypoplasia, fluorosis, or caries lesions on smooth or proximal surfaces, were selected from a pool of extracted teeth, which were stored in 0.1% thymol solution at 4°C until use. Calculus and debris were removed using a scaler, and the teeth were then cleaned for 15 seconds with water and Robson brush in a low-speed handpiece.

Black-and-white photographs of the occlusal surfaces were taken under a stereomicroscope (SZX7, Olympus Corporation, Tokyo, Japan) with 10× magnification. One occlusal site per tooth, varying from sound to cavitated, was selected at random as the test site by an independent person who was not an examiner of this study, avoiding selection bias. Each photograph, printed on draft-quality paper, had an opaque dot covering the test site to allow the examiners to localize precisely the test site during the examinations and to avoid potential bias due to the magnification of the photograph. Standardized BW radiographs were taken of all teeth using a fixed apparatus with a film holder, with a distance of 23 cm from the x-ray tube, an x-ray machine (Spectro 70X, Dabi-Atlante, Ribeirão Preto, São Paulo, Brazil), and a single ultra-speed film (Kodak Insight, 22 × 35 mm, Kodak, Rochester, MN, USA) at 70 kVp, 8 mA, and exposure time of 0.30 seconds. All radiographs were processed by an automatic x-ray film developer (Dent-X 9000, Dent-X, Emsford, NY, USA), placed in transparent cards and identified.

Visual caries examinations were performed by four dentists from the Department of Pediatric Dentistry, including two adjunct professors with 15 years' postgraduate experience and two PhD students with eight years' postgraduate experience. The assessments were carried out twice, separated by a one-week interval, for assessment of intraexaminer repeatability.

Before the assessments, the four examiners participated in a training session. First, the examiners simultaneously performed the online ICDAS e-learning program[40] developed by the ICDAS Foundation, which consists of a 90-minute course regarding the application and collection of the coding system divided into the following: introduction, ICDAS examination protocol, ICDAS caries codes, information on the application of the coding system, a decision tree, instructions on how to collect data for the recording codes, and interactive quizzes. Afterward, a discussion session regarding the differentiation of the clinical aspects of the ICDAS carious lesion stages was followed by practice exercises using clinical photographs and 18 extracted teeth, which were not part of this study.

Visual examination was performed independently using the ICDAS codes. The occlusal surface of each tooth was examined with direct visualization, with the aid of a light reflector and a 3-in-1 air syringe. The teeth were coded as shown in Table 1.

After the visual examination, the radiographs were then examined independently using an x-ray viewer and an x-ray film magnifier (magnification 2×; VRX-Fabinject, Taubaté, São Paulo, Brazil) in a dark room to determine whether the occlusal surfaces under study showed (0) no radiolucency, (1) radiolucency in enamel, (2) radiolucency in the outer half of dentin, and (3) radiolucency in the inner half of dentin.[31] The examiners were blinded during the x-ray examination, and they did not have access to the test tooth.

TD evaluations were performed independently based on visual examination associated with the radiographic examination. For this procedure, the ICDAS and the radiographic examination (BW) scores were available to the examiner when selecting the TD score for each tooth. The following scores were used: (0) no treatment, (1) sealant application, (2) microabrasion and sealant application, (3) round bur and sealant application, (4a) composite resin restoration, or (4b) amalgam restoration. Visual examination, radiographic examination, and TD were performed on the same day. The teeth were randomly numbered and reordered before each evaluation.

For validation, black-and-white copies of the digital photographs, printed on draft-quality paper,

Table 1: *International Caries Detection and Assessment System Codes and the Corresponding Histological Criteria According to Ekstrand and Others*[17]

Code	Clinical Criteria	Histological Criteria
0	Sound tooth surface: no evidence of caries after 5 s air drying	No enamel demineralization
1	First visual change in enamel: opacity or discoloration (white or brown) is visible at the entrance to the pit or fissure after prolonged air drying	Demineralization limited to the outer half of the enamel thickness
2	Distinct visual change in enamel visible when wet; lesion must still be visible when dry	Demineralization between inner half of the enamel and outer third of the dentin
3	Localized enamel breakdown (without clinical visual signs of dentinal involvement) seen when wet and after prolonged air drying	Demineralization in the middle third of the dentin
4	Underlying dark shadow from dentin with or without localized enamel breakdown	Demineralization in the middle third of the dentin
5	Distinct cavity with visible dentin	Demineralization in the inner third of the dentin
6	Extensive (more than half of the surface) distinct cavity with visible dentin	Demineralization in the inner third of the dentin

were used for the test site identification. The teeth were longitudinally sectioned through the center of each test site with a water-cooled diamond disk in a machine (ISOMET 1000, Buehler Ltda, Lake Bluff, IL, USA), resulting in two sections corresponding to the test site. The section with a more severe lesion was analyzed under a stereomicroscope (SZX7, Olympus Corporation, Tokyo, Japan) with 10× magnification. The deepest demineralization area either in the enamel or both the enamel and the dentin tissues was analyzed according to the five-point histological classification system proposed by Ekstrand and others[23]: (D_0) no caries, (D_1) caries lesion limited to the outer half of the enamel, (D_2) caries extending into the inner half of the enamel or outer half of the dentin, (D_3) caries limited to the middle third of the dentin, and (D_4) caries involving the inner half of the dentin. Two experienced examiners, who also performed the other assessments, examined each tooth section independently. Sections with disagreements were reexamined, and a consensus was reached.

The intraexaminer and interexaminer repeatability for ICDAS, BW radiographs, and TD scores were analyzed using two-way tables and intraclass correlation coefficients (ICCs). ICCs were used rather than kappa statistics because of the full set of repeats for all specimens for all four examiners. Associations among the ICDAS, BW radiographs, and TD were assessed using two-way tables. Comparisons among specificity, sensitivity, and area under the receiver-operating characteristic (ROC) curve of the ICDAS, radiographic examination, and TD, as well the correlation between the ICDAS and the radiographic examination scores and the histology scores, were performed using bootstrap analyses. The bootstrap methodology uses resampling techniques to estimate statistics and perform comparisons for values that are not normally distributed. Accuracy was measured by the area under the ROC curve, using the following guidelines: an area of 0.90 to 1.0 represented an excellent test, an area of 0.80 to 0.90 indicated a good test, 0.70 to 0.80 was fair, 0.60 to 0.70 was poor, and 0.50 to 0.60 was a failure.[41]

RESULTS

Based on the histological evaluation of the tooth sections, six teeth had no caries, 21 had a caries lesion limited to the outer half of the enamel, 47 had caries extending into the inner half of the enamel or outer half of the dentin, eight had caries limited to the middle third of the dentin, and 22 had caries involving the inner half of the dentin.

Table 2 shows the ICCs for intraexaminer and interexaminer repeatability for the ICDAS, radiographic examination (BW), and TD. ICCs for intra-

Table 2: *Intraclass Correlation Coefficients for Intraexaminer and Interexaminer Repeatability for the ICDAS, Radiographic Examination (BW), and TD*

Examiner	ICDAS	BW	TD
1	0.89	0.74	0.81
2	0.91	0.73	0.89
3	0.88	0.87	0.87
4	0.86	0.80	0.76
Overall intraexaminer	0.88	0.78	0.82
Interexaminer	0.81	0.74	0.76

Abbreviations: BW, bitewing; ICDAS, International Caries Detection and Assessment System; TD, treatment decision.

examiner repeatability were high for the ICDAS, BW, and TD, indicating good repeatability for each examiner (ranging from 0.78 to 0.88). For interexaminer repeatability, the ICC values were also high, indicating good agreement between examiners for the ICDAS (0.81), BW (0.74), and TD (0.76).

Correlations were moderate to high between the ICDAS and BW (0.74), ICDAS and TD (0.85), and BW and TD (0.78).

Specificity, sensitivity, area under the ROC curve, and correlation between the ICDAS and radiographic examination scores and histology are shown in Table 3. The correlation between the methods and histology scores was moderate (0.63 for ICDAS and 0.61 for BW). The ICDAS had a significantly lower specificity than BW (p=0.0269, 79% vs 94%); however, the sensitivity was much higher for the ICDAS than for BW ($p<0.0001$, 83% vs 44%).

Table 3: *Sensitivity, Specificity, Area under the ROC Curve (A_z), and Correlation of the Methods With the Histology Scores*

Method	Specificity	Sensitivity	A_z	Correlation
ICDAS	0.79[a]	0.83[a]	0.85[a]	0.63[a]
BW	0.94[b]	0.44[b]	0.69[b]	0.61[a]

Abbreviations: BW, bitewing; ICDAS, International Caries Detection and Assessment System; ROC, receiver-operating characteristic.
[a,b] Significant differences represented by different superscript letters ($p<0.05$; Bootstrap test).

Table 4 presents the TD score distributions within the ICDAS and BW for all examinations. It should be noted that the ICDAS and the radiographic examination (BW) scores for each tooth were available to the examiner when making the TDs. If the ICDAS and BW considered the surface sound (score 0), the TD score was mostly no treatment (99%). However, in all cases in which the surface was sound (score 0) based on the ICDAS but presented a radiolucency on BW (scores 1 or 2), the TD was to seal (100%). If the ICDAS showed initial lesions[42] (scores 1 and 2) and BW showed no radiolucency (score 0) or radiolucency in enamel (score 1), the TD score was mostly to seal the surface with or without previous microabrasion cavity preparation. On the other hand, approximately one-third of the initial lesions (ICDAS scores 1 and 2) without radiolucency on BW (score 0) were recommended to be left untreated. In cases in which there is radiolucency in the outer (score 2) or inner half of the dentin (score 3) on BW, the TD was to seal after microabrasion or round bur cavity preparation. If ICDAS indicated moderate lesions[42] (scores 3 and 4) and BW showed no radiolucency (score 0), the TD score was mostly to seal after round bur cavity preparation. Conversely, when BW showed radiolucency in the outer (score 2) or inner half of the dentin (score 3), the TD was mostly to seal after round bur cavity preparation or to restore using composite resin and amalgam. If the ICDAS indicated extensive lesions[42] (score 5 and 6), the TD scores were mostly to restore using composite resin when BW showed radiolucency in the outer half of the dentin (score 2) and using amalgam when BW showed radiolucency in the inner half of the dentin (score 3).

DISCUSSION

Optimal management of a lesion requires accurate and reliable diagnosis combined with an appropriate TD.[2] However, variation in caries diagnosis and treatment decision making is a well-recognized reality.[4,13,14] Considerations for treatment planning involve the correct diagnosis, the individual patient factors (trigger conditions, risk factors, compliance), and the dentist factors (characteristics, biases, preferences, practice variables).[22]

With respect to treatment planning, the ICDAS visual criteria can provide information to be collected at the tooth/surface level. This information is then synthesized with information at the patient level (patient caries risk assessment, dentition and lesion history, and patient behavioral assessment) to

Table 4: *Percentages for the Treatment Decision Scores Within the ICDAS and BW Considering All Examinations*[a]

ICDAS	BW	Treatment Decision					
		0	1	2	3	4a	4b
0	0	99	1				
	1		100				
	2		100				
	3						
1	0	32	38	29	1		
	1	7	48	31	7	7	
	2		14	43	43		
	3			100			
2	0	26	27	35	11		
	1		33	40	26	2	
	2		14	43	43		
	3						
3	0	15	26	20	30	9	
	1		4	20	46	30	
	2			11	46	43	
	3				50		50
4	0			33	67		
	1				50	50	
	2					67	33
	3						100
5	0						
	1					50	50
	2					92	8
	3					43	57
6	0						
	1						
	2					100	
	3					33	67

Abbreviations: BW, bitewing; ICDAS, International Caries Detection and Assessment System.
[a] According to Zero and others[42]: ICDAS scores 1–2, initial lesions; ICDAS scores 3–4, moderate lesions; ICDAS scores 5–6, extensive lesions.

inform integrated and personalized treatment planning.[35]

In this study, the ICC values for the ICDAS, radiographic examination, and TD were high for both intraexaminer and interexaminer repeatability, indicating excellent agreement. Our results agreed with those found by Ekstrand and others,[29] in an *in vitro* study, who observed high weighted Kappa values for ICDAS criteria for intraexaminer (0.82 to 0.87) and interexaminer repeatability (0.82). High Kappa values were also found by Kühnisch and others,[34] in an epidemiological study applying ICDAS criteria, for both intraexaminer (0.88) and interexaminer (0.90) repeatability. However, Ismail and others,[26] Rodrigues and others,[31] and Diniz and others[32] observed lower Kappa coefficients for ICDAS for intraexaminer (0.58-0.82) and for interexaminer (0.51-0.75) agreement. This difference could be explained by 1) the fact that in our study the examiners were trained for the ICDAS criteria by the e-learning program, a new interactive tool available online to provide an overview of the criteria and to demonstrate the different ICDAS codes,[43] and 2) in our study extracted teeth were used, which is different from the study conducted by Ismail and others,[26] which was an *in vivo* study.

In contrast to our results, Rodrigues and others[31] found lower kappa values for radiographic examination for both intraexaminer (0.62) and interexaminer (0.50) repeatability. This dissimilarity can be attributed to the different examiners' training and skills. The ICC for TD repeatability was moderate (0.76) for interexaminer repeatability and varied from 0.76 to 0.89 for intraexaminer repeatability. Another study reported a good intraexaminer agreement and moderate interexaminer agreement for restorative treatment decision making on occlusal surfaces.[12] However, Maupomé[15] showed in his study lower kappa values for interexaminer agreement (ranging from 0.05 to 0.65) for treatment planning. This variation could be explained by the examiners' decision-making skills, which in his study were senior dental students. According to Bulman and Osborn[16] and Souza-Zaroni and others,[17] even when the examiners are accurately trained, there is no guarantee that they will agree on diagnoses because their decisions will be made based on knowledge and experience previously acquired. Nevertheless, our results showed that the examiners presented good intraexaminer and interexaminer agreement, indicating that the examiners were consistent in their ICDAS examination, radiographic examination, and treatment decision making. This could be related to the clinical experience level and similar level of training of the observers participating in the current study, considering that all of them were from the same department. The examiners in our study independently carried out the examinations on the same day, and after one week, all teeth were reassessed. In addition, the teeth were randomly numbered and reordered before each evaluation to reduce recall bias.

Overall, the analysis of sensitivities and specificities showed that BW presented higher specificity (0.94) and lower sensitivity (0.44), while ICDAS showed higher sensitivity (0.83) for occlusal caries detection. Souza-Zaroni and others[17] and Rocha and others[18] reported similar values of sensitivity (varying from 0.56 to 0.57) and specificity (from 0.74 to 1.00) when experienced professionals evaluated BW radiographs for occlusal caries detection. For the ICDAS criteria, after a training session, Jablonski-Momeni and others[30] observed comparable specificity and sensitivity values, ranging from 0.74 to 0.91 and from 0.59 to 0.73, respectively. Rodrigues and others[31] and Diniz and others[32] observed sensitivity of 0.73 and 0.62, respectively, and specificity of 0.65 and 0.75, respectively, for ICDAS considering only dentin caries when no training was given to the examiners. It is important to point out that there is a great balance between specificity (proportion of negatives that are correctly identified by the test) and sensitivity (proportion of actual positives that are correctly identified by the test) for ICDAS criteria, which is essential for an optimal diagnostic test.[2] An imperfect specificity of the diagnostic test may cause a tremendous amount of overtreatment.[4]

The area under the ROC curve is considered a particularly valuable and easily interpretable measure of diagnostic accuracy.[44] The findings of the current study indicate that the area under the ROC curve (A_z) for ICDAS was higher (0.85) than the area for BW (0.69), indicating a better performance of the visual examination. Rodrigues and others[31] showed similar results for the ICDAS criteria (0.75) and for the radiographic examination (0.71) concerning occlusal caries detection.

A strong correlation (0.74) was observed between the ICDAS and radiographic examination (BW). An *in vivo* study[34] also showed a strong correlation (0.70) between visual and radiographic examination when the Ekstrand visual criterion was used. It should be stressed that the Ekstrand visual criterion[23] is less discriminative than the ICDAS criteria, which could explain the high correlation coefficients reported in that study. Good correlation was also observed between BW and TD. However, previous studies of dentists have shown variation in the accuracy of caries diagnosis from radiographs and subsequent treatment decision making.[19-21]

The strongest correlation in this study was found between the ICDAS and TD (0.85). This information suggests that the ICDAS is the primary criterion used for evaluating the condition of the dental surface before the establishment of a treatment plan. This is important since cavitation should be the crucial endpoint before operative treatment is initiated.[9] However, it should be emphasized that the ICDAS presented only moderate correlation with histology, which presents a problem for the validity of the method. According to Huysmans and Longbottom,[45] an optimal validation of a continuous diagnostic method involves a gold standard that is also continuous. The requirement of the sample being representative or even only well distributed may be one of the biggest challenges because extracted teeth are ever harder to come by and constitute an inherently biased group. In the present study, although efforts have been made for a representative sample, it was not well distributed with respect to the number of sound teeth and teeth

with lesions in the middle and in the inner third of the dentin.

In a meta-analysis, Ie and Verdonschot[3] observed that although carious lesions can be observed by visual examination, caries preventive strategies will be initiated very late. A solution to this problem would be to detect caries lesions at an early stage of development. In the present study, although ICDAS has demonstrated reliability for early caries detection, it does not correlate strongly with histology. Previous studies also reported a moderate correlation between the ICDAS and the histological classification.[30-32] However, Ekstrand and others[23] observed stronger correlation with histology for visual inspection in detecting occlusal caries. These differences could be explained by the fact that in our study, most of the teeth had caries extending into the inner half of the enamel or outer third of the dentin. This means that the sample distribution was not homogeneous, which might have influenced our results. Another point that should be stressed is that in the Ekstrand and others[23] study, the examiners were trained for a less discriminative visual inspection criterion than the ICDAS when the lesion was at an advanced stage, reducing chances for errors.

Even though the BW radiograph is recognized as inaccurate to detect small carious lesions since it is a specific rather than sensitive method,[6] the results of this present investigation indicated that BW radiographs could add substantial information to the visual examination using ICDAS criteria, leading the examiners to a more watchful treatment decision making. Other studies have also shown that BW radiographs can add information to the visual examination about many of the clinical stages of the caries process at more advanced stages,[6,9] including hidden caries.[46]

According to Pitts and Richards,[35] the ICDAS criteria provide information to be collected at the tooth/surface level and at the patient level, which can be synthesized to institute an appropriate treatment planning. Ekstrand and others[29] suggested that the appropriate treatment for active lesions should be related to the depth/severity of the lesions assessed by the ICDAS criteria. Active lesions with ICDAS codes 1 and 2 require nonoperative/preventive treatment, including sealants, while active lesions with ICDAS codes 4, 5, and 6 require operative treatment. In cases of teeth with ICDAS code 3, it is important to use supplemental diagnostic tools, such as BW radiographs, to decide which teeth should be restored operatively. The results of the association between ICDAS criteria and radiographic examination for treatment decision making conform with the guidance proposed by Ekstrand and others.[29] Recently, another guidance of caries-preventive treatment options was provided by Longbottom and others[36] for the different ICDAS scores. In general, it was proposed that for ICDAS scores 1 and 2 (initial lesion) and 3 and 4 (moderate lesion), measures to prevent the initiation of the disease (primary) and treatment to arrest and/or reverse the caries process (secondary) would be appropriate, and for ICDAS scores 5 and 6, primary and an interaction of nonoperative (secondary) and operative procedures (tertiary) to prevent further progress of the caries process would be required. In the present investigation, it can be observed that the treatments presented were sequentially used with increased ICDAS lesions score.

In this investigation, it could be observed that sealing after minimal cavity preparation with microabrasion or round bur was indicated for initial lesions (ICDAS scores 1 and 2) when associated with radiolucency signals. According to Beauchamp and others,[47] removing tooth structure before placing a sealant is not recommended since current evidence indicates that sealants are also an effective secondary preventive approach when placed on early noncavitated carious lesions. Minimal interventions (microabrasion or round bur cavity preparation) were proposed as treatment options in this study, aiming to verify if dental practitioners are in reality moving from operative to nonoperative/preventive treatment of dental caries in clinical practice. It could be suggested that the examiners might be influenced by the different TDs about sealant use. As they did not have access to the patients' risk factors and needs or to the caries activity status of the lesions, there was a tendency to decide to an operative intervention.

It is important to address that the decision to restore or not to restore cannot be made in a simple manner. It depends not only on occlusal surface condition and lesion location but also on caries activity and caries risk assessments, on factors related to the pathogenesis of caries, and on the abilities, knowledge, and efforts of the patient and dentist to effectively control the caries process. However, this *in vitro* study did not attempt to provide simulated data for caries activity and caries risk assessments.

It could be suggested that the ICDAS criteria might benefit the community if they could be used to guide dentists for treatment decision making. However, further clinical studies are required to assess

the relevance and viability of combining adjunct methods, such as radiographic examination with ICDAS criteria, to enhance the accuracy of occlusal caries detection and, consequently, for a personalized treatment decision making avoiding both overtreatment and undertreatment, considering important patient factors such as caries activity, caries risk assessment, diet, oral hygiene, and fluoride.

CONCLUSIONS

Based on the findings of the current study, and within the limitations of an *in vitro* investigation, the ICDAS visual criteria showed better performance than radiographic examination for occlusal caries detection. The ICDAS was highly correlated with TD (0.85). Although the correlation between the ICDAS and BW was lower (0.74), it would still be of value in the clinical decision-making process. It should be stressed that the ICDAS did not correlate strongly with the histology gold standard, which presents an important question to the validity of the method.

(Accepted 23 November 2010)

REFERENCES

1. Lussi A, Imwinkelried S, Pitts N, Longbottom C & Reich E (1999) Performance and reproducibility of a laser fluorescence system for detection of occlusal caries in vitro *Caries Research* **33(4)** 261-266.
2. Verdonschot EH, Wenzel A & Bronkhorst EM (1993) Assessment of diagnostic accuracy in caries detection: An analysis of two methods *Community Dentistry and Oral Epidemiology* **21(4)** 203-208.
3. Ie YL & Verdonschot EH (1994) Performance of diagnostic systems in occlusal caries detection compared *Community Dentistry and Oral Epidemiology* **22(3)** 187-191.
4. Verdonschot EH, Angmar-Månsson B, ten Bosch JJ, Deery CH, Huysmans MC, Pitts NB & Waller E (1999) Developments in caries diagnosis and their relationship to treatment decisions and quality of care. ORCA Saturday Afternoon Symposium 1997 *Caries Research* **33(1)** 32-40.
5. Pretty IA & Maupomé G (2004) A closer look at diagnosis in clinical dental practice: Part 5. Emerging technologies for caries detection and diagnosis *Journal of the Canadian Dental Association* **70(8)** 540, 540a-540i.
6. Lobo MM, Pecharki GD, Gushi LL, Silva DD, Cypriano S, Meneghim MC, Pereira AC (2003) Occlusal caries diagnosis and treatment *Brazilian Journal of Oral Science* **2(6)** 239-244.
7. Traebert J, Marcenes W, Kreutz JV, Oliveira R, Piazza CH & Peres MA (2005) Brazilian dentists' restorative treatment decisions *Oral Health & Preventive Dentistry* **3(1)** 53-60.
8. Wolwacz VF, Chapper A, Busato AL & Barbosa AN (2004) Correlation between visual and radiographic examinations of non-cavitated occlusal caries lesions—An *in vivo* study *Brazilian Oral Research* **18(2)** 145-149.
9. Wenzel A (2004) Bitewing and digital bitewing radiography for detection of caries lesions *Journal of Dental Research* **83(Spec No C)** C72-C75.
10. Kay EJ, Watts A, Paterson RC & Blinkhorn AS (1988) Preliminary investigation into the validity of dentists' decisions to restore occlusal surfaces of permanent teeth *Community Dentistry and Oral Epidemiology* **16(2)** 91-94.
11. Lewis DW, Kay EJ, Main PA, Pharoah MG & Csima A (1996) Dentists' variability in restorative decisions, microscopic and radiographic caries depth *Community Dentistry and Oral Epidemiology* **24(2)** 106-111.
12. Akarslan ZZ & Erten H (2009) The use of a microscope for restorative treatment decision-making on occlusal surfaces *Operative Dentistry* **34(1)** 83-86.
13. Elderton RJ & Nuttall NM (1983) Variation among dentists in planning treatment *British Dental Journal* **154(7)** 201-206.
14. Bader JD & Shugars DA (1995) Variation in dentist's clinical decisions *Journal of Public Health Dentistry* **55(3)** 181-188.
15. Maupomé G (1998) A comparison of senior dental students and normative standards with regard to caries assessment and treatment decisions to restore occlusal surfaces of permanent teeth *Journal of Prosthetic Dentistry* **79(5)** 596-603.
16. Bulman JS & Osborn JF (1989) Measuring diagnostic consistency *British Dental Journal* **166(10)** 377-381.
17. Souza-Zaroni WC, Ciccone JC, Souza-Gabriel AE, Ramos RP, Corona SA & Palma-Dibb RG (2006) Validity and reproducibility of different combinations of methods for occlusal caries detection: An *in vitro* comparison *Caries Research* **40(3)** 194-201.
18. Rocha ASPS, Almeida SM, Bóscolo FN & Haiter Neto F (2005) Interexaminer agreement in caries radiographic diagnosis by conventional and digital radiographs *Journal of Applied Oral Science* **13(4)** 329-333.
19. Espelid I (1986) Radiographic diagnosis and treatment decisions on approximal caries *Community Dentistry and Oral Epidemiology* **14(5)** 265-270.
20. Mileman PA & van der Weele LT (1990) Accuracy in radiographic caries diagnosis: Dutch practitioners and dental caries *Journal of Dentistry* **18(3)** 130-136.
21. Traebert J, Wesolowski CI, de Lacerda JT & Marcenes W (2007) Thresholds of restorative decision in dental caries treatment among dentists from small Brazilian cities *Oral Health & Preventive Dentistry* **5(2)** 131-135.
22. Bader JD & Shugars DA (1993) Agreement among dentists' recommendations for restorative treatment *Journal of Dental Research* **72(5)** 891-896.
23. Ekstrand KR, Ricketts DN & Kidd EA (1997) Reproducibility and accuracy of three methods for assessment of demineralization depth on the occlusal surface: An *in vitro* examination *Caries Research* **31(3)** 224-231.

24. Nyvad B, Machiulskiene V & Baelum V (1999) Reliability of a new caries diagnostic system differentiating between active and inactive caries lesions *Caries Research* **33(4)** 252-260.

25. Bader JD, Shugars DA & Bonito AJ (2001) Systematic reviews of selected dental caries diagnosis and management methods *Journal of Dental Education* **65(10)** 960-968.

26. Ismail AI, Sohn W, Tellez M, Amaya A, Sen A, Hasson H & Pitts NB (2007) The International Caries Detection and Assessment System (ICDAS): An integrated system for measuring dental caries *Community Dentistry and Oral Epidemiology* **35(3)** 170-178.

27. Pitts N (2004) "ICDAS"—An international system for caries detection and assessment being developed to facilitate caries epidemiology, research and appropriated clinical management *Community Dental Health* **21(3)** 193-198.

28. Zandoná AF & Zero DT (2006) Diagnostic tools for early caries detection *Journal of the American Dental Association* **137(12)** 1675-1684; quiz 1730.

29. Ekstrand KR, Martignon S, Ricketts DJ & Qvist V (2007) Detection and activity assessment of primary coronal caries lesions: A methodologic study *Operative Dentistry* **32(3)** 225-235.

30. Jablonski-Momeni A, Stachniss V, Ricketts DN, Heinzel-Gutenbrunner M & Pieper K (2008) Reproducibility and accuracy of the ICDAS-II for detection of occlusal caries *in vitro Caries Research* **42(2)** 79-87.

31. Rodrigues JA, Hug I, Diniz MB & Lussi A (2008) Performance of fluorescence methods, radiographic examination and ICDAS II on occlusal surfaces in vitro *Caries Research* **42(4)** 297-304.

32. Diniz MB, Rodrigues JA, Hug I, Cordeiro RCL, Lussi A (2009) Reproducibility and accuracy of the ICDAS-II for occlusal caries detection *Community Dentistry and Oral Epidemiology* **37(5)** 399-404.

33. Zandona AGF, Al-Shiha S, Eggertsson H & Eckert G (2009) Student versus faculty performance using a new visual criteria for the detection of caries on occlusal surfaces: An *in vitro* examination with histological validation *Operative Dentistry* **34(5)** 598-604.

34. Kühnisch J, Berger S, Goddon I, Senkel H, Pitts N & Heinrich-Weltzien R (2008) Occlusal caries detection in permanent molars according to WHO basic methods, ICDAS II and laser fluorescence measurements *Community Dentistry and Oral Epidemiology* **36(6)** 475-484.

35. Pitts NB & Richards D (2009) Personalized treatment planning *Monographs in Oral Science* **21** 128-143.

36. Longbottom C, Ekstrand K & Zero D (2009) Traditional preventive treatment options *Monographs in Oral Science* **21** 149-155.

37. Machiulskiene V, Nyvad B & Baelum V (1999) A comparison of clinical and radiographic caries diagnoses in posterior teeth of 12-year-old Lithuanian children *Caries Research* **33(5)** 340-348.

38. Kay EJ, Nuttall NM & Knill-Jones R (1992) Restorative treatment thresholds and agreement in treatment decision-making *Community Dentistry and Oral Epidemiology* **20(5)** 265-268.

39. Mileman PA, Mulder E & van der Weele L (1992) Factors influencing the likelihood of successful decisions to treat dentin caries from bitewing radiographs *Community Dentistry and Oral Epidemiology* **20(4)** 175-180.

40. Topping GVA, Hally J, Bonner B, Pitts NB (2008) International Caries Detection and Assessment System (ICDAS) e-learning Package Interactive CD ROM and Web-based software. Smile-on, London.

41. Metz CE (1978) Basic principles of ROC analysis *Seminars in Nuclear Medicine* **8(4)** 283-298.

42. Zero DT, Ferreira Zandona A, Vail MM, Spolnik KJ (2011) Dental caries and pulpal disease *Dental Clinics of North America* **55(1)** 29-46.

43. Diniz MB, Lima LM, Santos-Pinto L, Eckert JG, Ferreira Zandoná AG, Cordeiro RCL (2010) Influence of the ICDAS e-learning program for occlusal caries detection on dental students *Journal of Dental Education* **74(8)** 862-868.

44. Verdonschot EH, Wenzel A, Truin GJ & König KG (1993) Performance of electrical resistance measurements adjunct to visual inspection in the early diagnosis of occlusal caries *Journal of Dentistry* **21(6)** 332-337.

45. Huysmans CDNJM & Longbottom C (2004) The challenges of validating diagnostic methods and selecting appropriate gold standards *Journal of Dental Research* **83** C48-C52.

46. Ricketts D, Kidd E, Weerheijm K & de Soet H (1997) Hidden caries: What is it? Does it exist? Does it matter? *International Dental Journal* **47(5)** 259-265.

47. Beauchamp J, Caufield PW, Crall JJ, Donly K, Feigal R, Gooch B, Ismail A, Kohn W, Siegal M, Simonsen R & American Dental Association Council on Scientific Affairs (2008) Evidence-based clinical recommendations for the use of pit-and-fissure sealants: A report of the American Dental Association Council on Scientific Affairs *Journal of the American Dental Association* **139(3)** 257-268.