©Operative Dentistry, 2016, **41-1,** 34-43

Detection of Caries Around Amalgam Restorations on Approximal Surfaces

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Clinical Relevance

In this investigation, the authors evaluated the *in vitro* performance of the International Caries Detection and Assessment System visual criteria, bitewing radiography examination, and a pen-type laser fluorescence device in detecting approximal caries around amalgam restorations in permanent teeth.

SUMMARY

To evaluate the *in vitro* performance of the International Caries Detection and Assessment System (ICDAS) visual examination, bitewing radiography (BW), and the DIAGNOdent 2190, a pen-type laser fluorescence device (LFpen), in detecting caries around amalgam restorations on approximal surfaces. Approximal surfaces (N=136) of permanent posterior teeth (N=110) with Class II amalgam restorations were assessed twice by two experienced examiners using ICDAS, BW, and LFpen. The occurrence of proximal overhangs was also evaluated. The teeth were histologically prepared and assessed for caries extension. Different cutoff limits for the LFpen were used. Intraexaminer and interexaminer reproducibility showed moderate to good agreement for all the methods (weighted κ/intraclass correlation coefficient=0.40 to 0.87). The specificities at D_1 (all visible lesions affecting enamel) and D_3 (lesions extended into dentin) were, respectively, 0.41 and 0.82 for ICDAS, 0.70 and 0.82 for BW, and 0.77-0.89 and 0.88-0.94 for LFpen. The sensitivities were 0.80 and 0.52 for ICDAS, 0.56 and 0.51 for BW, and 0.04-0.23 and 0.01-0.02 for LFpen at D_1 and D_3, respectively. At the D_1/D_3 thresholds, the accuracy and the area under the receiver operating characteristic curve (A_z) values were similar and statistically higher for ICDAS (0.65/0.68 and 0.633/0.688) and BW (0.64/0.68 and 0.655/0.719), respectively; whereas, LFpen presented lower accuracy (0.37-0.44/0.49-0.52) and A_z (0.390-0.454/0.345-0.395) values. The occurrence of overhangs (26.8%) was shown to be irrelevant in determining the presence of secondary caries. The ICDAS and BW methods presented

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DOI: 10.2341/14-048-L

the best performance in detecting caries lesions affecting enamel and dentin on approximal surfaces of amalgam restorations.

INTRODUCTION

In dental practice, secondary caries is defined as a lesion that occurs at the margin of an existing restoration, and it is the most common reason for filling replacement.[1-3] Histopathologically, caries lesions around restorations may show lines of demineralized tissue along the cavosurface margin (called outer lesions) and the cavity wall (called wall lesions).[2]

The detection of secondary caries lesions is extremely challenging due to difficulties encountered during the clinical examination, such as stained restoration margins, gaps, crevices, and ditches.[2] Traditional methods for detecting secondary caries include bitewing radiographs and visual-tactile examinations.[1] Bitewing radiographs are important for secondary caries detection because the disease often occurs cervically.[1,4] Nevertheless, radiographs can lead to underestimation of the lesion extension and cannot predict the presence or absence of cavitation of the approximal surface.[5] In addition, restorative materials are radiopaque and can partially or completely hide the lesion.[6]

Enamel translucency, cavitation, consistency or hardness, and the color of dentin and enamel are considered to be the best clinical parameters for determining the activity and extent of secondary caries.[7] However, gray or blue discoloration next to an amalgam restoration presents limitations for caries detection because the discoloration could be due to a large amalgam restoration or the products of its corrosion. This confounding factor associated with the subjective criteria used by dental practitioners can lead to false-positive results for secondary caries.[8,9]

The International Caries Detection and Assessment System (ICDAS) visual criteria were introduced to assist in caries detection.[10] Given that outer lesions from secondary caries are considered similar to primary caries, the broad principles applied to the criteria for primary caries can also be applied to caries around restorations and sealants (CARS).[11] Research has shown that the ICDAS presents good reproducibility and accuracy for *in vitro* and *in vivo* detection of primary caries lesions at different stages of the disease.[10,12-15] To our knowledge, no studies have been published that evaluate the performance of the ICDAS visual criteria in the detection of caries around restorations on approximal surfaces.

New early-caries detection methods, such as laser fluorescence (DIAGNOdent 2095 [LF], KaVo, Biberach, Germany) have received considerable attention as aids in the detection and quantification of demineralized dental tissue beneath restorations.[16-19] In 2006, a new laser fluorescence device (DIAGNOdent 2190 [LFpen], KaVo) was developed to assist the detection of occlusal and approximal caries.[20] The LFpen is able to capture, analyze, and quantify the fluorescence emitted from bacterial porphyrins and other chromophores when the tooth is illuminated by a diode laser with a wavelength of 655 nm.[20] To date, few reports have evaluated the capacity of the LFpen device to detect caries around restorations.[21,22]

The marginal integrity of the restorations on the approximal surface is critical, because cervical overextension of the restoration can lead to plaque accumulation and periodontal inflammation, and underfilled restorations may result in marginal leakage and secondary caries.[23] Studies[24-26] have shown an alarming prevalence of overhanging restorations (57%-64%), which might predispose patients to the development of secondary caries.[7]

Therefore, the purpose of this *in vitro* study was to evaluate the *in vitro* performance of the ICDAS visual criteria, bitewing radiography examination (BW), and the LFpen in detecting secondary caries on approximal surfaces of amalgam restorations in permanent teeth. The association between the presence of overhangs and secondary caries was also evaluated.

METHODS AND MATERIALS

A total of 110 posterior permanent human teeth (56 premolars and 54 molars) with Class II amalgam restorations were selected from a pool of extracted teeth obtained from dental practitioners in the United States. A total of 136 surfaces were included in this study, which included restorations with intact margins, visual signs of demineralization, or cavitated margins on the approximal surfaces. The teeth were cleaned with water and a prophy angle, and calculus and debris were removed using a scaler. The teeth were then numbered and were stored individually in plastic containers at −20°C until use.

The approximal surfaces were photographed at 10× magnification using a stereomicroscope (model SMZ1500, Nikon, Tokyo, Japan) equipped with a digital camera (model DXM1200, Nikon) and imaging software (Nikon ACT-1, version 2.62, Nikon). The occlusal surfaces were also photographed for tooth identification.

The teeth were mounted in plastic dental models (upper and lower arches) (Nissin Dental Products Inc, Kyoto, Japan), using base wax in order to obtain a contact surface, and stored at 100% humidity throughout the study. The surfaces under study were placed next to surfaces with or without restorations in order to simulate the contact point between the crowns, similar to clinical oral conditions. The models were placed in a phantom head (Kilgore International Inc, Coldwater, MI, USA) to simulate clinical examination conditions.

The assessments were independently performed twice by two experienced examiners, observing a one-week interval. The examiners assessed the teeth using the ICDAS criteria for CARS, digital BW, and the DIAGNOdent 2190 device (LFpen, KaVo).

Visual Examination

Before the assessments, the two examiners, who had previous experience with ICDAS, participated in a training session involving ICDAS criteria for CARS. Training consisted of the online ICDAS e-learning program, an evaluation of 20 extracted teeth with amalgam restorations on two occasions with a one-week interval, and a discussion of each code until consensus was reached.

Each surface was assessed by the examiners using the ICDAS criteria proposed for CARS according to the ICDAS Coordinating Committee[27]: 0, sound tooth surface with restoration or sealant; 1, first visual change in enamel; 2, distinct visual change in enamel/dentin adjacent to a restoration/sealant margin; 3, carious defects of <0.5 mm with the signs of code 2; 4, marginal caries in enamel/dentin/cementum adjacent to a restoration/sealant with underlying dark shadow from dentin; 5, distinct cavity adjacent to a restoration/sealant; and 6, extensive distinct cavity with visible dentin.

The examinations were performed in the same room, under good illumination, using a portable dental light, and aid of a three-in-one air syringe, a dental mirror, and a ballpoint probe. The teeth were analyzed moist and then dried from both the buccal and lingual sides.

Radiographic Examination

Digital BW were taken of all teeth using an x-ray unit (Heliodent DS, Siemens Co, München, Germany) and a charge-coupled device (CCD) sensor of a direct digital system (Schick CDR, Schick Technologies Inc, Long Island City, NY, USA) by the same operator at 60 kV and 7 mA, with an exposure time of 0.06 seconds. The radiation source was perpendicularly directed to the sensor and the tooth, following the principles of the parallelism technique, and was placed 2 cm from them.

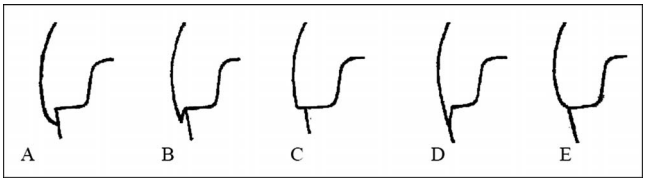

Figure 1. *Definition of overhang.*

The radiographs were viewed using the software supplied by the CCD manufacturer (CDR DICOM 4.5 software, Schick Technologies) on a 15.4-inch computer screen under the same lighting conditions, at a standardized distance and viewing angle. No modification of the original image or screen adjustments was allowed and no image enhancement software was used.[28] The criteria used to indicate enamel or dentin caries lesions were 0, no radiolucency; 1, radiolucency adjacent to the restoration consistent with enamel caries; and 2, radiolucency adjacent to the restoration consistent with dentin caries.

Laser Fluorescence

The LFpen measurements were performed using the wedge-shaped tip (1.1 mm). Before each measurement, the device was calibrated with a ceramic standard and on a sound smooth surface of each tooth, in accordance with the manufacturer's instructions. The approximal surfaces were assessed by each examiner by moving the tip from the buccal toward the lingual side, underneath the contact area. The same procedure was performed moving the tip from the lingual toward the buccal side.[22] Each surface was assessed by scanning the margin and recording the maximum reading (peak value) for each measurement. For statistical analysis, the greater of these values was considered.[22]

Overhang Evaluation

An overhang is a restoration that extends beyond the prepared cavity and does not conform to the proximal contour of the tooth. The examiners evaluated the BW and classified each surface accordingly (Figure 1). Types A, B, and C were defined as overhangs, whereas types D and E were not.[29]

Validation (Gold-Standard)

For validation, the restorative material was removed carefully by one of the examiners using a tungsten carbide bur in a high-speed handpiece under copious water cooling. Care was taken to avoid any contact with the cavity walls and margins. Any remnants of amalgam in the cavity were removed using a sharp excavator.[18]

The teeth were then longitudinally hemisectioned, perpendicular to the approximal surfaces, with a water-cooled diamond blade (Gillings-Hamco, Hamco Machines Inc, NY, USA). Both sides of each section were examined carefully by two experienced examiners using visual examination in a stereomicroscope at 10× magnification; the most severely affected section determined the lesion depth.[18] In cases of disagreement, the results were discussed until a consensus was reached. Each section was scored independently according to the following criteria: 0, no caries, 1, caries lesion limited to the outer half of the enamel, 2, caries extending into the inner half of the enamel or outer half of the dentin, 3, caries limited to the middle third of the dentin, and 4, caries involving the inner half of the dentin.[30]

Statistical Analysis

Data from both examiners were used for statistical analysis. For LFpen measurements, the mean value of the two measurements obtained for each surface was used in the analysis. The cutoff limits for LFpen were based on a previous study[31] for primary approximal caries (0-6, sound; 7-15, caries in enamel; and 16-99, caries in dentin); on a study[21] for approximal caries around composite restorations (0-18, sound; 19-30, caries in enamel; and 31-99, caries in dentin); and on a study[17] for approximal caries around amalgam restorations (0-8, sound; 9-30, caries in enamel; and 31-99, caries in dentin).

The sensitivity, specificity, accuracy, and area under the receiver operating characteristic curve (A_z) of each method were calculated at D_1 ("all visible lesions affecting enamel," considering scores of 1 to 4 as the disease gold-standard) and D_3 ("caries extended into dentin," considering scores of 3 and 4 as the disease gold-standard) diagnostic thresholds (MedCalc for Windows, version 9.3.0.0, Mariakerke, Belgium). Diagnostic accuracy relates the ability of a test to discriminate between and/or to predict disease and health and can be quantified by measures such as sensitivity and specificity, predictive values, likelihood ratios, A_z, overall accuracy, and diagnostic odds ratio.[32] The McNemar test ($p<0.05$) was applied to compare statistically significant differences among the methods. In addition, a nonparametric statistical test for paired data was applied to assess the difference in the A_z by estimating the covariance matrix for the A_z, based on the general theory of U-statistics, and then constructing a large-sample test in the usual way.[33]

The intraexaminer and interexaminer reproducibility was assessed by means of weighted κ (WK) and intraclass correlation coefficients (ICC). The ICC was assessed as poor when the values were below 0.40, fair for values between 0.40 and 0.59, good for values between 0.60 and 0.75, and excellent for values above 0.75. WK values above 0.75 denoted excellent agreement, whereas values between 0.40 and 0.75 indicated good agreement.[34]

The Spearman rank correlation coefficient was determined to compare all three methods with histological scores. The occurrence of proximal overhangs and their possible association with secondary caries was also evaluated using the Fisher exact test. The criterion for significance was set at 5%.

RESULTS

Of the 136 approximal surfaces available for this study, histological examination showed that 52 (38.2%) presented no caries, five (3.7%) presented caries limited to the outer half of the enamel, 18 (13.2%) had caries extending into the inner half of the enamel or outer half of the dentin, 27 (19.9%) had caries limited to the middle third of the dentin, and 34 (25.0%) presented caries involving the inner half of the dentin.

Table 1 presents the cross-tabulation for the ICDAS, BW, and LFpen methods and the corresponding histological results. The analyses were performed twice by two experienced examiners on 136 surfaces, totaling 544 surfaces. The results show a tendency for underestimation and overestimation of the depth of secondary caries lesions. Both BW and LFpen correctly indicated a greater amount of sound approximal surfaces than carious surfaces.

Table 2 presents the sensitivity, specificity, accuracy, and A_z for all methods at the D_1 and D_3 thresholds. At the D_1 threshold, ICDAS presented a statistically higher sensitivity value, whereas LFpen showed lower sensitivity and higher specificity values. Regarding accuracy and A_z values, ICDAS and BW presented statistically comparable results. At the D_3 threshold, both ICDAS and BW presented similar sensitivity, specificity, and accuracy values.

Table 1: *Cross-tabulation of the ICDAS, BW, and LFpen Measurements With the Corresponding Histological Scores*

	Histological Score					
Codes	**0, n**	**1, n**	**2, n**	**3, n**	**4, n**	**Total, n (%)**
ICDAS						
0	85	6	20	12	29	152 (27.9)
1	17	3	12	6	9	47 (8.6)
2	63	7	32	37	25	164 (30.1)
3	11	1	2	14	5	33 (6.1)
4	11	0	2	9	14	36 (6.6)
5	15	3	2	18	32	70 (12.9)
6	6	0	2	12	22	42 (7.7)
Total, n (%)	208 (38.2)	20 (3.7)	72 (13.2)	108 (19.9)	136 (25.0)	544 (100)
BW						
0	153	11	46	52	56	318 (58.5)
1	20	1	16	7	5	49 (9.0)
2	35	8	10	49	75	177 (32.5)
Total, n (%)	208 (38.2)	20 (3.7)	72 (13.2)	108 (19.9)	136 (25.0)	544 (100)
LFpen						
0	161	8	49	86	117	421 (77.4)
1	23	10	12	21	15	81 (14.9)
2	24	2	11	1	4	42 (7.7)
Total, n (%)	208 (38.2)	20 (3.7)	72 (13.2)	108 (19.9)	136 (25.0)	544 (100)

Abbreviations: BW, bitewing radiography; ICDAS, International Caries Detection and Assessment System; LFpen, DIAGNOdent 2190, a pen-type laser fluorescence device (KaVo, Biberach, Germany).

However, LFpen showed statistically lower sensitivity and higher specificity values.

Table 3 presents the intraexaminer and interexaminer reproducibility assessed by calculating the WK and ICC. For the LFpen, the ICC varied from 0.690 (interexaminer) to 0.878 (intraexaminer A). For intraexaminer reproducibility, the WK values ranged from 0.575 (BW) to 0.819 (overhangs); whereas, for interexaminer reproducibility, the WK values ranged from 0.404 (BW) to 0.673 (ICDAS), indicating good to excellent agreement.

The Spearman rank correlation coefficients for all methods with histology were 0.321 for ICDAS, 0.309 for BW, −0.103 for the LFpen device, and −0.077 for overhangs. A nonstatistically significant correlation was determined between the occurrence of overhangs and the presence of secondary caries ($p>0.05$); whereas, minimal significant correlation was determined for ICDAS, BW, and LFpen ($p<0.05$).

Different overhangs were detected: type A in 3.3% of the radiographs, type B in 1.6%, type C in 21.9%, type D in 5.8%, and type E in 67.4%. Table 4 shows

Table 2: *Sensitivity, Specificity, Accuracy, and Area Under the Receiver Operating Characteristic Curve (A_z) for All the Methods at D_1 and D_3 Thresholds*

	Sensitivity		Specificity		Accuracy		A_z	
Method	**D_1[a]**	**D_3[b]**	**D_1**	**D_3**	**D_1**	**D_3**	**D_1**	**D_3**
ICDAS	0.80 A	0.52 A	0.41 A	0.82 A	0.65 A	0.68 A	0.633 A	0.688 A
BW	0.56 B	0.51 A	0.70 B	0.82 A	0.64 A	0.68 A	0.655 A	0.719 A
LFpen[c]	0.23 C	0.02 B	0.77 C	0.88 A	0.44 B	0.49 B	0.390 B	0.345 B
LFpen[d]	0.04 D	0.01 B	0.89 D	0.94 B	0.37 C	0.52 C	0.454 B	0.395 B
LFpen[e]	0.16 E	0.01 B	0.80 C	0.94 B	0.41 B	0.52 C	0.403 B	0.395 B

Abbreviations: BW, bitewing radiography; ICDAS, International Caries Detection and Assessment System; LFpen, DIAGNOdent 2190, a pen-type laser fluorescence device (KaVo, Biberach, Germany).
[a] D_1: 0 = sound, 1-4 = decayed; [b] D_3: 0-2 = sound, 3-4 = decayed. Significant differences are represented by different small capital letters considering the same column (McNemar test, $p<0.05$ for specificity, sensitivity and accuracy; nonparametric statistical test for paired data for A_z).
[c] Lussi and others (2006): 0-6, sound; 7-15, caries in enamel; 16-99, caries in dentin.
[d] Rodrigues and others (2010): 0-18, sound; 19-30, caries in enamel; 31-99, caries in dentin.
[e] Ando and others (2004): 0-8, sound; 9-30, caries in enamel; 31-99, caries in dentin.

Table 3: *Intraexaminer and Interexaminer Reproducibility for All the Methods*

	Intraexaminer Reproducibility		Interexaminer Reproducibility
Method	Examiner A	Examiner B	All
ICDAS[a]	0.783 (0.708-0.858)	0.657 (0.533-0.761)	0.673 (0.610-0.737)
BW[a]	0.802 (0.701-0.904)	0.575 (0.459-0.691)	0.404 (0.321-0.487)
LFpen[b]	0.878 (0.833-0.911)	0.861 (0.811-0.899)	0.690 (0.622-0.747)
Overhangs[a]	0.819 (0.734-0.904)	0.656 (0.540-0.771)	0.591 (0.511-0.672)

Abbreviations: BW, bitewing radiography; ICDAS, International Caries Detection and Assessment System; LFpen, DIAGNOdent 2190, a pen-type laser fluorescence device (KaVo, Biberach, Germany).
[a] *Weighted κ (95% confidence interval).*
[b] *Intraclass correlation coefficient (95% confidence interval).*

the overhang results and their association with the presence or absence of secondary caries. According to the radiographs, 36 (26.8%) of the amalgam restorations exhibited detectable overhangs and 100 (73.2%) did not present overhangs. Of the total number of amalgam-restored proximal surfaces, 84 (61.8%) presented secondary caries lesions. Of all the proximal surfaces with overhangs (N=36), 20 (55.6%) exhibited secondary caries versus 64 (64.0%) of the restorations without overhangs. No statistically significant difference was determined between overhangs and the presence or absence of secondary caries ($p>0.05$).

DISCUSSION

In this study, the performance of the ICDAS visual criteria, BW, and LFpen in detecting caries around Class II amalgam restorations was compared. Although a previous study[35] had evaluated the prevalence and severity of primary and secondary dental caries in low-income African American adults, to our knowledge, this is the first study to investigate the performance of the ICDAS in detecting caries around approximal amalgam restorations in permanent teeth.

The gold standard used in this study involved microscopic examinations after restoration removal and tooth hemisectioning. Another study also assessed cavities in this manner.[18] Given that it is difficult to validate secondary caries, caution was taken during tooth preparation and examination. However, different histological methods for validating secondary caries are described in the literature, including confocal laser scanning microscopy examination,[17] caries-detector dye application,[36] and histological specimen preparation associated with microhardness evaluation.[21,22]

The LFpen cutoff limits used in this study were proposed by Lussi and others[31] for approximal primary lesions. Other studies[21,22] have also evaluated these cutoff values for secondary caries detection around approximal restorations. The cutoff limits were tested following the principles that secondary caries on approximal surfaces appeared and progressed similar to primary caries.[37] The cutoff limits proposed by Rodrigues and others[21] for the LFpen device using a wedge-shaped sapphire fiber tip to detect caries around approximal composite restorations and the cutoffs proposed by Ando and others for the LF (DIAGNOdent 2095, KaVo) device using a tapered fiber-optic tip (tip A) to detect caries around Class II amalgam restorations in permanent teeth were also evaluated. It is important to emphasize that cutoff limits should be carefully interpreted, because they are used to determine the borderline between health and disease. An attempt was made to establish the optimal cutoff points for this investigation. However, inconsistency was verified between the D_1 and D_3 thresholds, and any value lower than 2.0 showed the optimal balance between sensitivity and specificity in detecting secondary caries in enamel or dentin. This variation

Table 4: *Overhangs Association With the Presence or Absence of Secondary Caries*

	Presence of Secondary Caries		Absence of Secondary Caries			
Overhangs	n	%	n	%	Total, n(%)	*p* Value*
Restored without overhang	64	64.0	36	36.0	100 (73.2)	0.4257
Restored with overhang	20	55.6	16	44.4	36 (26.8)	
Total, n (%)	84 (61.8%)		52 (38.2%)		136 (100)	

** Fisher exact test (p<0.05).*

could be attributed to the distribution of lesion types and the different LFpen readings due to the marginal integrity of the tooth around the restoration. According to Lussi and others,[38] some interference can occur due to the materials and caries when fluorescence is measured approximally, leading to false-positive results. In this work, the surfaces under examination were placed next to surfaces with or without restoration in order to simulate the contact point, similar to clinical oral conditions. A previous study on secondary caries detection confirmed that amalgam restorations did not influence laser fluorescence examinations.[17] Thus, it can be assumed that the LFpen findings could be basically attributed to the cutoff limits evaluated in the present investigation. Superior cutoff ranges are necessary to interpret the LFpen assessments for secondary caries detection.

According to Neuhaus and others,[22] refinishing and cleaning restoration facets by adequate means before LF assessment is indispensable. Thus, all the surfaces of our samples were cleaned before the assessments to avoid false-positive results.

ICDAS and BW were better at detecting secondary caries than the LFpen. Considering all visible lesions affecting enamel, ICDAS showed statistically greater sensitivity than BW. Our results are in agreement with the results presented by Neuhaus and others,[22] who reported high specificities and low sensitivities for BW. According to Sikri and Sikri,[39] the detection of secondary caries by BW is obscured by adjacent superimposing structures. It is known that digital radiography does not fully address the problems associated with conventional radiography,[39] as verified in this investigation. For the detection of lesions extended into dentin, ICDAS and BW showed statistically similar performances, with high specificity and low sensitivity values. Diniz and others[14] reported lower specificity (0.69) and higher sensitivity (1.00) values for ICDAS in detecting occlusal primary caries in permanent teeth.

The LFpen showed poor performance in terms of sensitivity and accuracy at the D_1 and D_3 thresholds for both cutoff limits tested. On the other hand, high specificity values were determined for both thresholds, indicating that the LFpen could be a useful tool for detecting the absence of secondary lesions. Rodrigues and others[21] and Neuhaus and others[22] showed lower specificity and higher sensitivity and accuracy values for secondary caries on crown surfaces at the D_1 threshold as well as higher sensitivity and accuracy values at the D_3 threshold when using the cutoff limits proposed by Lussi and others.[31] Ando and others[17] observed higher sensitivity and accuracy values for the LF device for the D_1 and D_3 thresholds for secondary caries on approximal surfaces when using the cutoff limits based upon the manufacturer's instructions and literature available. These differences could be due to the smaller number of approximal surfaces analyzed, the distribution pattern of caries lesions, with minimal areas of sound surfaces, the LF devices used and their different tips, the simulated contact point between two sound teeth, and the histological validation method used in their studies. Even though the LF method has been evaluated for secondary caries detection on occlusal surfaces around amalgam restorations,[18,36] these studies used a different device (DIAGNOdent 2095, KaVo), and the actual numbers may not be comparable.

The Spearman correlation coefficients were statistically significant for ICDAS, BW, and LFpen. These results showed that there was a positive association between the histological scores and the methods. However, it is important to emphasize that ICDAS and BW presented higher values compared with the LFpen device. Rodrigues and others[21] obtained similar results for BW (0.29) and the visual examination (0.29), but a higher Spearman correlation coefficient for the LFpen (0.54). It should be highlighted that Rodrigues and others[21] evaluated the detection of secondary approximal caries associated with composite restorations, which might explain the differences verified between their work and this study.

Despite the training in visual ICDAS criteria, interexaminer and intraexaminer reproducibility varied from good to excellent, illustrating the need for additional training. Lower reproducibility values were described by Rodrigues and others[21] when assessing caries around composite restoration on approximal surfaces, using different criteria for visual examination. The reproducibility values reported by previous *in vitro* studies[12-14] involving ICDAS criteria for primary caries also varied from good to excellent. Direct visual examination is hard to perform on approximal surfaces, especially around amalgam restorations, in which the presence of ditches, stain, gaps, and crevices may confound clinicians. The ICC values obtained for the LFpen measurements in our study were high for intraexaminer reproducibility, showing excellent agreement. This result corroborates *in vitro* reproducibility results for approximal secondary caries detection.[21-22] For BW, the WK value for interexaminer agreement was lower compared with the other methods, similar to that

described by Rodrigues and others[21] but in contrast to Neuhaus and others,[22] who reported higher values for interexaminer reproducibility. These varied results could be attributed to the differences in the examiners' clinical experience in radiographic caries detection.[40]

Overhangs in dental restorations are a major dental health problem, and they are defined as an extension of restorative material beyond the confines of a cavity preparation.[41-43] Overhangs are primarily iatrogenic, caused by poor operator skills and exacerbated by unusual dental morphology.[44] Clinical and radiographic assessments are the most reliable way of diagnosing overhanging margins.[45] In this investigation, no significant correlation between overhangs and approximal secondary caries (p=0.3750) was determined. Similarly, no statistically significant difference was determined between surfaces restored with or without overhangs and the presence or absence of caries (p=0.4257). This is in disagreement with Svensson,[29] who reported 1.6 times more secondary caries on restored surfaces with overhangs compared with restored surfaces without overhangs. These data were derived from a clinical study in which conventional radiographs were taken of 235 patients aged 20-70 years. A total of 1787 proximal amalgam restorations were assessed, and the prevalence of detectable overhangs was 16%; however, a magnifier was used to evaluate the radiographs. In this study, higher percentages of detectable overhangs (26.8%) were observed, even though the digital radiographs were not magnified or altered when assessed.

The LFpen and BW showed good agreement with the histological score in detecting sound surfaces. These results are in accordance with previous studies[17,22] that demonstrate higher specificity values for the LF device and BW in detecting caries around amalgam restorations. Thus, BW and LFpen assessments could be recommended to complement the detection of sound surfaces on approximal amalgam restorations. In contrast, the ICDAS criteria showed a tendency to overestimate the presence of caries around amalgam restorations when no caries were identified by the histological analysis. This result indicates that ICDAS should be used with care when assessing amalgam restorations. Any visual change in the surface around amalgam restorations, such as stained restoration margins, gaps, crevices, and ditches, may lead to false diagnostic outcomes.[2] The examiner using the ICDAS codes might overestimate caries around an amalgam restoration due to the variety of causes of discoloration around it, such as corrosion products or darkly stained areas that are probably from exogenous dietary sources. This is an important observation given that the principles applied to the criteria for primary caries are also applied to CARS.[11] However, it should be noted that the scientific basis for that has not been established and the literature in the area is limited. It should also be stressed that there is difficulty directly inspecting the approximal surfaces once the adjacent tooth and gingival tissue hamper visual access, especially when a restoration is involved, complicating the differentiation between noncarious changes and secondary caries. A temporary tooth separation with an orthodontic rubber ring placed around the contact point for 2-3 days might be indicated when visual inspection is doubtful.

The LFpen showed a tendency to underestimate enamel and dentin carious lesions. This finding must be considered carefully when using the LF device for treatment decision making because carious lesions will be missed and, consequently, they will be left untreated.

CONCLUSION

In conclusion, ICDAS and BW performed better at detecting caries lesions affecting enamel and lesions extended into dentin on approximal surfaces of amalgam restorations compared with the LFpen device at different cutoff limits. LFpen results should be considered with caution when assessing Class II amalgam restorations. In contrast, the ICDAS criteria showed a tendency to overestimate the presence of caries around amalgam restorations when no caries were present, indicating that ICDAS should be interpreted with care when assessing amalgam restorations.

Acknowledgements

The authors would like to thank the Coordination of Improvement of Higher Education Personnel (CAPES) Doctoral Program in Brazil with Work Experience Abroad (PDEE) for its financial support.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of Araraquara School of Dentistry, São Paulo State University. The approval code for this study is 48/08.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature

or kind in any product, service, and/or company that is presented in this article.

(Accepted 12 September 2014)

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