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Occlusal Caries Extension in Relation to Visual and Radiographic Diagnostic Criteria: Results from a Microcomputed Tomography Study

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Clinical Relevance

The use of a combination of visual and radiographic criteria for caries diagnostics results in fewer invasive treatment decisions.

SUMMARY

Objective: This *in vitro* study aimed to evaluate occlusal caries extension in relation to visual and radiographic diagnostic criteria and their clinical value to indicate operative or preventive dental care.

Methods: A total of 196 third molars with clinically sound occlusal fissures or noncavitated lesions were collected. Before microcomputed tomography (μCT) investigation, each tooth was examined visually and radiographically. Kühnisch's μCT-based caries-extension index (CE index) was used to determine the caries depth on a numeric scale (0 = sound; 0.01-0.99 = enamel caries; 1.0-1.99 = dentin caries). Sensitivities (SEs), specificities (SPs), and area under the receiver operating characteristic curve (Az value) were also calculated.

Results: Based on μCT data, the following mean CE index values and standard deviations (SDs) were documented according to the visual criteria: sound = 0.6 (0.4); first visible signs = 0.9 (0.4); established lesions = 1.3 (0.3); microcavities = 1.4 (0.2); dentin exposure = 1.5 (0.2); and large cavities = 1.5 (0.3). The radiographic categories according to Marthaler (enamel

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caries [D0-2], caries in the outer half of dentin [D3], and caries in the inner half of dentin [D4]) were related to CE index values of 0.9 (0.4), 1.4 (0.2) and 1.6 (0.4), respectively. Caries detected visually or radiographically showed an SE of 84% and an SP of 85% (Az = 0.85). When both methods were used to predict dentin involvement simultaneously, SE = 27%, SP = 100%, and Az = 0.63; this combined visual and radiographic approach was associated with a perfect specificity and no false-negative decisions. The proportion of false-positive diagnoses was moderately high, and lesion extension in these cases was mainly limited to the outer 20% of the dentin.

Conclusions: Our results might be useful for differentiating between preventive and operative dental care for pits and fissures.

INTRODUCTION

Comprehensive caries treatment protocols include preventive and operative measures to reduce ongoing damage of the dental hard tissue. Precise caries diagnostic methods are needed to determine whether remineralization of the damaged tissue is appropriate in a single tooth or if removal of the diseased tissue is necessary. These caries diagnostic methods should reliably predict (dentin) caries lesions and provide valid cutoff values or intervals to support shifting from preventive to operative treatment for each caries site. Most recently, some studies have indicated that caries activity and patient-related risk factors should be used as primary indicators to decide whether restorative treatment is necessary.[1-3] Due to the phenomenon of hidden occlusal caries, which is often linked to a noncavitated but deep caries lesion, it seems worthwhile to rethink using caries activity and risk factors to determine treatment.[4-6] Therefore, it seems to be necessary to discuss the caries extension as another fundamental factor for the decision-making process.

Caries extension is mainly determined semiquantitatively according to the D classification system, which is used for diagnostic and histologic purposes.[7] The D3 score describes dentin caries that ranges from that just penetrating the enamel-dentin junction up to lesions comprising the complete outer half of the dentin and has limitations in differentiated treatment recommendations, such as caries monitoring, pit and fissure sealants, or invasive restorative treatment. Therefore, using a quantitative measure, such as the caries extension (CE) index appears to be a more precise approach because it incorporates caries depth in relation to overall hard tissue thickness.[8] Although high-resolution and nondestructive microcomputed tomography (μCT) has not yet been evaluated for *in vitro* investigation of occlusal caries, it appears to be another innovative method to determine the number or percentage of caries extensions as precisely as possible and may enhance the informative value of validation studies.

Therefore, our investigation aimed to determine the diagnostic performance and caries extension of the routinely used visual and radiographic caries diagnostic criteria and the combination of both methods on occlusal surfaces using μCT and the CE index as reference standards. Based on these data, potential thresholds or cutoff intervals were determined that can be used to distinguish between preventive and operative dental care.

METHODS AND MATERIALS

Sample Size

A sample of 196 seemingly sound or noncavitated third molars was selected from a pool of teeth extracted for surgical or orthodontic reasons. Molar teeth with sealants, fillings, or caries lesions on their smooth surfaces were excluded. After the gross debris was removed, the teeth were carefully cleaned with an airflow device (ProphyFlex, KaVo, Biberach, Germany) and a rotating bristle brush. To prevent bacterial growth, all of the teeth were stored in separate containers with physiologic saline containing 0.02% sodium azide.

Determining the Universal Visual Scoring System Consensus Diagnosis

All of the teeth were examined visually using compressed air and illumination from a dental unit light. The visual inspection was carried out according to the Universal Visual Scoring System (UniViSS)[8,9] under the following principles: for detectable occlusal caries lesions, the severity (first signs, established lesion, microcavity, or dentin exposure) and discoloration (white, brown, or white-brown) were assessed separately with respect to opalescence and enamel translucency as well as tactile inspection with a blunt probe (ISO 21672-2:2012) (Figure 1a).[8,9] Two dentists (M.G. and M.S.) performed visual inspections independently. All of the assessments were cross-checked two weeks later with an experienced dentist (J.K.) to form a consensus diagnosis for each surface. In case of

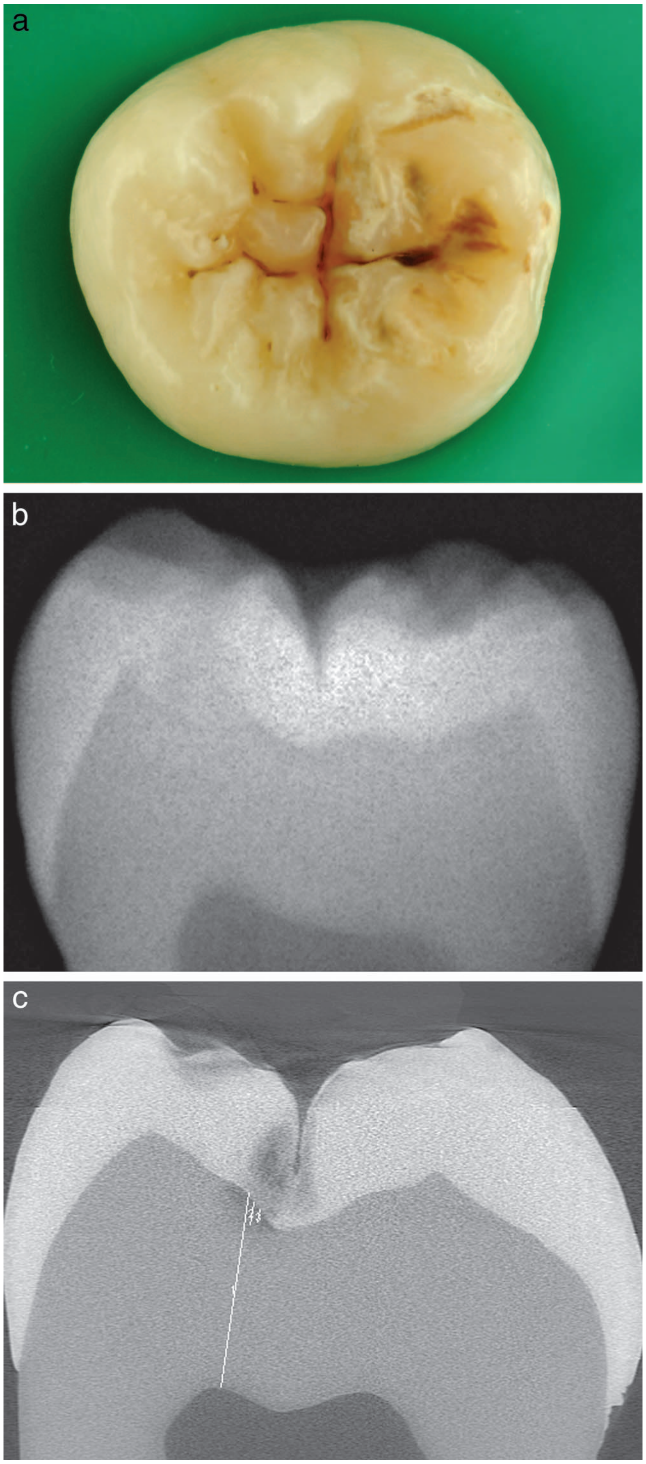

Figure 1. *(a): The occlusal lesion of the central fissures shows a white-brown lesion with dentin exposure that was also detectable with a blunt probe. After use of the Universal Visual Scoring System (UniViSS), preventive measures only were recommended for this tooth. (b): No dentin caries was detectable in the x-ray. The tooth was classified as enamel caries (D0-2 after Marthaler). (c): The micro-computed tomography slice reveals a dentin caries lesion near the enamel-dentin junction (D3 after Marthaler). A maximum score of 1.11 was calculated according to the Caries Extension Index.*

different findings, all of the examiners discussed the discordant findings to reach a consensus.

Determining the Digital Radiography Consensus Diagnosis

All of the digital radiographs were taken using a charged-coupled device system (Sidexis, Sirona, Bensheim, Germany). The exposure time was 0.06 seconds at a cathode voltage of 60 kV and a cathode current of 7 mA. A standardized alignment fixture with a soft-tissue scattering equivalent was used to reproduce the exact object-to-film distance. Two dentists (M.G. and M.S.) evaluated the digital radiographs independently in a darkened room using system-related analysis software (version 2.53, Sirona), with the option to adjust the brightness and contrast. Each examiner determined the caries depth on each radiograph semiquantitatively according to the Marthaler categories of D0-2 for enamel and D3 and D4 for dentin caries and quantitatively by the CE index (Figure 1b).[7,8] All of the radiographic decisions were reassessed two weeks later in collaboration with an experienced examiner (J.K.) to arrive at a consensus diagnosis. When the examiners came to different conclusions, they reassessed the corresponding radiograph, discussed their points, and modified the diagnosis accordingly.

Microcomputed Tomography

A high-resolution μCT system (μCT40, Scanco Medical, Basserdorf, Switzerland) was used to obtain digital three-dimensional (3D) data sets of the teeth. The x-ray source was set at 70 kV and 114 μA. The sample time was 600 milliseconds. Image resolution was fixed at a voxel size of 20 μm. For further evaluation, the reconstructed data sets were imported into ImageJ (ImageJ, US National Institutes of Health, Bethesda, MD, USA; http://rsb.info.nih.gov/ij).[10-12] The analysis of each 3D data set was performed by two blinded dentists (M.G. and M.S.). In the first step they detected the deepest caries progression. In the second step, the caries extension in the enamel and dentin toward the pulp was determined, as well as the enamel and dentin thicknesses, to calculate the CE index (Figure 1c).[8] All of the data sets were reassessed two weeks later by a third examiner (J.K.), and the decisions were finalized for each specimen. In case of different findings, all of the examiners discussed their discordant measures and reached a consensus. Specimens with demarcated defects in the dentin

Table 1: *Visual Caries Diagnosis in Relation to Caries Depth[1]: Number of Surfaces Classified and Mean (SD) CE Index Values*

N (Surfaces) **Mean CE Index** (sd)/ Min-Max		**Visual discoloration**					
		None	**White**	**White-brown**	**Brown**	**Greyish**	**∑**
Visual severity	**Sound**	35 **0.6** (0.4)/ 0-1.1	-	-	-	-	35 **0.6** (0.4)/ 0-1.1
	First visible signs	-	29 **0.8** (0.3)/ 0-1.5	13 **1.2** (0.1)/ 1.0-1.4	8 **0.9** (0.3)/ 0.21.4	-	50 **0.9** (0.4)/ 0-1.5
	Established lesion	-	7 **1.1** (0.3)/ 0.4-1.4	54 **1.3** (0.2)/ 0.8-1.7	9 **1.1** (0.3)/ 0.5-1.5	1 **1.2** (-)/ 1.2-1.2	71 **1.3** (0.3)/ 0.4-1.7
	Microcavity	-	2 **1.4** (0.3)/ 1.2-1.6	20 **1.4** (0.2)/ 1.0-1.7	2 **1.6** (0.0)/ 1.6-1.7	1 **1.7** (-)/ 1.7-1.7	25 **1.4** (0.2)/ 1.0-1.7
	Dentin exposure	-	-	8 **1.4** (0.2)/ 1.1-1.7	1 **1.6** (-)/ 1.6-1.6	-	9 **1.5** (0.2)/ 1.1-1.7
	Large cavity	-	-	3 **1.6** (0.4)/ 1.2-1.9	3 **1.8** (0.1)/ 1.6-1.9	-	6 **1.7** (0.3)/ 1.2-1.9
∑		35 **0.6** (0.4)/ 0-1.1	38 **0.9** (0.4)/ 0-1.6	98 **1.3** (0.2)/ 0.8-1.9	23 **1.2** (0.4)/ 0.2-1.9	2 **1.4** (0.3)/ 1.2-1.7	196 **1.1** (0.4)/ 0-1.9

[1] Caries depth was quantified using microcomputed tomography images and the caries extension index.
[2] The bold/dashed line illustrates the cutoff threshold for caries detection. Based on mean CE index values >1.0, the cutoff threshold (bold line only) for detecting dentin caries lesions was determined.

beneath the enamel-dentin junction were excluded from this investigation.[6]

Statistical Analysis

The data were analyzed using Excel 2007 (Microsoft Corporation, Redmond, WA, USA) and SPSS 15.0 (SPSS Inc, Chicago, IL, USA) to cross-tabulate the findings and calculate the mean (mean), standard deviation (SD), and minimum (min) and maximum (max) values of the CE index for each diagnostic score. A CE index of 0 was associated with sound surfaces, and values between 0.01 and 1.0 corresponded with enamel caries lesions. Dentin caries lesions corresponded with a CE index value between 1.01 and 1.99.[9] Overall diagnostic performance was determined by calculating the sensitivity (SE), specificity (SP), positive predictive value, negative predictive value, and area under the receiver operating characteristic (ROC) curve (Az). An Az value near 1 indicated a high accuracy.[13] Performances of all diagnostic methods were evaluated separately. In addition, two combinations of both methods were tested. First, diagnostic performance was calculated for those teeth in which at least one of the methods had predicted dentin caries (visual or radiographic). Second, the performance was evaluated if both visual and radiographic methods diagnosed dentin caries simultaneously (visual and radiographic).

RESULTS

Table 1 summarizes the CE index based on the μCT data in relation to each UniViSS score. In general, established lesions and microcavities were linked to a dentin caries lesion. In cases of established lesions, a white-brown discoloration indicated deeper caries lesions (CE index = 1.3) compared with white or brown discolorations (CE index = 1.1). Microcavities reached nearly half of the dentin.

The CE index for the radiologic findings is reported in Table 2. Interestingly, 44.2% (53/120) of all radiographically diagnosed D0-2 lesions showed caries penetration into the dentin with μCT. However, the mean CE index of 1.2, which indicates a 20% extension into the dentin below the enamel-dentin junction, suggested minimal dentin involvement. All of the D3-4 lesions observed on radiography were found in the dentin and were correlated with a mean CE index of at least 1.4 according to μCT (40% dentin caries extension, Table 2).

The combined visual and radiographic diagnostic evaluation was also analyzed in relation to the caries extension (Table 3). All of the caries lesions associated with a D0-2 lesion on the dental radiographs

Table 2: *Radiographic Diagnosis for All Occlusal Surfaces in Relation Caries Depth Quantified Using Microcomputed Tomography (μCT) Images and the Caries Extension (CE) Index*

Digital Radiography	CE Index (μCT)[1]					Σ
	D0	D1	D2	D3	D4	
No dentin caries	10; **0.0** (0.0)/ 0.0-0.0	12; **0.3** (0.1)/ 0.2-0.5	45; **0.8** (0.1)/ 0.5-1.0	53; **1.2** (0.1)/ 1.0-1.4	-	120; **0.9** (0.4)/ 0-1.4
D3	1; **0.0** (0.0)/ 0.0-0.0	-	-	39; **1.4** (0.1)/ 1.1-1.5	21; **1.6** (0.1)/ 1.5-1.7	61; **1.4** (0.2)/ 0.0-1.7
D4	-	-	-	4; **1.4** (0.2)/ 1.2-1.3	11; **1.7** (0.1)/ 1.6-1.9	15; **1.6** (0.2)/ 1.2-1.9
Σ	11; **0.0** (0.0)/ 0.0-0.0	12; **0.3** (0.1)/ 0.2-0.5	45; **0.8** (0.1)/ 0.5-1.0	96; **1.2** (0.1)/ 1.0-1.5	32; **1.6** (0.1)/ 1.5-1.9	196; **1.1** (0.4)/ 0-1.9

[1] For each Marthaler category (D0–D4), values shown are number of classified surfaces, mean (SD) CE index value (boldfaced)/minimum-maximum.

showed minimal caries extension into the dentin and were associated with a maximum CE index of 1.2. Radiographically detectable D3 and D4 lesions were linked to a mean CE index of at least 1.4 and 1.6, respectively (Table 3).

The overall diagnostic performances of the visual, radiographic, and visual-radiographic techniques for (dentin) caries detection are reported in Table 4. The Az values under the ROC curves were found to be greater than 0.75, with the exception of the combined visual and radiographic approach, which had an Az value of 0.63. The overall specificity was near 1.0.

DISCUSSION

The main finding of our study was that the overall diagnostic performances for visual caries detection and diagnosis ranged in a good order of magnitude (Table 4). This finding is remarkable because most of the lesions were noncavitated caries lesions, which

Table 3: *Combined Visual and Radiographic Assessment for All Occlusal Surfaces in Relation to Caries Depth Quantified Using Microcomputed Tomography (μCT) Images and the Caries Extension (CE) Index*

Severity	Discoloration	Digital Radiography[1]			Σ
		No Dentin Caries	D3	D4	
Sound	None	34; **0.6** (0.4)/0.0-1.1	1; **0.0** (-)/0.0-0.0	-	35; **0.6** (0.4)/0.0-1.1
First visible signs	White	28; **0.8** (0.3)/0.0-1.2	1; **1.3** (-)/1.3-1.3	-	29; **0.8** (0.3)/ 0.0-1.5
	White-brown	8; **1.2** (0.1)/1.0-1.3	5; **1.3** (0.1)/1.2-1.4	-	13; **1.2** (0.1)/1.0-1.4
	Brown	8; **0.9** (0.3)/0.2-1.4	-	-	8; **0.9** (0.3)/0.2-1.4
Established lesion	White	4; **1.0** (0.4)/0.4-1.2	3; **1.4** (0.1)/1.3-1.4	-	7; **1.1** (0.3)/0.4-1.4
	White-brown	23; **1.1** (0.1)/0.8-1.3	28; **1.4** (0.1)/1.1-1.7	3; **1.6** (0.1)/1.5-1.7	54; **1.3** (0.2) /0.8-1.7
	Brown	7; **1.0** (0.3)/0.5-1.3	2; **1.4** (0.1)/1.4-1.5	-	9; **1.1** (0.3)/ 0.5-1.5
	Greyish	1; **1.2** (-)/1.2-1.2	-	-	1; **1.2** (-)/1.2-1.2
Microcavity	White	1; **1.2** (-)/1.2-1.2	1; **1.6** (-)/1.6-1.6	-	2; **1.4** (0.3)/1.2-1.6
	White-brown	5; **1.1** (0.2)/1.0-1.4	9; **1.5** (0.1)/1.3-1.7	6; **1.5** (0.2)/1.2-1.7	20; **1.4** (0.2)/1.0-1.7
	Brown	-	1; **1.6** (-)/1.6-1.6	1; **1.7** (-)/ 1.7-1.7	2; **1.6** (0.0)/1.6-1.7
	Greyish	-	1; **1.7** (-) /1.7-1.7	-	1; **1.7** (-)/1.7-1.7
Dentin exposure	White	-	-	-	-
	White-brown	1; **1.1** (-)/ 1.1-1.1	6; **1.4** (0.1)/1.3-1.7	1; **1.7** (-)/1.7-1.7	8; **1.4** (0.2)/1.1-1.7
	Brown	-	1; **1.6** (-)/1.6-1.6	-	1; **1.6** (-)/1.6-1.6
	Greyish	-	-	-	-
Large cavity	White	-	-	-	-
	White-brown	-	2; **1.5** (0.3)/1.2-1.7	1; **1.9** (-)/1.9-1.9	3; **1.6** (0.4)/1.2-1.9
	Brown	-	-	3; **1.7** (0.1)/1.6-1.9	3; **1.7** (0.1)/1.6-1.9
Σ		120; **0.9** (0.4)/0.0-1.4	61;**1.4** (0.2)/0.0-1.7	15; **1.6** (0.2)/1.2-1.9	196; **1.1** (0.4)/0.0-1.9

[1] For each group classified according to UniViSS and Marthaler, values shown are number of classified surfaces, mean (SD) CE index values (boldfaced)/minimum-maximum.

Table 4: *Both Investigated Visual-Radiographic Approaches (Visual or Radiographic; Visual and Radiographic) Resulted in Different Findings*

	SE	SP	NPV	PPV	Az Value
Caries detection level (D0 versus D1-4)					
Visual (UniViSS)	0.86	0.91	0.29	0.99	0.82
Digital radiographic Visual or radiographic Visual and radiographic	*Impossible to calculate because of the limited ability to detect enamel caries lesion on dental radiographs*				
Dentin caries detection level (D0-2 versus D3-4)					
Visual (UniViSS)	0.87	1.00	0.28	1.00	0.89
Digital radiographic	0.59	0.99	0.56	0.99	0.79
Visual or radiographic[1]	0.84	0.85	0.74	0.92	0.85
Visual and radiographic[2]	0.27	1.00	0.42	1.00	0.63

Abbreviations: SE, sensitivity; SP, specificity; NPV, negative predictive value; PPV, positive predictive value; Az value, area under the receiver operating characteristic curve; UniViSS, Universal Visual Scoring System.
[1] A true positive test result was assumed if at least one of the test methods indicated a dentin caries lesion and the microcomputed tomography revealed a caries extension index value >1.00.
[2] A true positive test result was assumed if both of the test methods indicated a dentin caries lesion and the microcomputed tomography revealed a caries extension index value >1.00.

are occasionally difficult to classify correctly. Established caries lesions and lesions that were more severe were always associated with dentin involvement. Lesions that had been diagnosed visually as established were found mostly in the outer third of the dentin according to μCT (mean CE index between 1.1 and 1.3; Table 1). More severe lesions were always connected with caries progression into the middle of the dentin (CE index >1.4; Table 1).

Another interesting finding involved the visually detectable discoloration of the caries lesion. Surfaces with white discolorations showed less caries extension compared to surfaces with brown discolorations. In addition, lesions with white-brown discolorations had progressed farther than other lesions (Table 1). Therefore, it can be argued that discoloration might be used as a clinical predictor of caries activity and should be included generally into visual assessments.

For digital radiography, a high sensitivity (0.99) and reduced specificity (0.59) were recorded. These values were in line with previously published studies and illustrated the high ability of these techniques to correctly classify sound occlusal surfaces as healthy (true negatives).[14-16] In contrast, identification of dentin caries lesions (true positives) is limited when using low-dose digital radiography. In 53 teeth evaluated as D0-2 lesions on digital radiographs, the real caries extension had progressed into the dentin and therefore farther than predicted (Table 2). However, when taking into account the CE index for these lesions, most of the lesions were located near the enamel-dentin junction (mean CE index 1.2; Table 2). Overall, digital radiography underestimated the real dentin caries extension.

A unique feature of our study was the analysis of the diagnostic outcome of the combined visual-radiographic diagnostics in relation to the quantitative caries extension determined according to μCT (Tables 3 and 4). Both investigated visual-radiographic approaches (visual or radiographic; visual and radiographic) resulted in different findings (Table 4). The best diagnostic performance was found when pit and fissure caries were diagnosed either visually or radiographically (SE=84%; SP=85%; Az=0.85). The second approach, which involved accepting dentin caries only when visual investigation and digital radiography predicted dentin involvement simultaneously, had a lower SE (27%) and Az value (0.63) but classified all sound teeth correctly (SP=100%; positive predictive value = 100%) (Table 4). This diagnostic approach would avoid overtreatment best because these false-negatives that were verified by μCT did not need operative care as they showed either enamel caries or only small dentin involvement of only 20% (mean CE index 1.2; Tables 2 and 3). Hence, nonoperative preventive dental care, including options such as pit and fissure sealing and/or regular fluoride applications, would be proposed as the treatment option of choice to reduce caries progression effectively.[17-19] However, other reports have recommended early operative intervention strategies for these lesions.[20] Therefore, studies should be initiated to investigate this ongoing discussion and dilemma.

The strength of this validation study lies in the large number of samples: 196 molars. To our knowledge, this number has been exceeded by only one previously published *in vitro* study.[21] Another unique feature was the use of μCT technology, with ~400 separate scans for each surface. This enabled a quantitative measurement of caries extension for each diagnostic score, which added valuable new data (Tables 1 through 3) to the conventional analysis of the diagnostic performance (Table 4). A possible limitation of the present study was that all of the teeth were third molars, which are generally characterized by a much more irregular fissure pattern than first or second permanent molars and premolars. Sample groups with different compositions should be taken into consideration when comparing our results with others and translating the documented experiences into clinical practice.

CONCLUSION

Simultaneous visual and radiographic prediction of dentin caries seems to result in a more conservative approach in comparison to visual or radiographic diagnostic only. Nevertheless, it has to be accepted that small dentin caries lesion will not be detected.

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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.

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