ORIGINAL ARTICLE

Influence of examiner's clinical experience on the reproducibility and accuracy of radiographic examination in detecting occlusal caries

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Abstract The aim of this in vitro study was to assess the influence of varying examiner's clinical experience on the reproducibility and accuracy of radiographic examination for occlusal caries detection. Standardized bitewing radiographs were obtained from 166 permanent molars. Radiographic examination was performed by final-year dental students from two universities (A, $n=5$; B, $n=5$) and by dentists with 5 to 7 years of experience who work in two different countries (C, $n=5$; D, $n=5$). All examinations were repeated after 1-week interval. The teeth were histologically prepared and assessed for caries extension. For intraexaminer reproducibility, the unweighted kappa values were: A (0.11–0.40), B (0.12–0.33), C (0.47–0.58), and D (0.42–0.71). Interexaminer reproducibility statistics were computed based on means±SD of unweighted kappa values: A (0.07±0.05), B (0.12±0.09), C (0.24±0.08), and D (0.33±0.10). Sensitivity, specificity, and accuracy were calculated at D_1 and D_3 thresholds and compared by performing McNemar test ($p=0.05$). D_1 sensitivity ranged between 0.29 and 0.75 and specificity between 0.24 and 0.85. D_3 specificity was moderate to high (between 0.62 and 0.95) for all groups, with statistically significant difference between the dentists groups (C and D). Sensitivity was low to moderate (between 0.21 and 0.57) with statistically significant difference for groups B and D. Accuracy was similar for all groups (0.55). Spearman's correlations were: A (0.12), B (0.24), C (0.30), and D (0.38). In conclusion, the reproducibility of radiographic examination was influenced by the examiner's clinical experience, training, and dental education as well as the accuracy in detecting occlusal caries.

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Introduction

Caries diagnosis is an important aspect in the prevention and treatment of lesions and a difficult mission in dentistry [1]. Radiographic examination has been widely used in dental practice as a supplement to the visual inspection for caries detection [2, 3]. However, it has been shown that radiographs present good performance only to detect dentine lesions [4–6]. The consciousness and the experience of "hidden caries," which is a caries lesion seen in

dentine by radiographic examination and clinically presents as sound or demineralized occlusal enamel, have promoted the clinician's attention to the value of radiographic examination for occlusal surfaces [7].

Nevertheless, occlusal surface radiographs represent a two-dimensional image of a three-dimensional tooth, making the detection of mineral loss in the enamel difficult, especially when it is hidden by sound tooth tissue or the caries lesion is superimposed onto the dentine due to the complex anatomy of the occlusal area [2, 8]. In addition, a failure of the radiographic examination is the false-negative and false-positive errors, which could make it difficult to decide on patient management and treatment [2, 3]. The examiner's experience or inexperience in detecting occlusal caries by bitewing radiographs is also a factor [9]. Some studies have shown that experience regarding radiographic analysis differs among clinicians to detect approximal or occlusal caries [2, 10]. There are some reports in the literature referring to student skills in detecting caries from bitewing radiographs and comparing it to faculty dentists or practitioners [11–13].

Since invasive treatment is usually required when a caries lesion extends into dentine, it is essential to analyze the performance of radiographic examination for occlusal caries detection. The great variation existing between examiners, mainly at radiographic detection of occlusal caries, brings up the interest to research the performance between different groups of examiners of higher and lower level of experience. Consequently, the purpose of this in vitro study was to assess the influence of examiner's clinical experience (dental students versus experienced dentists) from two different countries on the reproducibility and accuracy of radiographic examination in detecting occlusal caries lesions.

Material and methods

Sample preparation

One hundred and sixty-six human third permanent molars were selected from a pool of extracted teeth with varying condition from sound to carious on occlusal surfaces. They were stored frozen at −20°C until use and during the experiments. Teeth with caries and noncaries defects on buccal, lingual, and proximal surfaces were not selected. All teeth were extracted by dental practitioners in Switzerland (no water fluoridation, 250 ppm F⁻ in table salt). Prior to extraction (which was scheduled for reasons other than the study), the patients were informed about the use of their teeth for research purposes, and their consent was obtained.

The teeth were defrosted for 3 h, and the calculus and debris were removed using a scaler (Cavitron). They were cleaned for 15 s with water and toothbrush (Trisa ultra-supersensitive, Triengen, Switzerland) and for 10 s with a water powder jet cleaner (PROPHYflex II, KaVo, Biberach, Germany) with sodium hydrogen carbonate powder. In order not to have powder remnants in the fissure, the teeth were then rinsed off with a three-in-one syringe for 10 s [14].

Photographs of the occlusal surfaces were taken at a ×6.25 magnification using a light microscope (Leica DC300, Leica, Heerbrugg, Switzerland) equipped with a video camera linked to a computer (Leica M420, Leica, Heerbrugg, Switzerland) to select one specific area (sound or carious) from each tooth in the fissure surface as the test site. This is an important step to permit proper assessments of the same area by different examiners.

Bitewing radiographs

The teeth were then embedded in wax blocks, and standardized bitewing radiographs were taken using a fixed apparatus with a film holder, an X-ray machine (HDX Dental EZ, USA), and double Kodak Insight films (22×35 mm, Kodak, Rochester, MN, USA) at 65 kV, 7 mA, and exposure time of 0.09 s. The source-to-film distance was 22 cm. Close to the object on the focus side, a 0.5-cm-wide plastic mold was placed to simulate soft tissues. All radiographs were processed by an automatic X-ray film developer XR 24 Pro (Dürr Dental, Bietigheim-Bissingen, Germany), placed in transparent cards, and identified.

Examiners

Four different groups of examiners assessed the bitewing radiographs twice, observing a 1-week interval between the analyses. The groups were arranged as follows:

Group A. Brazilian final-year dental students (*n*=5)
Group B. Swiss final-year dental students (*n*=5)
Group C. Brazilian dentists with 5 to 7 years of experience (*n*=5)
Group D. Swiss dentists with 5 to 7 years of experience (*n*=5)

The examiners did not receive an additional training or calibration in interpretation of bitewing radiographs. In fact, each group of examiners was equally instructed through oral orientation about the scores and interpretation for caries detection on radiographs before the examinations [15]. Each examiner performed the radiographic examination guided by black and white photographs printed in draft quality paper. Each photograph of the occlusal surface had a dot on the test site to allow the examiners to localize precisely the test site during the following analysis. This precaution was taken to avoid examiner bias toward the photographs. All the

examiners independently analyzed the films using an X-ray viewer (Imatec Röntgentechnik, Switzerland) and an X-ray film magnifier (magnification ×2; Svenska Dental Instrument, Sweden), in a dark room, to determine whether the occlusal surfaces under study showed: no radiolucency (0), radiolucency in enamel (1), radiolucency in the outer half of dentine (2), and radiolucency in the inner half of dentine (3).

Validation (gold standard)

The teeth were ground longitudinally on a Knuth-Rotor polishing machine (Struers, Denmark) with silicone carbide paper of grain size 60 μm, cooled under tap water. To confirm the grinding process, teeth were analyzed under the microscope at a magnification of ×3.2. When the test site was reached, papers of grain size 30, 18, and 10 μm were used. The occlusal cut surfaces were photographed, and it was ensured that the caries lesion was not ground away. The tooth surfaces were then colored with saturated rhodamine B (Fluka, Buchs, Switzerland) dissolved in water. Sites were histologically assessed for caries extension according to the rhodamine B penetration (magnification ×10) either into the enamel or both the enamel and the dentine tissues, according to Lussi et al. [16] in a five-point scale:

D_0 no caries
D_1 caries extending up to halfway through the enamel
D_2 caries in the inner half of enamel
D_3 caries limited to the outer half of dentine
D_4 caries extending into the inner half of dentine

Statistical analysis

Accuracy was calculated by means of sensitivity and specificity at D_1 and D_3 thresholds (MedCalc for Windows, version 9.3.0.0, Mariakerke, Belgium). D_1 threshold considers enamel and dentine caries lesions as decayed, and D_3 threshold considers only dentine caries lesions as decayed. McNemar test was applied to compare the performance of

the different groups of examiners. The receiver operating characteristic (ROC) curve was also evaluated, in which the area beneath the ROC curve (A_z) indicated the quality of the observer performance. The closer to the upper left corner the curve is located, the better is the observer's performance. Diagnosis by chance will give an area of 0.5, whereas perfect performance gives 1. In general, values will be between these outer limits [8]. Pairwise comparison of ROC curves was performed at D_1 and D_3 thresholds.

Additionally, Spearman's correlation coefficient between the radiographic examination and the histological analysis was performed for the four groups of examiners.

Reproducibility was evaluated by means of interexaminer and intraexaminer agreement, and Cohen's unweighted kappa values were used [17]. Reproducibility indicates the closeness of the agreement between the results of measurements carried out under changed conditions of measurement [18]. Kappa values above 0.75 denoted excellent agreement, while values between 0.40 and 0.75 indicated good agreement, and less than 0.40 denote marginal agreement [19]. The means of kappa values of different groups of examiners were compared using the t test. The level of significance was taken as $p < 0.05$.

Results

In this study, from the 166 occlusal sites analyzed (one test site per tooth), the histological examination revealed that eight (4.8%) were caries free (D_0); 12 (7.2%) had caries extending up to halfway through the enamel (D_1); 69 (41.6%) had caries extending in the inner half of enamel (D_2); 47 (28.3%) had caries in the outer half of the dentine (D_3), and 30 (18.1%) had deep dentinal caries (D_4).

The mean sensitivity, specificity, and accuracy are reported in Table 1. At D_1 threshold, dentists from group D presented a significant lower sensitivity (0.29) and higher specificity (0.85) than the three other groups. Dental students from group B achieved higher sensitivity

Table 1 Sensitivity, specificity, and accuracy of radiographic examination for caries detection of the different examiner groups

Examiners groups	Sensitivity		Specificity		Accuracy	
	D_1	D_3	D_1	D_3	D_1	D_3
A	0.54a	0.21a	0.43a	0.88a	0.53a	0.57a
B	0.75b	0.57b	0.24b	0.62b	0.73b	0.60a,b
C	0.37c	0.22a	0.54a	0.95c	0.38c	0.61b
D	0.29d	0.29c	0.85c	0.91a	0.32d	0.62b

D_1:D_0=sound; D_1–D_4=decayed; D_3: D_0–D_2=sound; D_3–D_4=decayed; Within columns, significant differences are represented by different letters (McNemar test, p=0.05)

(0.75) and lower specificity (0.24). However, the best value of accuracy (0.73) was presented by the group of students B. At D_3 threshold, groups A, C, and D presented lowest values of sensitivity (from 0.21 to 0.29) and group C the highest value of specificity (0.95), with statistically significant difference when compared to the other groups. For accuracy, there was statistically significant difference only among groups A, C, and D.

The ROC curve (Figs. 1 and 2) gives a graphic representation of the true-positive fraction (sensitivity) and the false-positive fraction. At D_1 threshold, group D presented higher area under the ROC curve when compared to group C. At D_3 threshold, groups B, C, and D presented the highest areas under the ROC curve, with no statistically significant difference among them.

Spearman's correlation coefficient is presented in Table 2. Group D presented the highest correlation (0.38) when compared to the others, and group A presented the lowest correlation (0.12).

Reproducibilities are represented in Tables 3 and 4. Regarding interexaminer reproducibility (Table 3), statistics were computed based on means±SD of unweighted

Cohen's kappa values. Dentists from group D presented the highest kappa value (0.33±0.10) comparing the groups. Overall, for the other three groups, the interexaminer agreement was considerably lower (varying from 0.07± 0.05 to 0.24±0.08). For intraexaminer reproducibility (Table 4), the unweighted Cohen's kappa values varied from 0.11 to 0.40 for group A, 0.12 to 0.33 for group B, 0.47 to 0.58 for group C, and 0.42 to 0.71 for group D.

Discussion

Few studies have evaluated the effect of the examiner's clinical experience on the performance of radiographic examination to detect occlusal caries lesion [2, 8, 11, 12, 20, 21]. In this study, we aimed to evaluate the differences presented by dental students and general dental practitioners of two countries on occlusal caries detection using the same series of quality-controlled duplicated bitewing radiographs.

It is important to stress that occlusal surface radiographs represent a two-dimensional image of a three-dimensional

Fig. 1 ROC curves for the four groups at D_3 threshold. The areas under ROC curve (A_z) are also shown. Different *superscript letters* mean statistically significance difference ($p<0.05$)
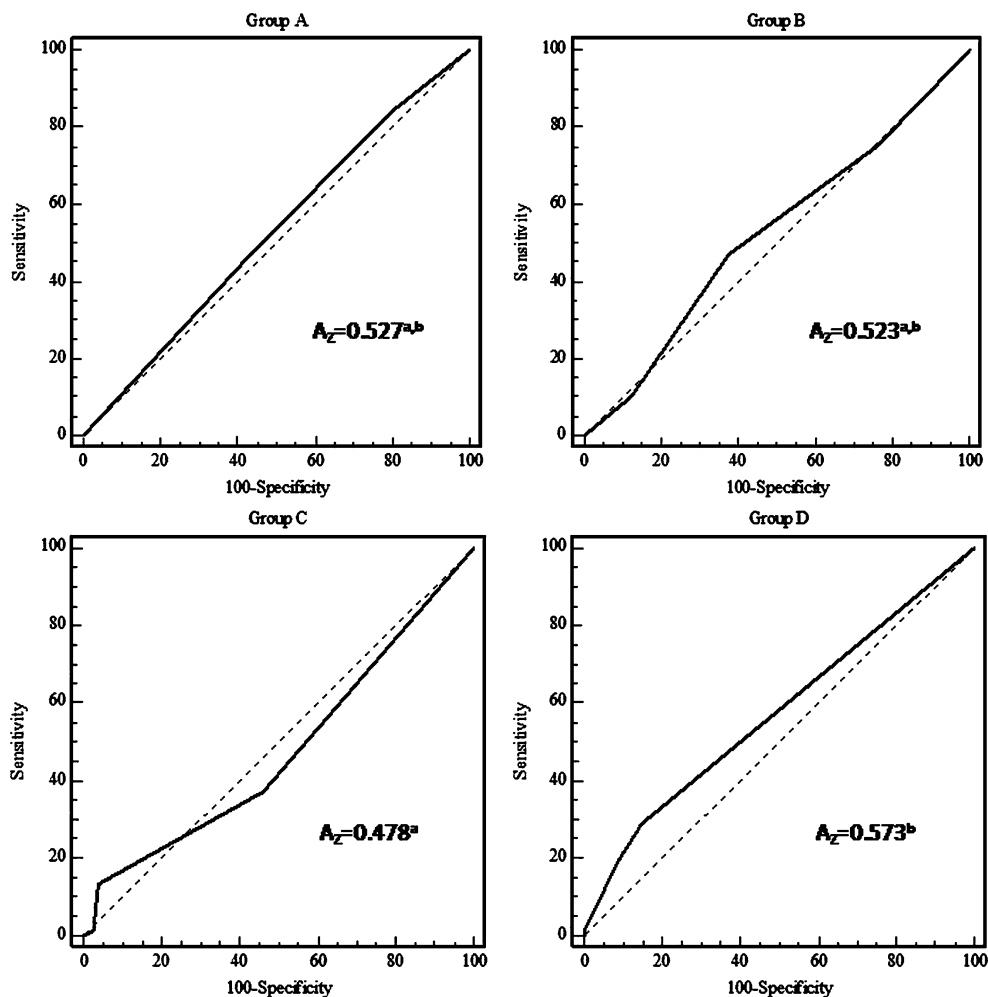
Fig. 2 ROC curves for the four groups at D_3 threshold. The areas under ROC curve (A_z) are also shown. Different *superscript letters* mean statistically significance difference ($p<0.05$)
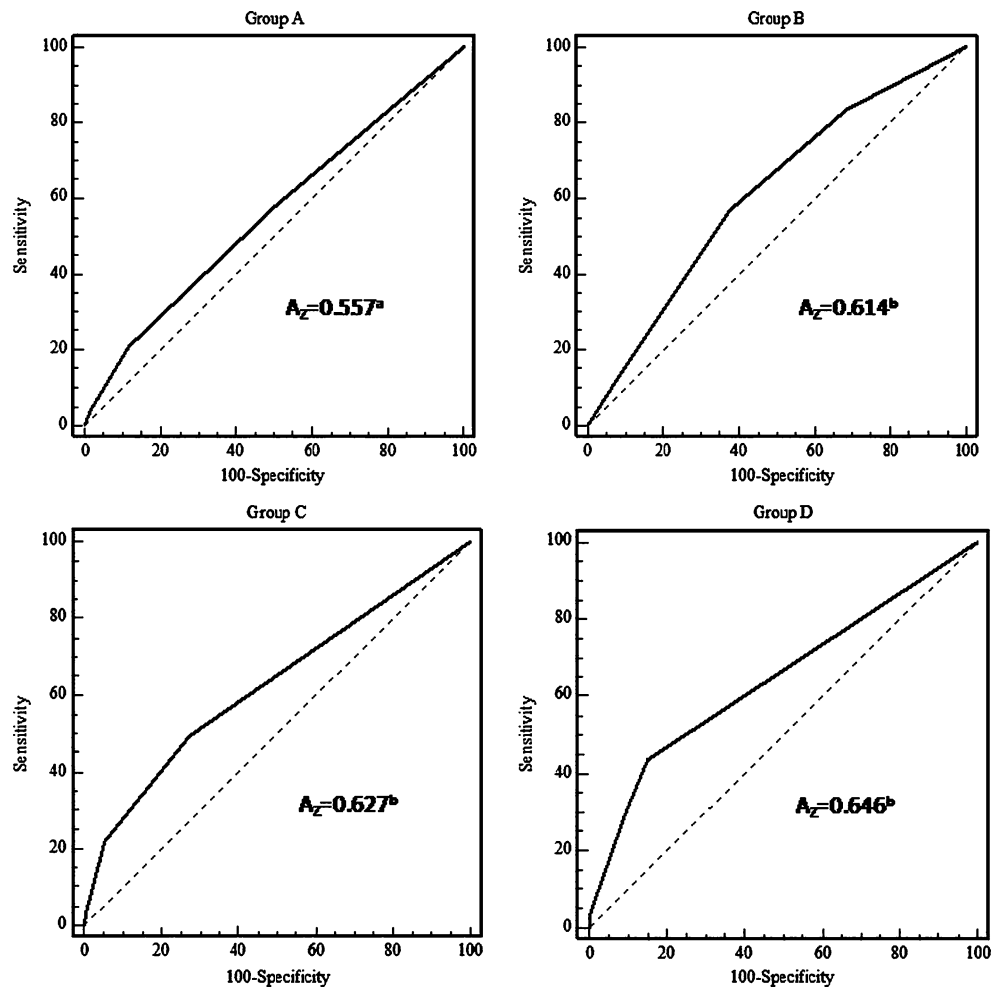
tooth, making the detection of mineral loss in the outer part of the enamel that is hidden by sound tooth structure difficult [8] or even the borderline between enamel and dentine [2]. A tendency to make false-positive scores is common, and this could be due to the Mach-band effect, which is an inclination to see a radiolucency in the dentine–enamel junction where no dentine lesion is actually present [2]. This effect is a perceptual phenomenon, an enhancement of the contrast between a dark and a relatively lighter area which are sharply demarcated [22]. Besides, another

Table 2 Mean±SD of unweighted kappa values obtained for interexaminer reproducibility for the four groups

Examiner groups	Mean±SD of kappa values
A	0.07±0.05a
B	0.12±0.09a
C	0.24±0.08b
D	0.33±0.10c

Statistics were computed based on ten pairwise Cohen's kappa coefficient. Different letters mean statistically significant difference among values within the same column (*t* test; $p<0.05$)

complicating factor could be explained by the fact that caries lesions located in pit and fissures might be super-imposed onto the dentine radiographically due to the complex anatomy of the occlusal area [2].

For D_1 threshold, the prevalence of caries was 95.2%. In the present study, students of group B exhibited the highest value of sensitivity (0.75) and the lowest value of specificity (0.24). Students of group A presented better specificity (0.43) when compared to the students of group B. The different results presented here could be explained by the differences related to the student's dental education. Brazilian dental education generally consists of 5 to 5 years of instruction, while Swiss dental education consists of 5 years of instruction, with 2 years of medicine studies and 3 years of dentistry studies. Although students from group B had different dental education when compared to the students from group A, they presented the ability to detect decayed occlusal surfaces on bitewing radiographs. However, they had the ability to detect sound surfaces as caries (false positive). On the other hand, dentists of groups C and D presented the highest values of specificity (0.54 and 0.85, respectively) and lowest values of sensitivity (0.37 and 0.29, respectively). These results might indicate that

Table 3 Unweighted kappa values for intraexaminer reproducibility of the different examiners

Group A		Group B		Group C		Group D	
Exam.	Kappa	Exam.	Kappa	Exam.	Kappa	Exam.	Kappa
1	0.21	1	0.25	1	0.50	1	0.49
2	0.11	2	0.16	2	0.47	2	0.54
3	0.23	3	0.33	3	0.54	3	0.47
4	0.31	4	0.12	4	0.58	4	0.71
5	0.40	5	0.31	5	0.50	5	0.42

dentists are more willing to accept a lower level of sensitivity in exchange for a higher level of specific caries [12, 20]. In other words, they are willing to not detect some caries lesions in order not to overtreat the disease since they have seen the long-term results of restoration placement. Quite the opposite, dental students have not had the experience of observing teeth over long periods of time and, consequently, they have not seen the long-term consequences of a restorative treatment [23, 24]. In contrast, dental students are more susceptible to classify any alteration on enamel as caries [12, 20]. Besides, they had learned that all disease in oral cavity must be detected and treated, and, for them, missing a caries lesion is a huge error. Rocha et al. [25] in an in vitro study evaluating conventional bitewing radiographs for diagnosis of occlusal caries by a group of 13 dental students and a radiologist with more than 10 years of experience showed that students presented a low sensitivity (0.21) and high specificity (1.00) and the radiologist presented moderate sensitivity (0.57) and high specificity (1.00). However, it should be highlighted that in the referred work the examiners were considered inexperienced students, and the professional had a renowned experience in radiology. Also, they received a special training before the examinations, different from the students and the professionals evaluated in our study. The results presented for D_1 threshold confirm that radiographic examination does not allow an early assessment of superficial lesions and also the inability of radiographs to detect lesions restricted to enamel [26].

For D_3 threshold, the prevalence of caries was 46.4%. The sensitivity was very low for groups A, C, and D (ranging from 0.21 to 0.29), with a statistically significant difference for group D. For group B, the sensitivity was

Table 4 Spearman's correlation coefficient for the different groups

Examiner groups	Spearman's correlation
A	0.12
B	0.24
C	0.30
D	0.38

significantly moderate (0.57). However, the specificity values were high for groups A, C, and D (ranging from 0.88 to 0.95) and moderate for group B (0.62). Others studies had described low results for sensitivity concerning radiolucency into dentin [27–30]. These authors had observed sensitivity values ranging from 0.14 to 0.34 and specificity values ranging from 0.89 to 1.00, with a prevalence of dentine caries ranging from 28% to 46%. Ekstrand et al. [31], Rodrigues et al. [27], and Ashley et al. [30] had shown a specificity value of 1.00, 0.97, and 0.89, respectively, when radiographic examination was performed to detect radiolucency to middle third of dentine of occlusal surfaces. Nevertheless, radiographs performed badly when compared with the results from previous studies. The poor performance of radiographs in this study may have been due to the very early nature of the lesions. In this study, only 18% of teeth with dentinal lesions had caries extending deeper than half of the depth of the dentine, while, in the studies of Lussi et al. [32] and Ricketts et al. [33], 36% to 67% of teeth with dentinal caries had deep lesions, and the sensitivity was recorded as a value around 0.62. We can presume that, if the images had been electronically enhanced, it would be possible to increase the validity of the radiographic examination in this study. This was also suggested by Ashley et al. [30]. It could also be observed that the dental practitioners and students had, as a group, a similar diagnostic accuracy (ranging from 0.57 to 0.62) for observing and recognizing dentine caries from bitewing radiographs. This is in agreement with Mileman and van den Hout [20].

Occlusal deep dentinal caries lesions should be correctly detected in need of operative treatment; this way, a high sensitivity is preferred [34]. However, the present results in this study showed extremely lower sensitivity values, especially for the professional groups. Based on that, we could observe that dentists were not able to detect dentine caries in the occlusal surfaces from bitewing radiographs. Another study had shown that dentists expressed doubts about the value of the radiograph in occlusal caries detection [8, 35]. Caution must be taken when decisions to restore are based on bitewing radiographs. The disease prevalence in our sample was high (95.2% caries with 46.4% dentine caries). According to Downer [36], a

positive correlation between the disease prevalence and the sensitivity of a diagnostic method has been demonstrated. In this study, we observed a negative correlation since a low sensitivity for dentine caries was observed for all groups.

Although the bitewing radiograph is indicated for approximal caries detection, in our study, Spearman's correlation coefficients were lower for all the groups, demonstrating that the bitewing radiographic examination was not a good method to detect occlusal caries lesions. Rodrigues et al. [27] found a Spearman correlation coefficient of 0.57 using experienced dentist for occlusal caries assessments. They have suggested that bitewing radiographs should be combined to visual examination for occlusal caries detection. However, Ekstrand et al. [31] and Ricketts et al. [37] had shown moderate values for Spearman's correlation coefficient, ranging between 0.76 and 0.78, for the bitewing radiographic examination.

Concerning ROC analysis, at D_1 threshold, group D presented the highest area under the ROC curve when compared to the others. At D_3 threshold, groups B, C, and D presented higher area under the ROC curve, with no statistically significant difference. This result shows that the examiner's experience has influenced the accuracy of the radiographic examination. The area under the ROC curve represents the probability that a random pair of normal and carious surfaces will be correctly ranked as to their disease state [38]. The larger is area under the ROC curve, the more accurate is the diagnostic process achieved by that group [11]. According to Nytun et al. [39], ROC method revealed a statistically significant difference between combined visual–radiographic examination and the two other but not between the isolated visual or radiographic examination. In this study, the area under the ROC curve was low to moderate for all the four groups for D_1 (ranging from 0.478 to 0.573) and D3 (ranging from 0.557 to 0.646) thresholds. The wide range of areas under the ROC curves indicates that radiographic examination for occlusal caries detection can be very worrying, even when practiced by experienced professionals. The results of ROC analysis on the data from radiographic examination concerning occlusal caries detection have previously been reported a moderate area under the ROC curve (ranging from 0.51 to 0.61) by Verdonschot et al. [40] and Angnes et al. [41]. However, previous laboratory studies have shown good values (from 0.71 to 0.72) [27, 34, 42]. This difference could be explained by the comparatively high prevalence of large dentinal lesions in their sample and also by the different techniques regarding standardization recording and X-ray development.

In the present study, radiographic examination yielded lower interexaminer reproducibility, mainly among the dental students and the dental practitioners. However, dentists from group D presented the highest interexaminer agreement. This lower reproducibility is consistent with previous studies [11, 12]. It has been shown that education and clinical experience increase interexaminer reproducibility in radiographic detection of occlusal caries [12]. In our study, both Brazilian and Swiss dentists were general dental practitioners with 5 to 7 years of experience, and they had the same education as described earlier. This also could be seen concerning the intraexaminer reproducibility, in which dental practitioners presented highest agreement when compared to the dental students for both countries. According to Bader and Shugars [43], the low agreement level might be a reflection of the multitude of factors involved in caries detection and treatment decision. In our study, five factors could be related: age, training, skills, preferences, and experiences, as also described by Lazarchik et al. [12].

Some researchers have been studying the effect of extra training to perform radiographic examination. Gröndahl [44] reported that Swedish dental students in the last year of the dental school performed diagnosis of approximal caries from bitewing radiographs as well as dental radiologists after the students had received additional training. According to Firestone et al. [11], a didactic instruction associated with clinical experience provides students with skills in the detection of approximal caries from bitewing radiographs similar to that of faculty dentists. In our study, no training was given to the dental students before the radiographic examination. We just tested their skills acquired during their dental education to detect occlusal caries from bitewing radiographs.

In conclusion, based on the methodology employed in this work and on the results evaluated and discussed, the reproducibility and the validity of radiographic examination were influenced by the dental education, training, and clinical experience of the examiners in detecting occlusal caries. The great disparity among the groups in the present study indicates that caution must be taken when decisions are made regarding restoration when based only on bitewing radiographs, especially regarding dentine caries lesions. This study reinforces the necessity of improvement of the detection methods that could lead to coherent decisions of treatment with minimum intervention. Caries detection is controversial among students and professionals and requires constant retraining, updating, and information due to the caries pattern and behaviors changes.

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Conflict of interest The authors declare that they have no conflict of interest.

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