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ORIGINAL ARTICLE

Detection of artificial demineralization bordering different types of laminate veneers using visual inspection and storage phosphor radiography

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Abstract
Objective The objective of this study is to compare the diagnostic accuracy of visual inspection (VI) and storage phosphor plate (SPP) radiography for the detection of artificial demineralization bordering different laminate veneers.
Materials and methods Twenty human maxillary canine teeth were prepared. All-ceramic (A) and hybrid ceramic (H) laminate veneers were fabricated and luted. Veneered teeth were covered except for a circular window on the proximal surface bordering restorations. Teeth were kept in acetic acid buffer to create demineralization and imaged with a SPP system. Ten observers evaluated all teeth first visually then with SPP images for the presence/absence of demineralization. Teeth were examined using scanning electron microscopy (SEM) as well. The accuracy was expressed as the area under the ROC curves (A_z). Pair-wise comparisons were performed using two-way ANOVA and post hoc *t* test (p=0.05). Fleiss kappa (κ) was used for agreement.
Results SPP radiography was better than the VI for both veneers (p=0.004). The A_zs of two veneers were different for both VI (p<0.005) and SPP (p<0.005). SEM evaluation revealed lesions confined to enamel. κ was fair for H, and fair to moderate for A. Agreement was higher for the radiographic evaluation for both veneers.
Conclusion Enamel demineralizations bordering hybrid and ceramic laminate veneers can be detected better with SPP radiography than VI and detectability was better for all-ceramic veneers than the hybrid ceramic ones.
Clinical relevance Early detection of enamel demineralizations bordering laminate veneers would result in time-saving and less-invasive treatment methods; therefore, SPP radiography may be recommended in clinically suspicious cases since it provides better diagnostic accuracy.

Keywords Caries · Adhesive luting · Laminate veneers · Digital radiography

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Introduction

All-ceramic veneer restorations are preferred in clinical dental practice mainly because of their superior aesthetics, inertness, and biocompatibility when compared to their metal–ceramic counterparts [1, 2]. Hybrid ceramic materials newly developed for indirect resin composite applications present the advantages of both ceramic materials and resin composites, such as improved wear resistance, physical properties and color stability [3]. These metal-free veneer restorations are generally luted with adhesive luting cements in order to overcome their inherent brittleness. However, adhesively luted all-ceramic veneer restorations cannot be removed without any damage in need of interventions such as treatment of secondary caries.

Secondary caries is defined as the lesion at the margin of an existing restoration [4]. One of the most frequent reasons for failure in ceramic restorations has been reported to be secondary caries. It was reported that most secondary caries lesions were located in proximal cervical locations, many diagnosed as surface lesions [5, 6]. It was well established that if an incipient caries, as detected by the radiograph, is not beyond the dentino-enamel junction, it can be arrested or reversed by remineralization [7, 8]. Therefore, early detection of enamel demineralization mimicking incipient secondary caries bordering adhesively luted all-ceramic veneer restorations is extremely important in order to decrease the time and cost of treatment[8].

The diagnosis of enamel demineralization mimicking secondary caries is problematic in teeth restored with laminate veneers. Since laminate veneers bond perfectly to tooth structure, diagnosis of non-cavitated demineralizations (carious lesions) is further challenging because clinical detection and/or progression of secondary caries might be easily overlooked [4]. Diagnosis of caries has been primarily a visual process, based principally on clinical inspection. Tactile information obtained through use of the dental explorer or “probe” has also been used in the diagnostic process. However, when visual and tactile cues are not enough, intra-oral radiography is the method of first choice for detection of caries/secondary caries. The performance of different intra-oral radiographic methods for the early detection of caries has been tested in numerous research [9, 10]. In addition to the radiographic methods, detection capacity of some novel diagnostic techniques such as fiber optic transillumination and quantitative light or laser-induced fluorescence has been investigated as well [11]. Yet, most of these studies were done to evaluate the detection of natural or artificial caries or secondary caries either under aesthetic restorations or different types of crowns. However, no study can be found evaluating the detection of artificial or natural enamel demineralization mimicking secondary caries under laminate veneer restorations.

Therefore, the aim of this in vitro study was to compare the diagnostic accuracy of visual inspection and storage phosphor plate radiography for the detection of artificial demineralization mimicking secondary caries created at the border of adhesively luted all-ceramic and hybrid ceramic laminate veneer restorations. The null hypothesis of this study was that detection of enamel demineralization under hybrid ceramic laminate veneers was easier than all-ceramic laminate veneers and diagnostic accuracy is better with visual inspection.

Materials and methods

Tooth collection

Twenty intact and non-carious human maxillary canines, that were relatively comparable in size, were used in the study. All tooth extractions were performed at the Oral Surgery Department, having patients sign the appropriate informed consent form approved by the institutional review board of the university. The extraction of canine teeth was due to periodontal disease. The teeth were cleaned of any residual tissue tags, pumiced, washed under running tap water and stored in distilled water not more than 1 month. After all test teeth were visually inspected to exclude any white or brown spot lesions, they were radiographed to confirm that no radiolucency could be seen on the images in order to prevent any diagnostic errors.

Preparation of the laminate veneer restorations

The roots of the teeth were mounted in a plastic holder filled with auto polymerizing acrylic resin (Palapress, Heraeus Kulzer, Wehrheim, Germany). Laminate veneer preparations were made using Modular Veneer Preparation Set (Intensiv SA, Lugano, Switzerland) using an air turbine followed by a red handpiece. Cervical marking was performed with the bur no: 200S (Intensiv SA). A 0.3-mm limited depth cutting was made with the bur no: S4 (Intensiv SA). Labial and incisal reductions were made with the bur no: 101 (Intensiv SA) and all of the chamfers were finished with the bur no: 4310S (Intensiv SA) (Fig. 1a). Impressions were made with a polyvinyl siloxane elastomeric material (Pentasoft Duo-Mix, 3M ESPE, Germany). Laminate veneers were fabricated from a lithium disilicate all-ceramic (A) (IPS E.Max, IvoclarVivadent, Schaan, Liechtenstein) (n=10) and hybrid ceramic (H) (Estenia, Kuraray, Osaka, Japan) (n=10) materials (Fig. 1b).

The lithium disilicate ceramic specimens were etched with 4.9 % hydrofluoric acid (IPS ceramic etching gel, IvoclarVivadent), while hybrid ceramic material was sandblasted with 50 μm aluminum oxide particles. Then, all specimens were silanated (Monobond-S, IvoclarVivadent) for 60 s and dried gently and the bonding agent (Heliobond, IvoclarVivadent) was applied. Ceramic specimens in each group were luted to tooth surfaces by a dual-curing cement (Variolink II with Syntac adhesive system, IvoclarVivadent) according to the manufacturer’s instructions (Fig. 1c). Each specimen was totally light cured for 120 s circumferentially with a light-curing unit (Elipar Trilight 3M ESPE, Germany) having an energy output exceeding 500 mW/mm^2 under a constant load of 300 g simulating finger pressure.

Artificial lesion formation

Veneered teeth were covered with acid-resistant varnish (Sally Hansen, New Jersey, USA) except for a circular window about 1.4 mm in diameter on the distal proximal surfaces at enamel-restoration junction (Fig. 2). Mesial halves of each tooth was spared to act as control groups, while their distal halves served as experimental groups.

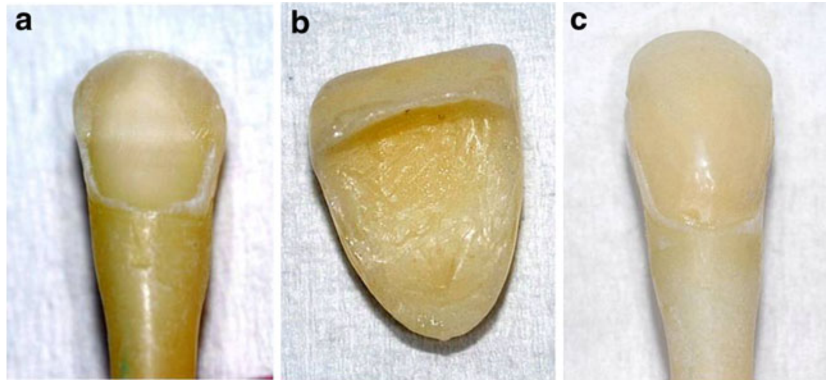

Fig. 1 **a** Canine tooth prepared for laminate veneer restorations. **b** Laminate veneer restoration. **c** Image showing the ceramic specimen luted to canine tooth surface

Acetic acid buffer with 0.34 M sodium acetate (pH4.0) was used for inducing secondary caries lesions. Twenty teeth (each in individual bottles) were kept immersed in 20 ml of acetic acid buffer solution (pH4.0) at 37 °C for 80 h [12, 13]. In an earlier study, the teeth were exposed for 6 h a day to a pH=4.3, 40 ml aliquot buffer solution containing calcium, phosphate and acetate that was prepared at 37 °C [13]. In the present study, based on a pilot study where the teeth were exposed to 20 ml acetic acid buffer solution (pH4.0) at 37 °C for 24, 48, and 80 h; it was observed that demineralizations that were confined only to the enamel tissue could have been detected only after 80 h. Therefore, 80 h was particularly chosen to produce enamel demineralizations as described previously [12]. Following demineralization, teeth were rinsed thoroughly with de-ionized water.

Radiographic procedure

The teeth were mounted in blocks of silicone with one test teeth and two non-test teeth in each block. The non-test teeth at either end created natural contact points. Standardized exposures of all specimens were done at the last day of 80 h of demineralization period (Fig. 3). All teeth were radiographed with Digora Optime storage phosphor plate (SPP) system (Soredex Corp., Finland). SPPs were exposed for 0.25 s. with a dental X-ray unit operating at 60 kVp, 7 mA, and 1.5 mm Al equivalent filtration at a focus-receptor distance of 25 cm. A 20-mm thick soft tissue equivalent material was placed close to the blocks and facing the X-ray tube. After the plates were scanned the resulting images were displayed in random order using the Digora for Windows software.

Fig. 2 Test tooth showing the area of acid application (*green area* covered with latex) and test tooth covered with nail varnish on proximal surface

Visual and radiographic evaluation

Five radiologists and five specialists in restorative dentistry with a mean age of 38.6 (range 31–59) and mean clinical experience of 17.8 (range 8–40) acted as evaluators and independently rated the presence/absence of enamel demineralization mimicking secondary caries using a five-graded scale for both visual and radiographic evaluation: 1—definitely present, 2—probably present, 3—unsure, 4—probably absent, 5—definitely absent. Observers were instructed to assess only gingivo-proximal surfaces at enamel-restoration junction at both sides (mesial and distal) of each test tooth. Observers were not informed about the details of the demineralization process regarding the site of demineralization (mesial or distal). Any sign of demineralization was to be considered as secondary caries, regardless of size and degree of penetration. Forty surfaces were evaluated first visually and then in storage phosphor plate images. Thus, a total of 800 evaluations were performed by ten observers.

Visual inspection was conducted using air/water spray, a mirror and a probe under daylight, and surfaces were scored according to the abovementioned scale. Evaluators were instructed to consider even the slightest change in enamel translucency after prolonged air drying. Any sign of demineralization was to be considered enamel subsurface caries, regardless of size and degree of penetration into enamel.

For radiographic evaluation; the storage phosphor plate images were displayed to observers at full size, 1:1 on a 15.4-in. high-resolution (XGA) color liquid crystal monitor with a resolution of 1,024×768 pixels and 256 gray levels (HP Pavilion DV6000, Santa Clara, CA). Observation conditions were optimized through use of the same computer monitor

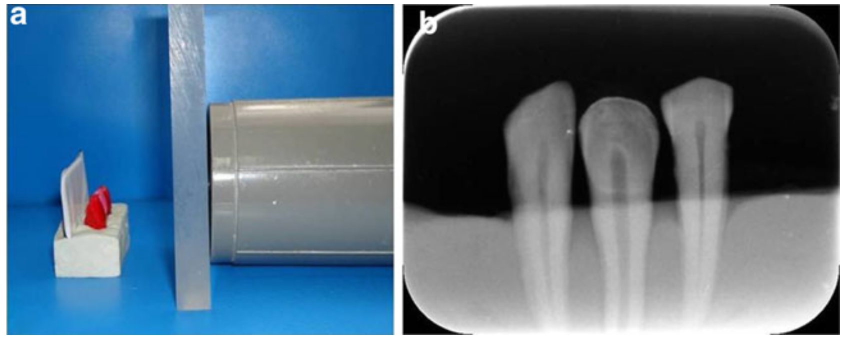

Fig. 3 **a** Picture demonstrating the test teeth in contact with non-test teeth on two sides mounted in silicon blocks and the projection geometry during radiographic exposures. **b** Storage phosphor plate image obtained with the set-up in **a**

when the images were displayed and the viewing distance was kept constant to about 50 cm for all observers and the lights were subdued during observations. A moderator presented each image for viewing and maintained a proper random sequence order. The observers were not given the option to perform any image enhancements to avoid the production of variety of different digital images. No time limit was set for the viewing procedure.

Scanning electron microscopic evaluation

Two samples from each group of veneered teeth were sectioned and examined using scanning electron microscopy (SEM) (JSM-5200, JEOL, Japan) to visualize enamel surfaces after acid exposure to observe the nature and extent of the artificially created lesions (Fig. 4a, b). In our previous study, scanning electron microscopic and stereomicroscopic observations demonstrated that 80 h of demineralization produced enamel defects confined only to the superficial layers of enamel tissue (with an average depth of approximately 18 μm) [12]. Further SEM observations in the present study were done to confirm the previous findings, i.e., the defects created by acid application were subsurface enamel demineralizations.

Data analysis

The accuracy of caries detection was expressed as the area under the receiver operating characteristic (ROC) curves (A_z). Sensitivity and specificity are the basic measures of the accuracy of a diagnostic test with sensitivity being defined as the number of true-positive decisions/the number of actually positive cases and specificity as the number of true negative decisions/the number of actually negative cases. They describe the abilities of a test to correctly diagnose disease when disease is actually present and to correctly rule out disease when it is truly absent. A ROC curve describes the trade-off between the rate of true-positive diagnostic decisions (sensitivity) and the rate of false-positive decisions (1−specificity) made by an evaluator of the image sets. The area under the ROC curve (A_z) is a measure of the accuracy of a diagnostic system. An A_z value of 0.5 represents chance performance and 1.0 perfect accuracy [14].

Comparison of mean A_zs was done with two-way ANOVA, with the factors ceramic type, evaluation type, and observers. Pair-wise comparisons were performed using post hoc *t* test (p=0.05). Fleiss Kappa (κ) was used to measure the level of agreement between observers.

Results

Table 1 displays mean A_z±standard deviation (SD) values for the visual and radiographic detection of enamel demineralization mimicking secondary caries. Mean A_z values for storage phosphor radiography for the detection of artificial secondary caries were 0.73 for H and 0.87 for A while A_z

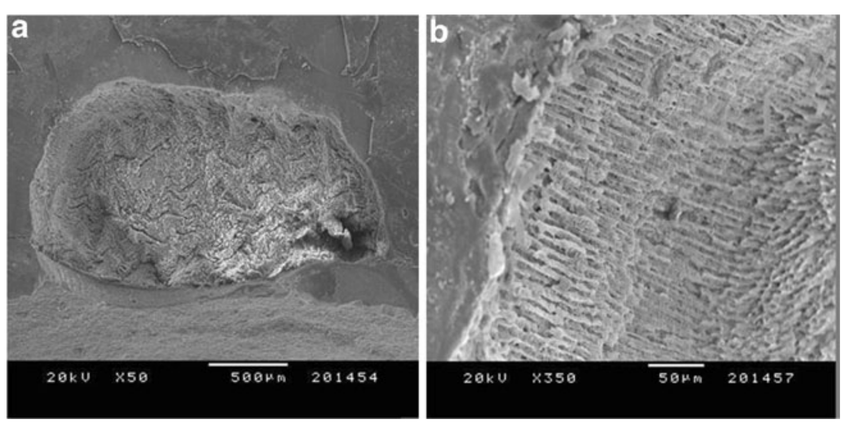

Fig. 4 **a** Scanning electron microscopy image representing the demineralization areas (magnification ×50). **b** The ×350 magnification of the border of demineralization seen in **a**

Table 1 Mean accuracy (A_z) ± standard deviation (SD) values for the visual and radiographic detection of artificially created secondary caries under two different laminate veneers

	Radiographic evaluation	Visual inspection
(A) All-ceramic	0.87±0.09	0.73±0.11
(H) Hybrid ceramic	0.73±0.07	0.68±0.15

values for visual evaluation were 0.68 and 0.73, respectively. Sensitivity and specificity of SPP radiography for H was 0.56 and 0.87 while it was 0.85 and 0.77 for A, respectively. On the other hand, sensitivity of VI was 0.46 and specificity was 0.90 for H while it was 0.61 and 0.85 for A, respectively. The comparison of the visual and radiographic methods revealed that the accuracy of storage phosphor radiography was significantly better than the visual evaluation for both restoration types (p=0.004).

Pair-wise comparisons revealed that the A_zs of the two different types of veneers were significantly different for both visual (p<0.005) and radiographic evaluation (p<0.005). All-ceramic restorations (A) were better than hybrid ceramic (H) for the detection of enamel demineralization mimicking secondary caries for both visual and radiographic evaluation (p=0.004).

Fleiss κ was fair for H (0.35 for radiography, 0.23 for visual evaluation), while it ranged between fair to moderate for A (0.46 for radiography, 0.33 for visual evaluation). Agreement of the observers was higher for the radiographic evaluation than the visual inspection for both restoration types.

Scanning electron microscopic evaluation revealed lesions from superficial to deeper layers of enamel. The mean of the largest diameter of demineralization (artificial lesion) that was measured in different samples was approximately 2.22 mm while the mean measured for the narrowest diameter was approximately 1.02 mm. The depth of demineralization was recorded by measuring the dentinal wall around the lesion cavity and ranged between 0.35 and 0.81 μm (Fig. 4a: H and b: A).

Discussion

In this study, recently extracted human canines were used to optimally represent the clinical situation because laminate veneers can be frequently applied to canine teeth for more harmonious smile design and because canines provide a larger area of tooth substance for caries detection. Since artificial teeth or bovine teeth differ from human teeth in elasticity, bonding properties, thermal conductivity, strength [15], and radiographic density human teeth were used in the present study. By choosing optimal preparation forms and adjusting the thickness of the restorations, variations in size, shape, and quality of the extracted teeth were tried to be standardized.

For improving the bond strength of the resin composite to the tooth surface enamel reduction is a prerequisite since the aprismatic top surface of mature unprepared enamel having a minor retention capacity should be removed [15]. The preparation is recommended to be maintained completely in enamel to achieve an optimal bond with the ceramic veneer [15, 16]. Although the performance of recent dentin adhesive systems are successful, the bond strength of ceramic to enamel is still superior when compared with the bond strength of ceramic to dentin [15, 16]. The laminate veneer restorations were made freehand in the present study. It has been previously reported that the proximal and cervical enamel was reduced more than 0.5 mm in the vast majority of cases with exposure of dentine in most teeth by freehand preparation [17]. In addition, the marginal openings at the gingivo-proximal corners were two to four times larger than at the mid-labial position [18]. This was attributed to shrinkage of porcelain towards the region of greatest bulk and the geometry of the margins [16–18]. This poor fit at the gingivo-proximal corners of the veneers causes difficulty in access for finishing of the luted veneers in these regions [18]. Considering the two factors mentioned above, a laminate veneer preparation set with limited preparation depths was preferred in the present study, and dentin exposure was tried to be avoided. Accordingly, all artificial lesions bordering laminate veneers were created on enamel tissue. The findings of SEM observations also confirmed that all artificial secondary demineralizations were confined only to enamel tissue. Therefore, evaluations done by observers with regard to demineralization detection were belonging to subsurface enamel lesions and performed at the gingivo-proximal borders of the restorations that were probably the most susceptible to caries formation. On the other hand, the method of demineralization formation in the present study had some limitations. It has been reported that in vitro secondary caries, development models around restorative materials may differ from chemical to biological simulations including static (acidic solutions) or dynamic methods (pH-cycling regimens with or without inclusion of microorganisms) [19]. Such models are mainly preferred to observe the cariostatic effects of restorative materials with cariostatic properties. Since the aim of the present study was to determine whether any demineralization areas under laminate veneers could be detected better with SPP imaging compared to conventional radiographic methods or not, and to observe if the employed materials' (ceramic and hybrid ceramic) properties differ from each other in terms of detectability in imaging; a static demineralization method was used in order to minimize the parameters that might affect the findings. Further studies may be performed in order to observe the effects of dynamic secondary caries development methods for detectability of demineralization and/or caries formation under laminate veneers, i.e., prepared on teeth with existing restorations.

An important issue in designing and performing diagnostic accuracy studies is determining the number of patients/samples and observers to meet the purposes of the study. For this purpose, in a previous study, tables were prepared to determine the number of samples required for detecting a suspected difference in accuracy [14]. According to the abovementioned sample size tables, for ROC studies with moderate accuracy values (0.75–0.89) and with large difference (0.15) between accuracies of two diagnostic techniques the total number of 20 samples (i.e., with and without the condition) requires ten observers. Since our sample size was relatively small (total of 20 surfaces) due to the high costs of laminate restorations we included ten observers for the statistical power to demonstrate a difference in diagnostic accuracy between two methods. On the other hand, Hintze et al. demonstrated that as long as the data are analyzed by a two-way analysis of variance, that study designs for comparing the accuracy of several diagnostic techniques can be composed freely in relation to the number of surfaces and observers provided that the total number of evaluations per system are identical [20]. In the present study, same number of evaluations was done for each method under investigation and two-way analysis of variance was used for the statistical analysis. Therefore, according to the aforementioned, the results of the present study may be generalized as regards the diagnostic performance of visual inspection and SPP radiography for the detection of enamel demineralizations bordering laminate veneers.

The longevity of a laminate restoration depends on long-term functioning and aesthetic maintenance free from carious lesions. Therefore, early detection of an enamel demineralization and/or secondary caries becomes a prerequisite for the longevity of the laminate restorations. Color and hardness measurements have been used as criteria for the early assessment of caries [21–23]. However, it was recognized that these methods were not always reliable guides for determining the infected tooth portion [23]. There also has been an effort to identify more technologically advanced measures to detect incipient dental caries including quantitative laser or light fluorescence, electrical conductance measurements, infrared laser fluorescence and digital imaging fiber optic transillumination. The evidence shows that methods based on optical properties (fluorescence and transillumination) have the highest potential [24]. Yet, many concerns and disadvantages of these methods were reported including the confounding effects of stains, plaque, and fluorosis or other enamel opacities such as hypermineralization as well as the concerns regarding detection based on subjective interpretation of the appearance of the lesion. Moreover, absence of clinical studies was another issue for the limitation of these advanced methods [25]. Therefore, intra-oral radiography—either digital or conventional still remains to be the most available and primary tool for caries diagnosis in dental clinics since it was well established that the use of radiographic techniques, whether conventional or digital, increases the number of caries diagnosed in comparison with conventional clinical examination [26]. Increase in diagnostic accuracy as well as the increase in agreements with the use of storage phosphor radiography obtained in the present study was in line with these assertions.

Inter-proximal caries diagnosis was generally made using conventional films or digital systems based on either solid state or photostimulable storage phosphor technologies [27]. Since diagnosis of inter-proximal caries by digital images has been previously shown to be comparable to conventional films [28], and dose to the patient was minimized, a digital imaging system was preferred for the evaluation of detection performance of artificial secondary demineralizations bordering laminate veneers. The present results revealed that artificial enamel demineralizations created at the border of laminate veneer restorations can be successfully diagnosed using storage phosphor plate images and better than visual detection for both laminate veneer types used in this study. These results cannot be compared since this is the first study in dental literature comparing the diagnostic accuracy of storage phosphor plate images to visual inspection for the detection of artificial demineralizations bordering different laminate veneers. However, our accuracy values (0.7 and 0.9) are in accordance with previously reported accuracies of 0.7 and 0.8 for the detection of secondary caries under occlusal amalgam restorations and crown margins, respectively [29, 30].

Although a relatively high number of excellent marginal adaptations after several years of clinical functioning for ceramic veneer restorations have been reported (65–98 %); small marginal defects due to wearing out of the composite luting agent and loss of bonding might also be seen [31]. When laminate veneers have to be removed from the tooth surface due to fracture, discoloration owing to luting cement and/or marginal failure; Er:YAG lasers have been recently introduced for non-destructive removal of especially ceramic laminate veneers from teeth. Er:YAG laser dissolves the moist resin cement layer only and does not harm the veneer [32]. However, cervical regions in ceramic laminate veneer restorations are prone to bacterial accumulation due to the difficulties in polishing, caries formation in these areas are frequent, particularly when the underlying tooth structure bears an existing restoration. In this case, remaking of the restoration might be necessary and this procedure requires meticulous clinical application steps that are expensive, time-consuming, and painful for the patient that makes the detection of incipient secondary caries under laminate veneers particularly important.

Hybrid ceramic veneers might be more permeable in demineralizing solutions and acid attacks causing rapid dissolution of the luting cement and accordingly deeper caries formation than that of all-ceramic veneers. However, according to the present results, the level of agreement between observers was in favor of all-ceramic veneers. The reason for this finding might be that hybrid ceramic material contains alumina particles and radiopaque ingredients in a composite matrix, which could have masked the radiodensity created by artificial demineralization and therefore resulted in decreased detectability. On the contrary, the all-ceramic material contains translucent leucite crystals in a glassy matrix which might contribute to higher image contrast by increasing the density difference between the lesion and the surrounding sound tissue allowing easier detectability and therefore higher accuracy for artificial lesion detection [1].

Inter-proximal caries, no matter primary or secondary, is difficult to perceive by the naked eye and this was previously proved by many scientific studies [33–35]. However, this was the first study evaluating the detection of enamel demineralizations mimicking secondary caries bordering laminate veneers. Since visual inspection is the basic method of diagnosis without any hazardous effects such as radiation it was particularly preferred for comparison with SPP radiography. It is apparent that early diagnosis of enamel demineralization bordering veneers would result in time-saving and less-invasive treatment methods than costly remaking of the restoration. Accordingly, in case of clinically suspicious cases, SPP radiography may be recommended since it provides better accuracy for caries detection bordering laminate veneers.

Considering the factors discussed above, the null hypothesis of this study was rejected. Artificial enamel demineralization mimicking secondary caries created under hybrid and ceramic laminate veneers can be detected better with SPP images than visual inspection, and detectability under the lithium disilicate all-ceramic was better than the hybrid ceramic restorations.

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

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