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Effects Of Denoising And Sharpening On Detection Of Secondary Caries Under Amalgam And Composite Proximal Restorations On Digital Periapical Radiographs

Research Article

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Abstract

Objectives: To assess the effects of denoising and sharpening on detection of secondary caries under proximal amalgam and composite restorations on digital periapical radiographs.
Methods: After preparing a single box in proximal surfaces of 144 proximal surfaces of extracted premolars, the cavities were restored with amalgam and composite resin. Next, artificial carious lesions were randomly induced on 72 surfaces by the acid challenge. The teeth then underwent photostimulable phosphor plate (PSP) digital radiography with the parallel technique. Images were enhanced using sharpening and denoising filters of the Scanora software. The images were evaluated by a restorative dentist and an oral and maxillofacial radiologist blindly. The sensitivity and specificity of denoised and sharpened images were calculated by the modified Wilson method via SPSS. The inter-observer agreement was assessed by the kappa analysis.
Results: Maximum sensitivity was noted for detection of caries under amalgam restorations on imagesenhanced with sharpness 3 with/without denoising (100%). Minimum sensitivity belonged to original images of amalgam restorations (36.1%). Maximum specificity belonged to original images of amalgam restorations and those enhanced by sharpness 1 (94.4%). Minimum specificity belonged to images of composite restorations enhanced by sharpness 3 (8.3%).
Conclusion: Increasing the sharpness increased the sensitivity for both restoration types but decreased the specificity. Denoising decreased the sensitivity for both restoration types. It also decreased the specificity of caries detection under amalgam restorationsand increased the specificity of caries detection under composite restorations. The sensitivity and specificity of caries detection were higher for amalgam than composite restorations.

Keywords: Diagnostic Sensitivity; Diagnostic Specificity; Secondary Caries; Proximal Caries; Digital Radiography; Sharpness; Denoising; Amalgam; Composite Resins.

Introduction

Dental caries is an infectious disease and a dynamic process, caused by demineralization of tooth structure by the acids produced by the bacteria. Dental caries is the most common infectious disease in humans, involving 95% of the population. It adversely affects the quality of life of individuals and their financial status and well-being [1]. According to the definition by the World Dental Federation, secondary caries refers to a carious lesion at the restoration margins. Occurrence of secondary caries is the most common cause of failure of restorations. Secondary caries histologically resembles primary caries. It occurs adjacent to a restoration due to poor quality of restoration, presence of gap, or poor marginal integrity. Secondary caries is susceptible to plaque accumulation [2]. Since dentin is more sensitive to acid attacks than the enamel, dentin caries progresses more rapidly than enamel caries. Thus, its early detection can help prevent its progression and save time and cost while following the principles of conservative dentistry [3].

Detection of secondary caries is difficult in proximal areas. Enamel translucency, cavitation, or change in hardness and color of the enamel and dentin are among the clinical signs and symptoms of

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secondary proximal caries. However, discoloration around composite restorations and corrosion products of amalgam restorations may be mistaken for caries, and increase the rate of false positive diagnoses. Also, proximal areas, especially towards the cervical, are often covered with the gingiva or the adjacent teeth, and are therefore less accessible for clinical examination. In most cases, carious lesions in such areas cannot be detected by clinical examination alone [4]. Radiography is the preferred technique for detection and confirmation of secondary caries. A good-quality radiograph can well visualize the contact points and the contact areas between the teeth, which cannot be easily accessed and examined clinically. For correct diagnosis and minimizing the risk of treatment failure, a combination of bitewing, periapical, or panoramic radiography along with precise clinical examination is often used [5]. Nonetheless, radiography is still not considered ideal for caries detection, and has a diagnostic value of 60% for this purpose. Digital radiography (without enhancement) has a diagnostic value similar to that of conventional radiography. However, the ability to use image enhancement filters and modifying the images is the main advantage of digital radiography over the conventional radiography. By using enhancement filters, the image properties can be modified as desired by the clinician [6]. Some settings of digital images can be enhanced for example by using sharpening and denoising filters. By changing these properties, the final quality of the image is changed, which can affect diagnosis.

It should be noted that changing such properties can increase the diagnostic value to a certain extent, and excessive enhancement can lead to false positive results and misdiagnosis. In other words, a thin line exists between correct and incorrect radiographic diagnoses. It appears that a suitable algorithm for higher diagnostic accuracy for caries detection has yet to be achieved. The sensitivity and specificity values are calculated to assess the diagnostic accuracy of a tool. The sensitivity of a diagnostic test refers to its ability to find disease cases. In other words, sensitivity is the ratio of true positive cases to the sum of true positive and false negative cases. Specificity refers to the ratio of true negative cases to the sum of true negative and false positive cases. The higher the sensitivity and specificity of a test, the higher its diagnostic value would be [7].

The available studies on this topic have mainly focused on the effect of enhancement filters on detection of primary caries [8-11], and studies on their efficacy for detection of secondary caries under restorations are limited [12]. Moreover, no previous study has assessed the effect of image enhancement filters on sensitivity and specificity of detection of secondary caries under amalgam and composite restorations or comparing these restorations in this respect. Thus, considering the high prevalence of secondary caries, the significance of their early detection, absence of an ideal diagnostic algorithm for this purpose, and lack of a study comparing the sensitivity and specificity of detection of secondary caries under amalgam and composite restorations, this study aimed to assess the efficacy of denoising and sharpening image enhancement filters for detection of secondary caries under proximal amalgam and composite restorations on digital periapical radiographs.

Materials and Methods

Specimen preparation

This *in vitro* study evaluated 108 sound human premolars (144 proximal surfaces) extracted for orthodontic treatment or periodontal problem. A single box was prepared in proximal surfaces of the teeth by 008 straight diamond fissure bur with high-speed hand-piece under water coolant. Half of the teeth were restored with amalgam. The other half were etched with 37% phosphoric acid, and after rinsing and drying, OptiBond 5th generation bonding agent (Kerr, Orange, CA, USA) was applied and cured. The cavities were then restored with Point Four composite resin (Kerr, Italy).

To induce random artificial carious lesions, half of the tooth surface was coated with acid-resistant nail varnish except for a square-shaped window measuring 2 x 2 mm (area to induce artificial caries). The other half was completely coated with acid-resistant nail varnish (to serve as a sound caries-free surface). The teeth then underwent pH cycling. During this process, the teeth were immersed in a demineralizing solution with a pH of 4 for 18 h and were then immersed in a remineralizing solution with a pH of 7 for 6 h. This cycle continued for 30 days to create artificial caries in the teeth.

The composition of the demineralizing solution included 0.05 mM $CaCl_2$, 2.2mM $NaH_2 PO_4$, and 50 mM acetic acid. The composition of the remineralizing agent included 20 mM HEPES, 1.5mM Ca^{2+} as $CaCl_2$, 0.9mM phosphate as $KH_2 PO_4$, and 1 ppm fluoride as NaF. After preparation of the teeth, they were mounted in gypsum blocks in a random manner in two groups of amalgam and composite resin restorations.

Imaging

The blocks were then radiographed in buccolingual dimension by the parallel technique. The images were obtained by Digora digital system (OptimeSoredex Corporation) with size 2 photostimulablephosphor plate (PSP) sensor with 70 kVp voltage, 1 mA amperage and 1 ms exposure time. In order to obtain ideal images, the distance from the tube was 25 cm [13]. After exposure, the PSP sensors were scanned by SoredexDigoraOptime scanner, and the original images were saved in DICOM format in a computer. Next, Scanora 4.3.1 software was used to filter the original images with denoising and sharpening 1, 2 and 3 filters. Each file was separately saved in a computer. By doing so, 7 images were obtained of each tooth block (Figure 1) as follows:

(I) Original image without sharpening and denoising filters
(II) Image enhanced with sharpening 1 without denoising
(III) Image enhanced with sharpening 2 without denoising
(IV) Image enhanced with sharpening 3 without denoising
(V) Image enhanced with sharpening 1withdenoising
(VI) Image enhanced with sharpening 2 with denoising
(VII) Image enhanced with sharpening 3 with denoising

Image interpretation

The obtained images were randomly observed by arestorative dentist and an oral and maxillofacial radiologist in a blind manner. The observers were allowed to change the brightness of images and had no time limitation for image interpretation. A total of 252 radiographs were evaluated for presence/absence of caries in the gingival floor of the restored cavities. Assessments were made in a semi-dark room on a 19-inch monitor with 1360 x 768 pixel resolution. The opinion of the observers regarding presence/absence of caries was recorded using a dichotomous yes/no system. The results were then statistically analyzed, and the sensitivity and specificity of images enhanced by denoising and sharpening were calculated using SPSS. The modified Wilson method was used to compare the data. The interobserver agreement was calculated by the kappa analysis.

Results

After data collection, the sensitivity and specificity of caries detection under amalgam and composite restorations were calculated for the two observers. As shown in Tables 1-4, the sensitivity increased by an increase in sharpness for both observers. The specificity of caries detection under amalgam restorations improved by applying sharpness 1 for the restorative dentist while it remained unchanged for the radiologist. The specificity of caries detection under amalgam restorations decreased by applying sharpness 2 and 3 for both observers. By applying denoising, the specificity of caries detection under amalgam restorations did not change significantly for the restorative dentist. However, the specificity of caries detection under amalgam restorations decreased by applying denoising for the radiologist.

The sensitivity of caries detection under composite restorations increased by an increase in sharpness for both observers. The specificity of caries detection under composite restorations decreased by an increase in sharpness for both observers. Applying denoising and sharpness 1 decreased the sensitivity of caries detection under composite restorations while applying sharpness 2 and 3 did not cause a significant change. Application of denoising did not significantly change the specificity of caries detection under composite restorations by the restorative dentist. However, application of denoising increased the specificity of caries detection under composite restorations by the radiologist. Comparison of amalgam and composite restorations revealed generally higher diagnostic sensitivity and specificity for detection of caries under amalgam restorations, compared with composite restorations.

Table 5 shows the inter-observer agreement calculated by the kappa analysis.

Table 1. Sensitivity and specificity of caries detection under amalgam restorations by the restorative dentist.

	Sensitivity	95% CI	Specificity	95% CI
Original image	44.4	36.4-52.4	75	68-82
Sharpness 1	72.2	65.2-79.2	88.9	80.9-93.9
Sharpness 2	83.3	77-89	80.6	74-87
Sharpness 3	86.1	81-91	58.3	50-66
Sharpness 1 and denoising	63.9	55.9-71.9	80.6	74-86
Sharpness 2 and denoising	75	68-82	83.3	77-89
Sharpness 3 and denoising	88.9	84-94	58.3	50-66

Table 2. Sensitivity and specificity of caries detection under amalgam restorations by the radiologist.

	Sensitivity	95% CI	Specificity	95% CI
Original image	36.1	28.1-44.1	94.4	91.4-97.4
Sharpness 1	63.9	55.9-71.9	94.4	90.2-98.2
Sharpness 2	91.7	87-96	77.8	70-84
Sharpness 3	100	100	27.8	20-34
Sharpness 1 and denoising	52.8	44-60	83.8	77-89
Sharpness 2 and denoising	91.7	87-96	58.3	50-66
Sharpness 3 and denoising	100	100	13.9	12-Jun

Table 3. Sensitivity and specificity of caries detection under composite restorations by the restorative dentist.

	Sensitivity	95% CI	Specificity	95% CI
Original image	44.4	36.4-52.4	77.8	70-85
Sharpness 1	69.4	62-77	66.7	59-74
Sharpness 2	72.2	65-79	66.7	58-74
Sharpness 3	61.1	53-69	63.9	55-71
Sharpness 1 and denoising	55.6	47-63	69.4	62-76
Sharpness 2 and denoising	69.4	61.8-77	66.7	59-83
Sharpness 3 and denoising	75	68-82	38.9	30-46

Table 4. Sensitivity and specificity of caries detection under composite restorations by the radiologist.

	Sensitivity	95% CI	Specificity	95% CI
Original image	50	42.58	91.7	87.2-96.2
Sharpness 1	69.4	61.8-77	63.9	55.9-71.9
Sharpness 2	83.3	77-89	30.6	22-37
Sharpness 3	94.4	90-98.2	8.3	4-12
Sharpness 1 and denoising	60	54-68	77.8	70-84
Sharpness 2 and denoising	86.1	80-92	36.1	28-44
Sharpness 3 and denoising	97.2	94-100	13.9	6-12

Table 5. Interobserver agreements.

Image	Restoration	Level of agreement
Original image	Amalgam	0.256
Original image	Composite	0.258
Sharpness 1	Amalgam	0.502
Sharpness 1	Composite	0.249
Sharpness 2	Amalgam	0.498
Sharpness 2	Composite	0.227
Sharpness 3	Amalgam	0.375
Sharpness 3	Composite	0.078
Sharpness 1 + denoising	Amalgam	0.444
Sharpness 1 + denoising	Composite	0.193
Sharpness 2 + denoising	Amalgam	0.486
Sharpness 2 + denoising	Composite	0.239
Sharpness 3 + denoising	Amalgam	0.246
Sharpness 3 + denoising	Composite	0.086

Discussion

At present, detection of secondary caries is highly important considering the increased use of restorative materials. Early detection of such lesions is imperative for decision making regarding restoration replacement and prevention of tooth loss.

Radiography is a standard technique for detection of secondary caries. At present, digital radiography is extensively used by dental clinicians, and it has been demonstrated that intraoral digital radiography is as accurate as the conventional film-based radiography for detection of proximal caries [14].

Two methods can be employed for artificial induction of caries namely cavity preparation by bur and the acid challenge technique. Since cavities prepared by bur have a more well-defined margins compared with naturally occurring caries, they may cause some errors in the accuracy of caries detection assessment. Thus, the acid challenge technique was used in the present study to induce carious lesions. Shokri et al, in 2018 used the acid challenge technique to induce caries [8]. Also, application of a thick layer of bonding agent under composite restorations in the clinical setting can lead to false positive results. Thus, to better simulate the clinical setting, bonding agent was applied under composite restorations of the teeth in the present study [15].

In digital radiography, use of image enhancement filters allows modification of images to obtain more accurate images for more accurate diagnosis. Enhancement of digital images improved the diagnostic accuracy [16]. Shokri et al. used sharpening and denoising for detection of primary occlusal and proximal caries and reported that increasing the degree of sharpening increased the diagnostic sensitivity and decreased specificity. Belém et al. reported that sharpened images had the highest accuracy and sensitivity. The current results confirm their findings [8, 17]. Also, in the study by Shokri et al, the images were evaluated by two radiologists and they assessed the effect of denoising on diagnostic accuracy. They concluded that denoised images had relatively lower sensitivity and higher specificity [8]. Similarly, application of denoising in the present study decreased sensitivity, which was in agreement with the results of Shokri et al. Diagnostic specificity did not experience a significant change after application of filters for the restorative dentist. However, the diagnostic specificity increased for detection of caries under composite restorations and decreased for detection of caries under amalgam restorations for the radiologist. Since this study was highly technique sensitive, it was observer-dependent,and, heterogeneity was noted between the observers.

In the present study, increasing the sharpness degree increased the sensitivity, and application of denoising decreased the sensitivity in general or did not significantly change it. Also, increasing the sharpness significantly decreased the specificity. In the present study, detection of caries under amalgam and composite restorations was also compared, and the results showed that in general, diagnostic sensitivity and specificity were higher for detection of caries under amalgam restorations due to their more opaque nature compared with composite restorations. Pedrosa et al. indicated that type of restorative material significantly affected the detection of secondary caries. Restorative materials with an opacity in between that of enamel and dentin often cause misdiagnosis while more opaque restorative materials enhance caries detection. This statement was also confirmed in the present study [18]. When restorative materials are not opaque enough, the observer may even mistake a restored tooth surface with a sound and unrestored surface. On the other hand, it should be noted that highly opaque materials may mask the carious lesions under restorations and thus, the clinicians may not be able to detect them [19]. Araujo et al, in 2012 evaluated the effect of radiopacity of composite resins and bonding agents on detection of secondary caries. They reported that all tested composite resins and bonding agents, except for Protect Liner F, had adequate radiopacity according to ISO 4049 standards. In their study, maximum rate of misdiagnosis was reported for restorations with Protect Liner F [20]. Similarly, in the present study, the sensitivity and specificity of caries detection under amalgam restorations were significantly higher than composite restorations due to higher radiopacity of the amalgam. Thus, the opacity of restorative material is highly important for sensitivity and specificity of caries detection. A restorative material with moderate radiopacity is clinically ideal since it would enhance the detection of adjacent secondary caries [19].

Conclusion

Considering the limitations of this study, it may be concluded that increasing the sharpness would increase the sensitivity and decrease specificity. Application of denoising decreases the diagnostic sensitivity. The diagnostic specificity decreases for detection of caries under amalgam and increases for detection of caries under composite restorations by application of denoising. The diagnostic sensitivity and specificityare significantly higher for detection of caries under amalgam restorations.

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