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RESEARCH ARTICLES

Accuracy of digital image processing in radiographic early caries detection

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ABSTRACT

Tooth surface with early caries lesion can remineralize into sound tooth surface with early intervention. However, early caries lesion is difficult to detect and frequently goes unnoticed during clinical or radiographic examinations. Image quality enhancement through imaging tools such as filters has the potential to increase the accuracy of early caries lesion detection. To compare the accuracy of original radiographic images to enhanced images with filters on digital dental x-ray for detection of early caries lesions. Five working models were utilized, containing 42 sound tooth surfaces, and 36 surfaces with early caries lesions. Radiographic images were taken using Vistascan storage phosphor plate system (Dürr Dental, Germany) and enhanced with Fine, Caries 1, Caries 2, and High Diagnostic (HD) filters. Original and enhanced radiographic images were assessed by three observers to record the presence or absence of early caries lesions. Sensitivity, specificity, and overall accuracy were calculated. Sensitivity of HD and Fine filter images were significantly higher ($p < 0.05$), but Caries 1 and Caries 2 images did not differ significantly from the original images ($p > 0.05$). There was no significant difference between the specificity of original filter images and filter enhanced images. The overall accuracy of original filter images and filter enhanced images increased significantly only on HD filter ($p < 0.05$). HD filter had significantly higher overall accuracy than the original images. In addition, it showed the highest sensitivity, specificity, and overall accuracy. Therefore, some filters may be used to enhance early caries lesion detection.

Keywords: computed radiography; diagnostic accuracy; digital imaging; early caries lesion

INTRODUCTION

Dental caries is well-known as one of the most prevalent oral diseases.[1,2] All cases of dental caries begin with early caries lesion or commonly referred to as white spot lesion. Unlike cavitated caries lesion, early caries lesion cannot be assessed using tactile sense with a probe. Early caries lesion can only be detected with visual observation and radiographic assessment.[3] However, studies have suggested that early caries detection with visual observation is difficult, especially when the lesion surface is wetted with saliva.[1] Furthermore, early caries lesion frequently goes undetected with conventional radiographic imaging.[4]

The use of enhancement filters has been shown to increase diagnostic accuracy of digital radiographs. Filter is a post-processing step in a digital image that applies algorithm to enhance or suppress specific features. These filters can be applied in spatial or frequency domains to perform adjustments such as edge enhancement, noise reduction, and contrast adjustment.[5] Filter usage appears to be a promising enhancement tool for images used for detection of shallow caries lesion or early caries lesion.[4,6]

Vistascan system DBSWIN V.5.5.0 software (Dürr dental, Bietigheim- Bissingen, Germany) provides imaging tools such as filters including the two specific filters to detect caries lesion.[7] Image quality enhancement using filters is expected to increase the accuracy of early caries lesion detection. Several studies have evaluated image enhancement for more accurate diagnosis. However, few have assessed caries diagnostic performance of predefined commercial digital

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filters using 16-bit PSP radiographs.[8] To our knowledge, this is the first study to evaluate the diagnostic accuracy of HD, Fine, Caries 1, and Caries 2 filters from the DBSWIN software in early caries detection. The aim of this study is to compare the accuracy of original radiographic images with that of images which have been enhanced with various filters on digital dental X-ray for detecting early caries lesion.

MATERIALS AND METHODS

Ethical approval for this study was obtained from the Faculty of Dentistry, Universitas Indonesia (protocol number: 091180919). Ten extracted human permanent premolars and 10 extracted human permanent molars without caries lesion were utilized in this study. Five blocks of dental gypsum were used to mount the teeth. Each block consisted of two premolars and two molars. The teeth were placed in the blocks from apex to the cementoenamel junction with proximal surfaces in contact.

Before the teeth were mounted, artificial caries was made randomly on tooth surfaces of these teeth. Artificial caries was made by making cavities using a diamond round bur with a diameter of 1.5 mm. The cavities were made randomly on one to two tooth surfaces (occlusal, mesial, distal, or buccal/lingual/palatal) for each tooth. These cavities were recorded which could later be used as a reference to validate the radiographic assessment. The depth of the cavities was no more than 2 mm, or before dentino-enamel junction. Then, the cavities were restored with dental plaster to resemble early caries lesion (D2 caries lesion according to ICDAS).[9]

The gypsum blocks were positioned in a jig to ensure the distances from the X-ray tube to tooth blocks were the same, a central beam orientation, and to achieve a perpendicular angle between the X-ray and tooth axis (Figure 1). The photostimulable phosphor (PSP) plates were placed at the rear and in contact with the gypsum blocks. All blocks were radiographed separately under the same conditions (60 kV, 4mA, paralleling technique, and the same tube-tooth-receptor distance). A 20 mm thick baseplate wax equivalent to soft tissue was placed between the X-ray tube and the teeth to act as artificial soft tissue material. The PSP plate was scanned in the Vistascan system in high resolution and 16-bit depth. The Vistascan system DBSWIN v.5.5.0 software provides 4 types of predefined filters: Fine filter, Caries 1 filter, Caries 2 filter, and HD (High Diagnostic) filter. The original images were enhanced with these filters separately and saved in non-compressed file format. Samples of these

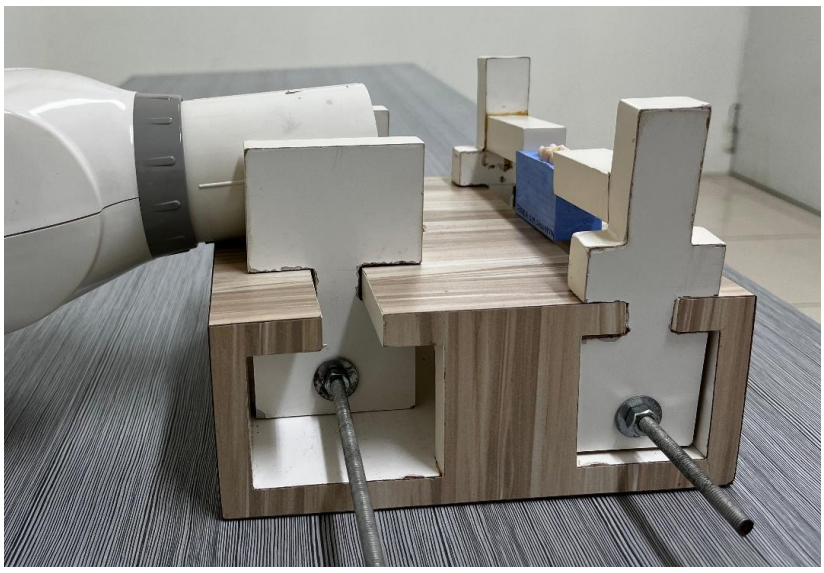

Figure 1. Positioning jig

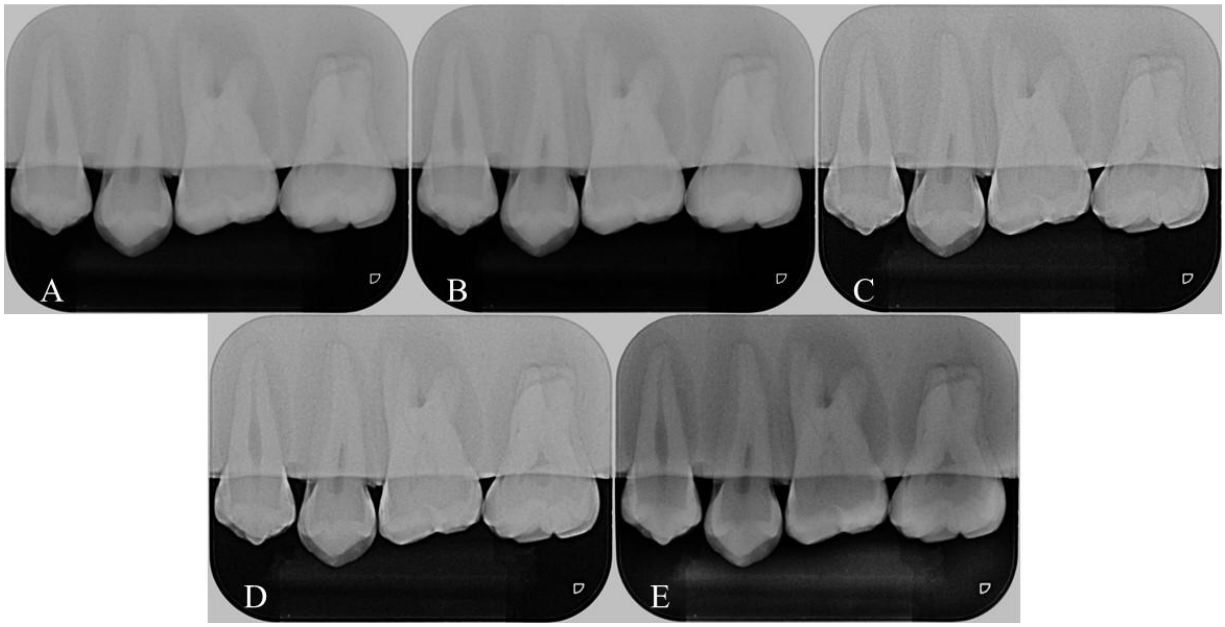

Figure 2. (A) Original 16-bit image. (B) Fine filter image. (C) Caries 1 filter image. (D) Caries 2 filter image. (E) High Diagnostic (HD) filter image

images are shown Figure 2. The original and enhanced images were coded to hide their origin and displayed in full size (1:1) in random order on Macbook Pro Retina 13 inch.

Three observers independently recorded the presence or absence of early caries lesion. Before they observed the images, a briefing session was held to calibrate scores used for the radiographic assessment. The reading order of the five image modalities were randomized for each observer. The assessments from each observer were then validated using the reference.

For each observer and each radiographic modality, the sensitivity, specificity, and overall accuracy were computed by comparing the radiographic scores to the reference. The sensitivity, specificity, and overall accuracy from each observer and radiographic modality were aggregated and calculated to determine the mean percentage of sensitivity, specificity, and overall accuracy for all radiographic modalities.[10] Then, a pair-wise comparison between original images and enhanced images were performed using a paired t-test. The level of statistical significance was $p < 0.05$. Cohen's Kappa test was used to assess inter-observer reliability.[11]

RESULTS

Of a total 78 tooth surfaces, 36 were artificial early caries lesion, and 42 were without lesion. Table 1 presents mean sensitivities, specificities, and overall accuracies for each radiographic modality. Table 2 presents the comparison between original images and filter-enhanced images. There were significant differences in sensitivity between original images and Fine filter images, and between original images and HD filter images ($p < 0.05$). There was also a significant difference in overall accuracy between original images and HD filter images ($p < 0.05$). Meanwhile, neither Caries 1 nor Caries 2 filters showed significant differences with original images in sensitivity, specificity, or overall accuracy ($p > 0.05$). Despite this, all filter modalities showed higher accuracy than original images (Table 1). Kappa agreement for inter-observer was 0.73 (substantial agreement).

DISCUSSION

This study aims to compare the diagnostic performance of original radiographic images and that of filter images in detecting the presence or absence of early caries lesion on tooth

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Table 1. Mean percentage (range) of sensitivity, specificity, and overall accuracy for each image modality: original images, fine filter, caries 1 filter, caries 2 filter, and HD (High Diagnostic) filter

	Original mean (range)	Fine mean (range)	Caries 1 mean (range)	Caries 2 mean (range)	HD mean (range)
Sensitivity	68.52 (52.78-77.78)	82.4 (72.22-91.67)	75 (63.89-83.33)	75.92 (66.67-83.33)	91.67 (86.11-97.22)
Specificity	88.89 (88.81-95.24)	91.27 (83.33-97.62)	88.09 (80.95-95.24)	91.27 (85.71-97.62)	93.65 (90.48-97.62)
Overall accuracy	79.48 (71.78-87.18)	87.40 (83.33-94.87)	82.05 (76.92-89.74)	84.19 (79.49-91.03)	92.40 (88.74-97.44)

Table 2. Paired t-test result for sensitivity, specificity, and overall accuracy between original images and filter-enhanced images

	Original vs Fine	Original vs Caries 1	Original vs Caries 2	Original vs HD
Sensitivity	0.049*	0.118	0.157	0.046*
Specificity	0.225	0.423	0.479	0.074
Overall accuracy	0.082	0.226	0.093	0.024*

*statistically significant (p-value < 0.05)

surfaces. Seventy-eight tooth surfaces were used, consisting of 36 artificial lesions and 42 intact tooth surfaces. Both original and enhanced radiographic images were assessed by three observers.

As shown in Table 1, the mean percentage of sensitivity and overall accuracy of image modalities from higher to lower are HD, Fine, Caries 2, Caries 1, and Original. Meanwhile, the mean percentage of specificity of image modalities from higher to lower are HD, Fine, Caries 2, Original, and Caries 1. A previous study concluded that there were no significant differences in accuracy between original images and enhanced images, and some filters had lower accuracy than the original images.[4] This outcome is contrary to our result. This difference may be due to differences in the bit depth used in this study and the previous study. In this study, we used 16-bit images, whereas the previous study used 8-bit images. Wenzel et al. concluded that caries diagnosis accuracy in digital radiograph is affected by bit depth, where the higher the bit depth, the more accurate the caries diagnosis may be.[12]

Interestingly, filters dedicated for caries detection showed lower diagnostic abilities in this study. Manufacturers rarely provide performance details of features released to medical and dental professionals. Therefore, studies of this kind are crucial in helping dentists choose the best available tools. As per the manufacturer's information, HD filter enhances objects of 2.5 mm, and Fine filter enhances objects of 2 lp/mm. Meanwhile, Caries 1 filter reduces low spatial frequency, and Caries 2 reduces both low and high spatial frequency. Theoretically, a reduction of low spatial frequency can enhance edges, while a reduction of high spatial frequency reduces noise at the risk of slight blurring.[13]

The relationship between spatial frequency to caries detection appeared to be more complex than expected. Despite the filters' descriptions, visually the images treated with Caries 1 and 2 filters had more apparent noise. Considering the role of contrast-to-noise ratio in object detection,[14] this may explain non-improvement or even worsening diagnostic performance of these filters.[15] Nevertheless, noise may have a limited effect on the radiographic appearance of early caries. According to Kajan et al., noise reduction did not increase early caries detection.[8]

HD and Fine filters should affect objects with specific sizes or features; therefore, the simulated defects in this study may be particularly suited for the aforementioned filters. Nevertheless, the findings of this study are consistent with the findings of other studies. Visually, HD filter resulted in an image with lower brightness and higher contrast, which is preferred by interpreters for caries detection, as indicated by previous research.[16] However, this preference may not be present for anatomical features.[17] Fine filter created very slight, but noticeable subtly enhanced edges. This finding is also consistent with that of Kajan et al,[8] who found improvement or caries diagnosis with Sharpening UM filter.

The detection of early carious lesions remains a considerable diagnostic challenge. Radiographic sensitivity has been reported to be as low as 14–38%,[18] limiting the accuracy of early detection through conventional imaging. Inter-observer agreement in early caries diagnosis is also often suboptimal, which highlights the challenging nature of its detection. Similar to this study, Bijle et al reported a Kappa value of 0.74.[19] In this context, the application of image enhancement filters may offer a valuable tool to improve diagnostic accuracy. In light of current findings, we recommend that dentists critically evaluate radiographic images both before and after filter application, rather than relying solely on manufacturers' recommendations.

An advantage of this study is that it uses standardized and verified defects as gold standard. However, an in vivo study should be conducted in the future to assess the effects of real soft tissue and different sized defects. Additionally, more assessments of different filters and sensor systems are needed to provide comprehensive diagnostic performance data for clinicians. More advanced or automated caries detection tools currently available need to be studied, such as using texture feature map[20] or artificial intelligence.[21]

This study demonstrates that image quality enhancement with digital filters can improve diagnostic accuracy for early caries detection in 16-bit images. Among the filters evaluated, high-diagnostic (HD) filter yielded more statistically significant improvement in diagnostic performance compared to the original images. Specifically, the HD filter exhibited high sensitivity in detecting the presence of early carious lesions, high specificity in identifying their absence, and a high level of overall diagnostic accuracy.

CONCLUSION

High-diagnostic (HD) filter significantly enhanced the accuracy of early caries detection in this in vitro study. These findings support the potential use of HD filter in future in vivo investigations aimed at improving early diagnosis of dental caries.

CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this study.

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