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Comparison of different enhancement filters of a digital system for caries detection

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Abstract

Statement of problem: Various intraoral digital radiographic systems are available as alternatives to film-based radiography. Advances in digital radiography enable image manipulation via using enhancement filters such as Emboss and reverse contrast. Objectives: This study was performed to assess the detection accuracy of proximal caries using Emboss and reverse contrast filters. Methods: This in-vitro study was conducted on 40 extracted premolars mounted in acrylic blocks. The teeth were radiographed using complementary metal oxide semiconductor (CMOS) digital sensor. Two observers evaluated images in terms of presence/absence of proximal caries with/without using Emboss and reverse contrast filters. The teeth were then sectioned and histologically examined. Diagnostic accuracy of each method was assessed using receiver operating characteristic (ROC) curve analysis. Comparisons were made using Wilcoxon signed rank test. Results: There were no significant differences between the Emboss enhanced and original digital (P=0.329) or reverse contrast and original digital (P=0.243) modes in terms of detection accuracy of proximal caries. Analysis of the diagnostic accuracy of Emboss and reverse contrast modes on lesion depth revealed no significant difference. Significant differences were noted between the two observers at their first observation in detection of proximal caries (P=0.034 for Emboss and P=0.005 for reverse contrast). Conclusion: The Emboss and reverse contrast digital enhancement filters do not offer significant improvements in the detection of proximal caries; therefor, their application remains optional based on the practitioners' individual preferences.

Keywords: Proximal Dental Caries Detection, Reverse Contrast Enhancement, Emboss Enhancement, CMOS Digital System

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Introduction

Radiography is a diagnostic tool that greatly enhances the detection of dental caries. Proximal caries are often found somewhere in between the contact point and the free gingival margin. Proximal surfaces of posterior teeth are wide and therefore, detection of slight demineralization in these areas is often difficult on radiographs. Digital image sensors have replaced conventional intraoral films in most radiographic systems (White & Pharoah, 2009). Several types of digital sensors are available in the market. Complementary metal oxide semiconductor image sensor is a technology for digital capturing of the images. Digital sensors are more sensitive than films and therefore, use of these sensors decreases the patient radiation dose. Moreover, digital systems enable changing the contrast and brightness of images and allow image enhancement; thus, repeat radiographs would no longer be required (White & Pharoah, 2009). Most digital radiography systems currently available in the market are accompanied by software programs that allow image enhancement. Reverse contrast and Emboss filters are available for most digital systems. Reverse contrast filter converts radiopaque structures on the image to radiolucent structures and vice-versa. Emboss filter confers a 3D shadow effect to an image. In a study by Scaf et al, inverted and unprocessed digitized radiographic images were not significantly different for measurement of the amount of periodontal bone loss (Scaf & Morihisa, 2007). Castro et al. showed that conventional films, unenhanced direct digital and inversion grayscale direct digital images made with CMOS sensor were not significantly different for detection of proximal caries (Castro et al., 2007) However, charge-coupled device (CCD) sensors were significantly more efficient for this purpose (Haak & Wicht, 2005). Kamburoğlu et al. found no significant difference with regard to the efficacy of original and enhanced (with reverse contrast and Emboss filters) digital images obtained using CCD sensors for detection of vertical root fractures (Kamburoğlu et al., 2010). However, Emboss enhancement of panoramic radiographs improved the detection of proximal caries (Akarslan et al., 2008).

In general, limited studies are available on the efficacy of enhancement filters of intraoral digital radiography for detection of proximal caries. Considering the extensive use of digital radiography and also great prevalence of proximal dental caries, assessment of the efficacy of digital enhancement filters is necessary. This study sought to assess the efficacy of reverse contrast and Emboss filters of CMOS digital sensor for detection of proximal caries.

Methods

This in-vitro study was conducted on 40 extracted premolars according to a similar previous study by Abreu et al (Abreu et al., 2001). Proximal surfaces of teeth were clinically examined to collect a group of teeth with sound and carious proximal surfaces of various depths (in the enamel and dentin). Teeth with restorations, large cavities or buccal and lingual caries were not chosen. The teeth were mounted in acrylic blocks to the level of the cemento-enamel junction and paired in close contact with one another. To create proximal contacts for all teeth, two extra teeth were placed at both sides of each pair of teeth (including a canine and a molar). These extra teeth were neither evaluated nor included in the statistical analysis.

The teeth were then radiographed using a digital radiography system (Planmeca, Helsinki, Finland) and CMOS digital sensor (Schick, USA). A wooden holder was designed to maintain a fixed position of teeth and digital sensor while taking the radiographs and keep 40cm distance from the X ray tube to the image sensor (Figure 1).

A glass slab with 2cm thickness was placed at 10cm distance from the sensor to simulate soft tissue. Radiographs were obtained with exposure settings of 55kVp, 0.2 seconds and 8mA. After exposure, the images were immediately displayed on a monitor (Benq, Japan) with 768×768 matrix resolution and 0–255 grayscale. After taking radiographs, two oral and maxillofacial radiologists with similar experience with regard to caries detection who were familiar with digital radiography systems evaluated the radiographs for presence/absence of proximal caries. These assessments were first made on original digital images and then the images were enhanced using Emboss and reverse contrast enhancement filters (Figures 2 a, b). Observers evaluated the images enhanced with reverse contrast and Emboss and recorded their diagnosis.

The observers expressed their opinion regarding the presence or absence of caries using the following 4-point scale: (0) absence of caries, (1) enamel caries, (2) caries at the level of the dentino-enamel junction (DEJ), and (3) dentin caries.

Radiographs were evaluated again after 4 weeks by the same observers to assess intra-observer reliability. Next, the teeth were sectioned using a low-speed Mecatome (T201 Model, Persi, France) with a diamond blade and evaluated under a stereomicroscope (SZ Olympus, Japan) at ×16 magnification (Figure 3). A maxillofacial pathologist evaluated sections and scored them using the above mentioned 4-point scale.

Data were entered into SPSS software .The diagnostic accuracy of each modality was assessed by calculating the area under the ROC curve (Az values). Pairwise comparison of Az values was done using Wilcoxon signed rank test. $P<0.05$ was considered to be statistically significant.

Results

Eighty proximal surfaces of 40 extracted premolar teeth were evaluated in this study. Histological assessments showed that 43 (53.75%) proximal surfaces were sound while 37 (46.25%) had carious lesions of variable depths. Of carious lesions, 5 (6.25%) were within the enamel, 2 (2.5%) were at the level of the DEJ and 30 (37.5%) were within the dentin.

To assess the intra-observer agreement, the observers evaluated images again after 4 weeks. The Wilcoxon signed rank test found no significant difference in this regard. However, with respect to the inter-observers reliability, a significant difference existed with regard to Emboss ($P=0.034$) and reverse contrast ($P=0.005$) in the first reading but not in the second observation.

The ROC curve was drawn for each scale of caries in Emboss, reverse contrast and original digital modes (Figure 4). The results are shown in Tables 1, 2 and 3. Pairwise comparison of A_z values showed no significant difference between Emboss and reverse contrast ($P=0.219$), Emboss and original digital ($P=0.329$) or reverse contrast and original digital modes ($P=0.243$) in terms of detection accuracy of proximal caries.

Table 1. The A_z values for the Emboss mode based on the scale of carious lesion

Scale of caries/ROC curve	Az	Std. error	95% CI Minimum Maximum	
Absence of caries	0.513	0.065	0.385	0.650
Enamel caries	0.475	0.065	0.348	0.602
Caries at DEJ	0.525	0.060	0.398	0.652
Dentin caries	0.513	0.065	0.385	0.640

Discussion

Advances in computer science have revolutionized dental radiography systems (Weeraya, 2012). At present, digital radiography has almost replaced conventional film-based radiography due to advantages such as lower patient radiation dose, elimination of chemical film processing steps and immediate image capture. Moreover, contemporary digital imaging systems enable manipulation and enhancement of images for a more accurate diagnosis. Enhancement filters include tools for changing the brightness and contrast of images, inversion gray

scale (reverse contrast), Emboss (3D conversion of image) and application of pseudo-color (White & Pharoah, 2009).

Table 2. The A_z values for the reverse contrast mode based on the scale of carious lesion

Scale of caries/ROC curve	Az	Std. error	95% CI Minimum	95% CI Maximum
Absence of caries	0.525	0.065	0.398	0.652
Enamel caries	0.450	0.065	0.323	0.577
Caries at DEJ	0.525	0.060	0.398	0.652
Dentin caries	0.550	0.060	0.423	0.677

Several studies have evaluated the accuracy of digital radiographic systems for detection of dental caries; however, most previous studies have compared film-based and digital radiographic systems in this respect (Castro et al., 2007; Weeraya, 2012; Tyndall et al., 1998; Nair ety al., 2009; Khan et al., 2005; Young & Featherstone, 2005; Ferreira et al., 2006; Rockenbach et al., 2008; Senel et al., 2010; Ulusu et al., 2010).

In the current study, the efficacy of reverse contrast and Emboss for detection of proximal caries was evaluated. In the reverse contrast mode, the enamel becomes radiolucent and the carious lesion becomes radiopaque. The Emboss enhancement filter confers a 3D shadow effect to an image. Our results showed no significant difference between Emboss and original digital, reverse contrast and original digital or Emboss and reverse contrast modes with regard to detection accuracy of proximal caries. Studies on the efficacy of enhancement filters for detection of caries are scarce. Castro et al. (Castro et al., 2007) found no significant difference between reverse contrast and original digital mode of CMOS sensors. On a digitally enhanced image with reverse contrast, a carious lesion is seen as a lighter (more opaque) zone surrounded by a dark (lucent) margin; while in an original digital image, a carious lesion is seen as a dark (radiolucent) area with light (opaque) margins. Although the eyes are more sensitive to slight changes in density in dark areas of an image, familiarity of observers with radiolucent appearance of carious lesions on radiographs may cause confusion and decrease the efficacy of reverse contrast mode for the purpose of caries detection (Castro et al., 2007).

Haak et al. (Haak & Wicht, 2005) compared direct digital images captured with CCD sensors with those enhanced with reverse contrast mode and reported no significant difference; which confirms our finding.

Tantanapornkul et al. (Weeraya, 2012). evaluated the efficacy of several digital image enhancement filters for detection of artificially created proximal caries using CCD digital sensors of Gendex, Planmeca and Dr. Suni Plus and reported that for all three imaging systems, the sensitivity of Emboss was lower than that of reverse contrast for detection of caries; but no significant difference was found in this regard between reverse contrast and original digital modes.

Table 3. The A_z values for the original digital mode based on the degree of carious lesion

Scale of caries/ROC curve	Az	Std. error	95% CI Minimum	95% CI Maximum
Absence of caries	0.525	0.060	0.385	0.640
Enamel caries	0.513	0.065	0.360	0.615
Caries at DEJ	0.500	0.060	0.385	0.640
Dentin caries	0.563	0.065	0.385	0.640

Reverse contrast and Emboss filters have also been evaluated in terms of efficacy for other dental applications. Elingsea et al. (Ellingsen et al., 1995). reported higher accuracy of detection of endodontic file tip using D speed films in comparison with digital images enhanced with reverse contrast. Leddy et al. (found no significant difference between conventional radiographs and digital images enhanced with reverse contrast for endodontic file length determination. Scaf et al. (Scaf & Morihisa, 2007) evaluated the efficacy of inverted and unprocessed digitized radiographic images for measurement of periodontal bone loss and found no significant difference. Some other studies also reported no significant difference in the efficacy of digitally enhanced and conventional images for diagnostic purposes (Lee et al., 2004; Baksi, 2008). However, Baksi (Lee et al., 2004). and Akdeniz and Soğur (Akdeniz & Soğur, 2005) reported that digitally enhanced images had higher diagnostic accuracy than the non-enhanced digital images. AzevedoVaz et al. (deAzevedo et al., 2013) assessed the efficacy of Emboss and reverse contrast filters for evaluation of the level of crestal bone around implants. They reported that measurements made after applying the Emboss filter were more accurate but found no significant difference between reverse contrast and original digital images.

In our study, a significant difference was found between observers in their first reading, which may be due to the fact that although digital sensors are widely used, enhancement filters such as Emboss and reverse contrast are rarely used. Weerayaet al, (Weeraya, 2012). also reported that the low sensitivity of Emboss was due to less application of this filter in the clinical setting.

ROC analysis has been suggested by many researchers for assessment of the efficacy of diagnostic tools for detection of dental caries (Khan et al., 2055; Li et al., 2002). Az values provide adequate information regarding the accuracy of diagnostic systems (Mohtavipour et al., 2012). In the current

study, ROC analysis was applied and the Az values for absence of caries and presence of dentin caries were higher than the Az values obtained for enamel caries in images enhanced with reverse contrast and Emboss and also in original digital images; however, this difference was small. Castro et al, (Castro et al., 2007) also reported higher Az values for dentin caries compared to enamel caries, which further confirms that a minimum of 40% demineralization is required in order for the lesion to become radiographically visible (White & Pharoah, 2009; Nair et al., 2001) compared digital images captured with CMOS sensors and conventional radiographs and reported that detection of deep lesions in both systems was easier than superficial lesions. Mohtavipour et al. (Mohtavipour et al., 2012) reported higher Az values for sound teeth and dentin caries compared to enamel caries and lesions at the level of DEJ. In our study, the Az values of enamel caries were the same in original digital and reverse contrast enhanced images. (Shi et al., 2009) also reported no significant difference in Az values of enamel and dentin caries in original digital and enhanced images taken with different digital systems.

Thus, considering the results of the previous studies (Shi et al., 2009; Zangooei et al., 2010) and the current study, it seems that Emboss and reverse contrast filters do not improve the accuracy of digital images obtained by any type of intraoral digital radiography system for detection of proximal caries and the depth of lesion has no significant effect in this regard. But, it should be noted that these filters do not result in loss of diagnostic data either. Considering the scarcity of studies in this regard, further investigations seem to be necessary.

The current study, similar to previous ones on the efficacy of digital enhancement filters for detection of caries (Shi et al., 2009; Zangooei et al., 2010), had an in-vitro design because the gold standard for caries detection is histological analysis which is not possible in vivo (Li et al., 2010). However ,(Li et al., 2010) compared in vitro and in vivo designs for detection of caries using digital radiography. They showed that the Az values on radiographs taken from teeth in vivo and later after their extraction were not significantly different in terms of caries detection accuracy. This indicates that results obtained under such conditions in vitro may be generalized to in-vivo conditions and it may be concluded that the diagnostic accuracy obtained via in vitro studies on proximal caries may be close to the diagnostic accuracy value in the clinical setting. Future studies are required to assess the efficacy of CMOS in comparison with other digital sensors such as PSP plates in this regard.

Conclusion

The diagnostic accuracy of digital images enhanced with Emboss and reverse contrast filters was similar to that of original digital images for both the detection of proximal caries and identification of depth of the lesions. Therefore, the application of these enhancement filters does not increase the efficacy of interproximal caries detection and solely depends on the practitioners' individual preferences.

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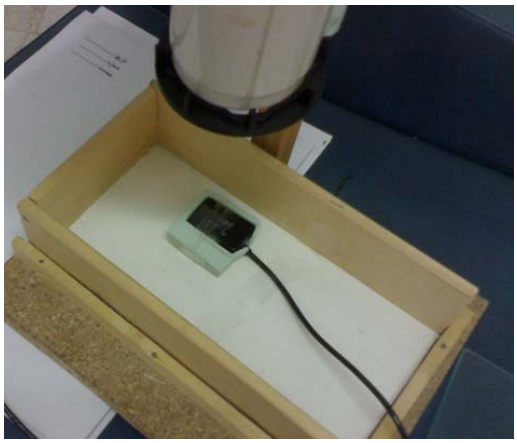

Figure 1: wooden holder used to maintain a fixed position of the teeth and digital sensor

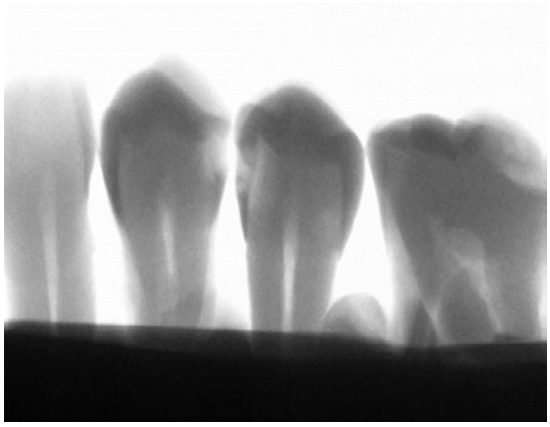

Figure 2a - Application of the reverse contrast filter on the radiographs of the teeth

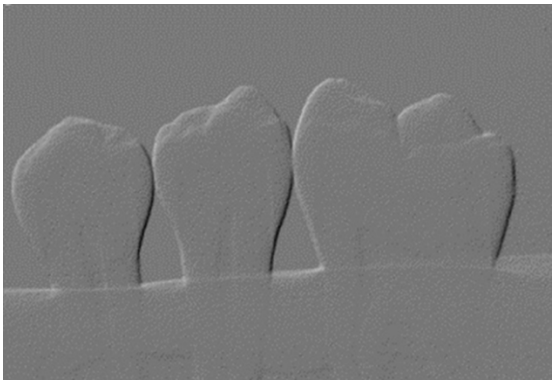

Figure 2b- Application of the Emboss enhancement filter on the radiographs of the teeth

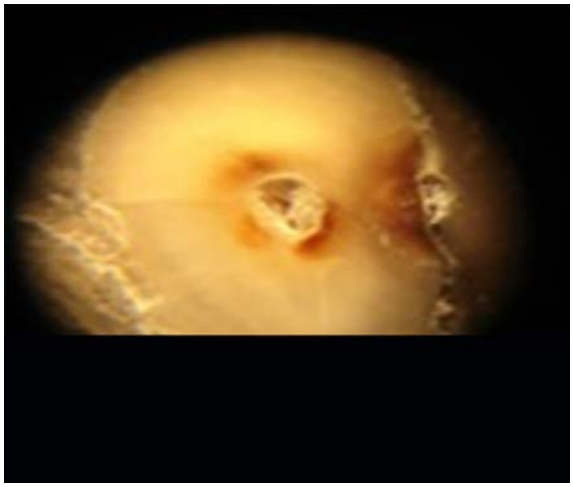

Figure 3: Photomicrograph of a sectioned premolar tooth

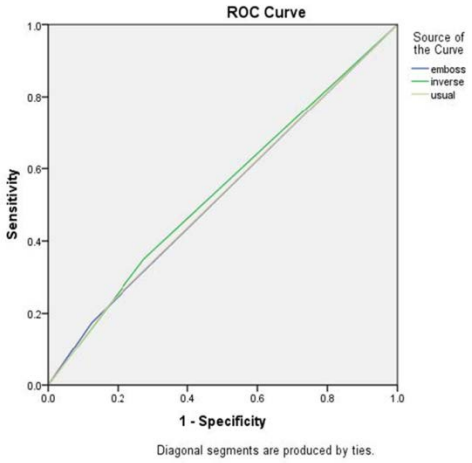

Figure 4: Roc curve for Emboss, reverse contrast and original modes based on the presence or absence of proximal caries