Clin Oral Invest (2011) 15:209–213
DOI 10.1007/s00784-010-0383-0

ORIGINAL ARTICLE

Effect of two X-ray tube voltages on detection of approximal caries in digital radiographs. An in vitro study

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Received: 15 May 2009 / Accepted: 11 January 2010 / Published online: 9 February 2010
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Abstract This study evaluated the effect of two different tube voltages on clinicians' ability to diagnose approximal carious lesions in digital radiographs. One hundred extracted teeth were radiographed twice at two voltage settings, 60 and 70 kV, using a standardized procedure. Seven observers evaluated the radiographs on a standard color monitor pre-calibrated according to DICOM part 14. Evaluations were made at ambient light levels below 50 lx. All observations were analyzed with receiver operating characteristic curves. A histological examination of the teeth served as the criterion standard. A paired *t* test compared the effects of the two voltages. The significance level was set to $p<0.05$. Weighted kappa statistics estimated intra-observer agreement. No significant difference in accuracy of approximal carious lesion diagnosis was found between the two voltage settings. But five observers rated dentin lesions on radiographs exposed at 70 kV better than on radiographs exposed at 60 kV. Intra-observer agreement differed from fair to moderate. There was no significant difference in accuracy of approximal carious lesion diagnosis between digital radiographs exposed with 60 or 70 kV.

Keywords Display monitor · Digital radiography · Dental caries · ROC curve · Kilo voltage

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Introduction

The outcome of dental digital radiographic examinations depends on many factors, such as viewing conditions and technical settings of the equipment. One major task of general practice dentists is evaluation of the number and size of carious lesions. Studies on dental digital radiography and its accuracy in detecting carious lesions have concluded that, to achieve high diagnostic accuracy, it is essential to ensure the quality of the radiographic equipment and ambient viewing conditions [1–9]. Digital detectors have frequently been evaluated, and previous studies have shown that the diagnostic accuracy of digital detectors is neither better nor worse than analogue film [8, 10]. It was suggested [11, 12] that, with analogue (film) techniques, higher tissue penetration of hard tissues such as teeth could be achieved with a higher tube voltage but that image contrast would be lower. This could decrease detectability of carious lesions if differences in image contrast were faint.

Svenson et al. [11] studied the effect of various tube voltages, (50, 60, 70, 80, and 90 kV) on image quality of and caries diagnosis on analogue film. They found that 60 kV produced a radiographic image with an optimal balance between absorbed dose to the patient and diagnostic accuracy.

But no published studies can be found that evaluate how varying voltages influence the diagnosis of carious lesions in digital radiographs. So the aim of this study was to investigate the effect of two voltages on the accuracy of approximal carious lesion diagnosis.

The hypothesis was that detection of approximal carious lesions on digital radiographs exposed at tube voltages of 60 or 70 kV would not differ significantly.

Materials and methods

One hundred human teeth (40 premolars and 60 molars) were visually chosen from a large sample of extracted teeth. Approximal surfaces were intact (50%) or had small carious lesions (50%) of varying sizes. The teeth were mounted in 30 blocks of PRESIDENT putty (Coltène Whaledent AG, Cuyahoga Falls, OH, USA), three or four teeth in each block. Radiographs were acquired in a standardized way [1]. The blocks were radiographed twice using a dental digital system (Schick CDR Wireless 2, Schick Technologies Inc., Long Island City, NY, USA) coupled to a Prostyle Intra X-ray machine (Planmeca Oy, Helsinki, Finland). Exposure settings were 60 kV, 8 mA, and 0.120 s the first time and 70 kV, 8 mA, and 0.10 s the second time [13]. The Monte Carlo program for spectrum calculations was used to establish the exposure time [14, 15]. Distance from the X-ray focus to the object was 22 cm. Figure 1a shows an example of a radiograph exposed at 60 kV and Fig. 1b a radiograph exposed at 70 kV. A 1-cm thick Plexiglas plate was placed in front of the blocks with teeth and the sensor to simulate soft tissue (Fig. 2).

Radiographs were evaluated on a standard 19-inch liquid crystal display monitor that was developed specifically for evaluation of medical radiographs (Olorin Vista Line VL191D BARTEN, Billdal, Sweden). The monitor displayed the radiographs using a built-in Barten [16] curve

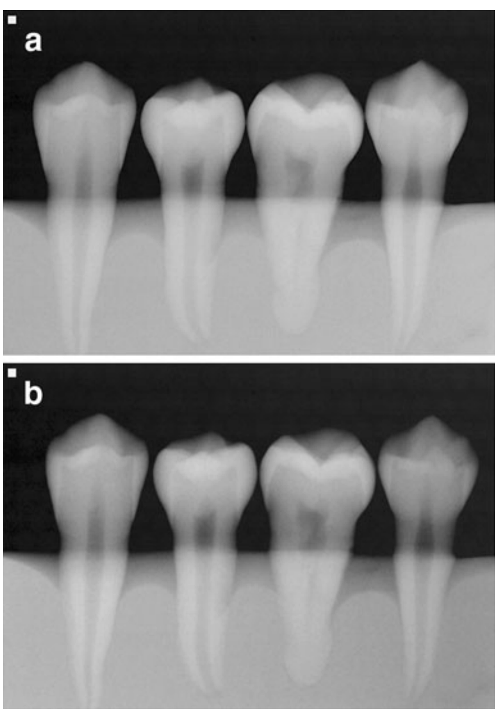

Fig. 1 **a** Radiograph of teeth mounted in a block of PRESIDENT putty (Coltène Whaledent AG, Cuyahoga Falls, OH, USA) and exposed at 60 kV. **b** Radiograph of teeth mounted in a block of PRESIDENT putty (Coltène Whaledent AG, Cuyahoga Falls, OH, USA) and exposed at 70 kV

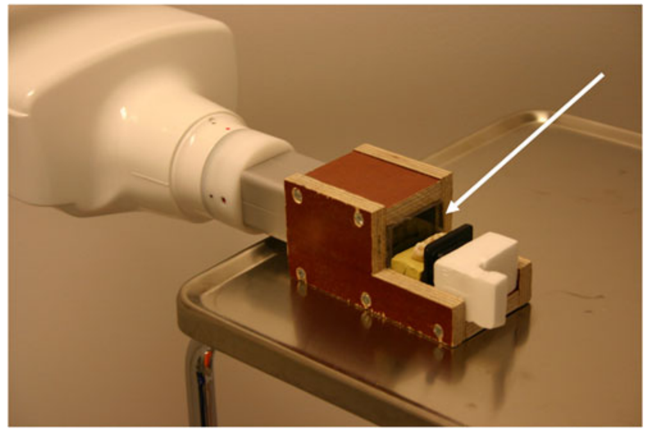

Fig. 2 Device for placing the block of teeth, digital sensor, and rectangular collimator of the X-ray machine in a standardized way. The *arrow* points at the Plexiglas

(DICOM part 14 [17]). Resolution was set to 1,280×1,024 pixels and 32-bit color. A luminance meter (LS-100, Konica-Minolta, Langenhagen [Hanover], Germany) measured display luminance before each evaluation with the TG18-LN12-01, -09, and -18 test images from the American Association of Physicists in Medicine (AAPM) [9] to ensure that evaluations were done at maximum luminance. The graphic card had 256 MB of memory.

The display screen was cleaned with a glass cleaner (Spectra, Nordex, Nilfisk-Advance, Stockholm) before each observation session.

The monitor reached maximum luminance 20 min after it had been switched on. Mean luminance was 135 cd/m^2 (range 132–136 cd/m^2).

Seven observers—one specialist in oral and maxillofacial radiology and six general practice dentists—evaluated the two sets (n=60) of radiographs on one occasion. The radiographs were randomly displayed. Evaluation was made in ambient light below 50 lx [1, 9] (range 43–47 lx) measured with a light meter (Light-O-Meter, P-11, Unfors, Billdal, Sweden). The observers were allowed to magnify the radiographs; no other image processing was allowed. The radiographs were displayed in the same random order for each observer. The observers were asked to rate their level of confidence about the presence of approximal caries, regardless of the depth of the lesion, using a 5-point scale:

1 = definitely not caries;
2 = probably not caries;
3 = questionable caries;
4 = probably caries;
5 = definitely caries.

Intra-observer agreement was determined by asking each observer to re-evaluate all 60 approximal surfaces after an interval of at least 14 days under the same conditions as in the first session.

Each tooth was cut in 1-mm slices with a low speed saw and diamond blade [18, 19] (IsoMet® II-1180 Low Speed Saw and IsoMet®, Diamond Wafering Blade, 4×0.012 [10.2 cm×0.3 mm]; Buehler Ltd; Greenwood, IL, USA). The tooth slices were glued with transparent glue to a microscope slide. Two observers evaluated the teeth separately (the author and a specialist in oral pathology) for caries under a light microscope (magnification ×40). A consensus was reached by evaluating the slides together in cases of disagreement. The tooth surfaces were graded for caries on a scale from 0 to 3 where 0 = sound, no visible lesion; 1 = lesion confined to the enamel; 2 = lesion involving the enamel and enamel–dentin border but not the body of the dentin; and 3 = lesion involving the enamel and undisputedly the body of the dentin. Caries was defined as present when demineralization was observed as opaque-white to dark brown color changes. The results were used as a criterion standard [18].

Statistical analysis

Receiver operating characteristic (ROC) curves [20] were used to analyze all radiographic evaluations. ROCFIT software (Charles Metz, Department of Radiology, University of Chicago, Chicago, IL, USA) calculated the areas under the curves (A_z). Data were pooled before analysis. A paired *t* test [21] compared the effects of the two kilovolt settings. The significance level was set to $p<0.05$. Weighted kappa statistics estimated intra-observer agreement [22]. Values were interpreted per Altman's adaptation [21] of the Landis and Koch [23] guidelines.

Results

The histological examination of the teeth found that 100 surfaces were sound and 100 surfaces had varying depths of carious lesions (Table 1). The two observers disagreed in 31% of the cases. Disagreement was confined to carious lesion grades 0 and 1.

Table 1 Histological evaluation of 200 approximal tooth surfaces

Lesion (grade)	Number of surfaces	Percent
Sound (0)	100	50.0
Enamel caries (1)	75	37.5
Enamel–dentin border (2)	14	7.0
Dentin caries (3)	11	5.5

0 sound, no visible lesion; *1* lesion confined to the enamel; *2* lesion involving the enamel and enamel–dentin border but not the body of the dentin; *3* lesion involving the enamel and undisputedly the body of the dentin

Table 2 Mean areas (A_z) under the receiver operating characteristic (ROC) curves for seven observers

Voltage	A_z (mean)		
	All caries	Dentin	Enamel
60 kV	0.6032	0.6682	0.5482
70 kV	0.5933	0.7110	0.5922

Radiographs were exposed at two voltage settings (60 and 70 kV)

Data were pooled from the seven observers in the ROC curve for each radiograph. Table 2 presents mean areas under the ROC curves for the two voltage settings according to lesion grade. There were no significant differences in diagnostic accuracy between the two voltage settings concerning approximal carious lesions. Compared with the histological results, five observers rated grade 3 dentin lesions more accurately on radiographs exposed at 70 kV than at 60 kV (Table 3).

Weighted kappas for intra-observer agreement were fair for three observers (0.30, 0.36, 0.38) and moderate for four observer (0.43, 0.44, 0.52, 0.54). Mean intra-observer agreement was 85% (range 75–93%).

Discussion

Few data are published concerning effects of different kilovolt setting on properties important in digital intraoral imaging. Kitagawa and Farman [24] studied effects of increased kilovolt on signal-to-noise ratio (SNR) measured in an image of an Aluminum (Al) step wedge. They found, somewhat surprising, that while using the same entrance dose the SNR decreased when the tube voltage was increased from 60 to 70 kV. Even more surprising was their finding that the SNR increased with thickness of the Al absorber. Kaeppler et al. [25] studied effects on local and effective doses of an increased kilovolt for intraoral images. Increasing the kilovolt from 60 to 90 kV had only a marginal effect on both the local absorbed dose and the

Table 3 Areas (A_z) under the receiver operating characteristic (ROC) curves for all observers according to dentin lesions (grade 3)

Observer	A_z (mean)	
	60kV	70kV
1	0.6353	0.6496
2	0.6805	0.6947
3	0.6815	0.7916
4	0.6673	0.7433
5	0.7415	0.7391
6	0.6640	0.6391
7	0.6770	0.7071

Radiographs were exposed at two voltage settings (60 and 70 kV) effective dose, respectively. However, effects on image quality or diagnostic efficacy or accuracy of an increased kilovolt were not evaluated nor discussed. de Almeida et al. [26] studied how five different image quality criteria were perceived when four different brands of digital detectors (sensors as well as storage phosphor plates) were exposed using 60 and 70 kV, respectively. No significant difference was found. The results found by Hayakawa et al. [27] clearly indicated that the low contrast resolution for a CCD sensor decreased when the tube voltage was increased from 60 to 70 kV. However, this finding cannot per se be generalized to a situation involving diagnosis of carious lesions in a clinical situation. In summary, these papers do not support the use of an increased kilovolt for reasons other than diagnostic accuracy.

This study, which is focused on diagnostic accuracy, found no difference between the two voltage settings concerning approximal carious lesions. The display used was calibrated per DICOM part 14, [17] which the AAPM recommends [9]. Ambient light remained below 50 lx per recommendations in the Hellén-Halme et al. study [1] and AAPM [9] guidelines for evaluation of radiographs on a standard monitor. Checks of monitor luminance found that it took some time to reach maximum luminance. This indicates that the monitor must be switched on well in advance of radiograph evaluation and is a factor that should not be neglected. But no studies have been published that investigate whether lower luminance decreases diagnostic accuracy in dental radiography.

One goal of studies like this is to mimic the clinical situation so that general dental practitioners can use the results clinically. For this reason, the dentists were not calibrated in carious lesion diagnosis and X-ray tube voltage was varied in the interval that normally occurs in dental practice (60–70 kV). In this study, tube current was the same for both voltages, but exposure times at 70 kV were lower than at 60 kV. The reduction in exposure time was calculated using a Monte Carlo program for spectrum calculations [12, 13], calculating the input dose to the patient per unit X-ray tube charge. Thus, the radiation dose to the patient would be the same for each exposure. This was considered to be important since any change, if detected, in the image quality therefore could be attributed to the slightly higher light conversion efficiency per photon of the cesium iodide scintillator in the sensor for the 70 kV photons compared to the 60 kV photons. However, no significant difference was found.

Histological evaluation of sliced teeth in millimeter slices or minor sections is well established [18, 19] and is often used for evaluating carious lesions in extracted teeth. The Hintze and Wentzel studies [18, 19] recommend this method as reliable for use as a criterion standard.

Although observer disagreement in this study was rather high, disagreement was limited to cases where a surface was healthy or the enamel lesion was small. These lesions were probably too small to be detectable on a radiograph. Human eyesight aided by a microscope is better at evaluating and diagnosing depths of caries in sliced teeth than human eyesight and a radiograph.

In this sense, the radiographic image is a rather blunt instrument. Mineral loss must be extensive for a carious lesion to be diagnosed in a radiograph. It is also easier to diagnose carious lesions that have extended deeper into the tooth. If dentists were to evaluate digital radiographs only for carious lesions that extended into the dentin, kappas for observer agreement and A_z would increase [28]. None of the teeth in this study had extensive carious lesions that had demolished the tooth. Only 6% of the teeth had carious lesions that extended into the dentin. In Sweden the same frequency of dentin caries was recently found in a young population of patients age 20 or younger [29].

Seven observers, all with several years in the profession, evaluated the radiographs. But while use of many observers is preferred, Swets and Pickett [30] maintain that use of more than seven observers in ROC studies like this adds little to the results. Hintze et al. [31] showed that results were almost unaffected by numbers of observers and evaluated surfaces above a certain level. We chose numbers of tooth surfaces and observers based on these studies [30, 31].

Hellén-Halme et al. [6] and Grondahl [28] evaluated observer performance and reported kappa values for intra-observer agreement similar to the ones in this study.

In conclusion, there is no difference in accuracy of approximal carious lesion diagnosis between digital radiographs made with 60 or 70 kV. But more studies are needed; in particular, sensitivity, contrast, and noise characteristics and their dependence on X-ray tube voltage should be studied further. In the transition from analogue to digital radiographic imaging, this is important since film and sensors may behave quite differently in this respect.

Conflict of interest The author declares that there is no conflict of interest.

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