RESEARCH

Detection of *in vitro* proximal caries in storage phosphor plate radiographs scanned with different resolutions

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Objectives: To investigate the effect of the scanning resolution of storage phosphor plate (SPP) radiographs on the detection of proximal caries lesions.
Methods: 10 dentists evaluated 72 proximal surfaces of premolars with respect to caries from SPP radiographs scanned with theoretical spatial resolutions of: (1) the Digora FMX at 7.8 lp mm^{-1}; (2) the Digora Optime at both 7.8 lp mm^{-1} and 12.5 lp mm^{-1}; and (3) the Dürr VistaScan at 10 lp mm^{-1} and 20 lp mm^{-1}, respectively. The lesions were validated by histological examination. Receiver operating characteristic (ROC) analysis was employed.
Results: The A_z value for the radiographs scanned with the Dürr VistaScan at 10 lp mm^{-1} is significantly lower than those for the other series of radiographs ($P = 0.000$).
Conclusions: For SPP radiographs, an increased theoretical spatial resolution *per se* is not related to an improved detection of proximal caries.
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Introduction

The spatial resolution of a sensor system is one of the parameters used to describe image quality. Two distinct but interrelated effects limit the spatial resolution: sample spacing and sampling aperture size. Should the sample spacing be exactly equal to the sample aperture, a sensor system would reach its maximum spatial resolution.[1] The spatial resolution is often expressed as line pairs per millimeter (lp mm^{-1}). Line pairs per millimeter correspond with the observed number of groups of radiopaque lines and radiolucent spaces in the image of a resolving power target. The value of line pairs per millimeter is sometimes derived from the pixel size; the formula used is lp mm^{-1} = $1/(2 \times$ pixel size). Thus, a digital detector with a pixel size of 50 μm has a spatial resolution of 10 lp mm^{-1} and a detector with a pixel size of 25 μm gives a spatial resolution of 20 lp mm^{-1}, and so on. It should be emphasised, however, that this is a theoretical spatial resolution, because other sensor characteristics such as noise and contrast also influence the visibility of small details in the digital image.

Today, many digital intraoral radiographic systems provide options to acquire radiographs at different spatial resolutions. For a solid-state device such as a charge-coupled device (CCD) detector, a lower resolution is accomplished by combining neighbouring pixels into a new single pixel with a larger size, usually double the size of the original pixels. For storage phosphor plate (SPP) radiographs, on the other hand, the resolution is changed by altering the scanning speed of the image plate in the scanner. The slower the scanning speed, the higher the spatial resolution.

It is often suggested that radiographs with a higher spatial resolution are better for detecting fine radiographic details.[2] Nowadays, phosphor plate scanners are available that give the user a choice between high and low resolution settings during the scanning procedure. SPP images with different theoretical spatial resolutions produced by the same scanner could thus provide more insight to substantiate the suggestion that a higher resolution is connected to a better diagnostic image quality. Therefore, the aim of this study was to

evaluate if SPP radiographs scanned with different theoretical spatial resolutions have an impact on detecting diagnostically relevant features in the digital image. Caries diagnosing is a common task in clinics, thus we used the detection of carious lesions to test this hypothesis in the present study.

Materials and methods

Digital imaging systems

The digital intraoral imaging systems employed in this study were the following SPP systems: Digora® FMX (Soredex, Helsinki, Finland), Digora® Optime (Soredex) and Dürr VistaScan® (Dürr Dental GmbH, Bietigheim-Bissingen, Germany). Details about the active area of an SPP, pixel size, spatial resolution and image size for each imaging system are shown in Table 1.

Teeth

90 human permanent premolars extracted from young adolescents in the course of orthodontic treatment were included. The teeth were mounted in plaster blocks in groups of five. The most prominent parts of the proximal surfaces were put at the same vertical level to simulate their normal anatomical positions. In total, 18 plaster blocks of teeth were constructed.

Test radiographs

The proprietary image plates were employed to expose radiographs for each imaging system. Exposures were made with a Heliodent MD (Siemens GmbH, Bensheim, Germany) DC X-ray unit for all SPP images. The exposure settings were 60.0 kVcp, 7.0 mA and 0.16 s. The operating distance between SPPs and focus was 35.0 cm. To mimic a bitewing radiograph, two tooth blocks in occlusion were exposed along with a 2.0 cm thick water phantom to simulate soft tissue. For reproducibility, the blocks were placed in a specially designed holder that enabled standard projection geometry (Figure 1).

The SPPs were then scanned immediately after exposure with the Digora® FMX scanner employing the proprietary software DfW v2.5, the Digora® Optime employing the proprietary software DfW v2.5 and the Dürr VistaScan® using the proprietary software

Figure 1 Schematic of the geometry for exposing test radiographs. SPP, storage phosphor plate

DBSWin v3.3, respectively. The selected scanning resolutions for each system are shown in Table 1. The raw-data images were subsequently processed with the proprietary default processing algorithm of each system and saved as 8-bit images. Thus, a total of 45 radiographs were created.

Viewing

Ten dentists experienced in caries diagnosis evaluated all test radiographs with respect to carious lesions. The radiographs were displayed on a NEC MultiSync LCD 1880SX monitor (NEC Inc., Tokyo, Japan). The screen resolution was 1600×1200 and the display ratio was 1:1. Prior to viewing, brightness and contrast of the monitor were calibrated by one of the investigators using the SMPTE test pattern that is included in the Emago® v4.0 software (Oral Diagnostic Systems, Amsterdam, The Netherlands). Additional adjustment of brightness and contrast of the displayed image by the observer was not allowed. To display the radiographs serially, the ACDSee v3.0 (ACD Systems International Inc., British Columbia, Canada) software package was employed. The order in which the radiographs were presented was individually randomized for each observer. The viewing sessions took place in a room with dimmed light and one image was displayed at a time.

Table 1 Technical characteristics of each storage phosphor plate imaging system

	Active area (mm²)	Pixel size (μm)	Calculated spatial resolution (lp mm⁻¹)	Image size (pixels)
Digora® FMX	30×40	64×64	7.8	466×628
Digora® Optime				
High resolution	31×41	64×64	7.8	462×624
Super resolution	31×41	40×40	12.5	740×1008
VistaScan				
Standard resolution	30×40	50×50	10	620×806
Fine resolution	30×40	25×25	20	1238×1616

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Table 2 Areas under receiver operating characteristic curve (A_z) from each observer

Observer	Digora FMX (7.8 lp mm^{-1})	Digora Optime (7.8 lp mm^{-1})	Digora Optime (12.5 lp mm^{-1})	VistaScan (10 lp mm^{-1})	VistaScan (20 lp mm^{-1})
1	0.619	0.752	0.709	0.606	0.720
2	0.733	0.746	0.730	0.644	0.711
3	0.750	0.783	0.711	0.555	0.745
4	0.729	0.780	0.805	0.612	0.583
5	0.646	0.741	0.670	0.629	0.667
6	0.738	0.670	0.738	0.511	0.666
7	0.676	0.698	0.711	0.536	0.721
8	0.695	0.705	0.771	0.600	0.765
9	0.729	0.779	0.771	0.641	0.754
10	0.767	0.763	0.787	0.656	0.831
Mean	0.708	0.742	0.740	0.599	0.716
SD	0.048	0.039	0.042	0.049	0.067

SD, standard deviation

Only the right proximal surface of each tooth coronal to the cementoenamel junction (CEJ) was included in this study. This was done intentionally to avoid the psychological effect that the assessment of one proximal surface could possibly bias the assessment of the neighbouring surface. To exclude the suggestion of a caries lesion by the black background, the extreme right-hand teeth in each radiograph were also excluded from evaluation. Thus, a total of 72 surfaces were observed for each series of radiographs.

Observers were asked to record their level of confidence about the presence or absence of carious lesions with the following five-point scale: 1 = definitely no caries; 2 = probably no caries; 3 = questionable; 4 = probably caries; 5 = definitely caries. No information about the number of carious lesions was given to the observers.

Histological validation
When all radiographs had been made, the teeth were cut into 300 μm thick slices and examined with a $10 \times$ magnifying stereomicroscope Stemi SV6 (Carl Zeiss Microscopy, Jena, Germany) by two investigators, together with an expert in cariology. The lesions were defined by the extension of a whitish decalcified zone or a brown zone extending in the direction of the proximal pulp chamber. The following four-point scale was used for histological categorization: 0 = sound; 1 = enamel caries; 2 = caries reaching but not crossing the enamel-dentine junction (EDJ); 3 = caries into dentine.

ROC analysis
With the histological examination as the reference, each observer performance was subsequently converted into a receiver operating characteristic (ROC) curve[3] with the program ROCKIT 0.9B, Beta version (University of Chicago, Chicago, IL). The maximum likelihood parameters were determined and the area under each ROC curve (A_z) was calculated.

Statistical analysis
Repeated-measures ANOVA was employed to analyse A_z values from each observer and interobserver variance, with $\alpha = 0.05$.

Results

Histological examination revealed that of the 72 proximal surfaces, 12 were sound, 19 showed enamel caries, 5 had caries reaching the EDJ and 36 had dentine caries.

Table 2 shows the area under ROC curve from each observer. The A_z values for radiographs scanned with the Digora® Optime at both resolutions were larger than others. The mean A_z value for the Dürr VistaScan radiographs scanned at 10 lp mm^{-1} was low and just above 0.5, a value indicating that decision-making was random. Generally, the standard deviation of the A_z values was large for radiographs scanned with the Dürr VistaScan® at 20 lp mm^{-1}, which indicates a low interobserver agreement. ROC curves (Figure 2) represent combined data from the ten observers.

Statistical analysis for pair-wise comparison of observer performance from each SPP imaging system is shown in Table 3. Significant differences were found
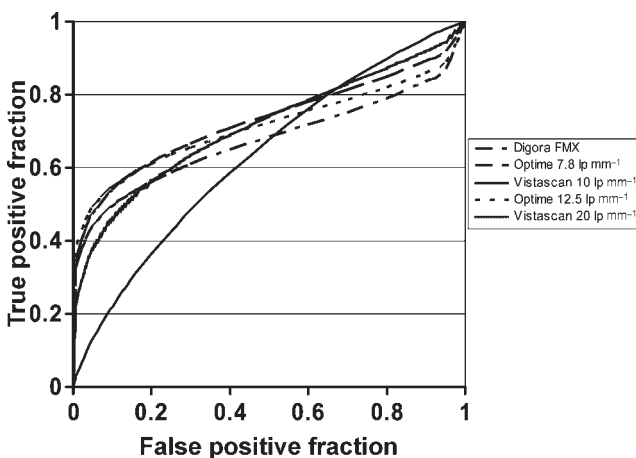

Figure 2 Receiver operating characteristic curves from combined observer performance

Table 3 *P*-values for observer performance from each storage phosphor plate imaging system

	Digora Optime (7.8 lp mm^{-1})	Digora Optime (12.5 lp mm^{-1})	VistaScan (10 lp mm^{-1})	VistaScan (20 lp mm^{-1})
Digora FMX (7.8 lp mm^{-1})	0.058	0.02*	0.00*	0.708
Digora Optime (7.8 lp mm^{-1})	–	0.924	0.00*	0.265
Digora Optime (12.5 lp mm^{-1})		–	0.00*	0.299
VistaScan (10 lp mm^{-1})			–	0.00*

*Denotes significant difference

between A_z values for radiographs scanned at 10 lp mm^{-1} with the Dürr VistanScan® and for radiographs scanned at 20 lp mm^{-1}, scanned with the Digora® FMX and the Digora® Optime at both resolutions ($P = 0.000$).

There is no significant difference between observers for detecting proximal caries ($P = 0.747$).

Discussion

Spatial resolution is one of the parameters that are employed to describe image quality. It is suggested that the higher the number of the spatial resolution, the smaller the radiographic details that can be observed. To our knowledge, there has been no study exclusively reporting the effect of different spatial resolutions from one imaging sensor system on the detection of caries lesions. The present study shows that no significant differences were found between A_z values for radiographs scanned with the Digora FMX, the Digora Optime at both resolutions of 7.8 lp mm^{-1} and 12.5 lp mm^{-1}, and the VistaScan at 20 lp mm^{-1}. This is in agreement with the result of a recent study about digitization of conventional films indicating that the highest digital camera resolution is not necessary to achieve high diagnostic accuracy for proximal caries detection.[4]

Although there are studies assessing the diagnostic accuracy of several digital imaging systems with respect to carious lesions, root canal length, periapical bony lesions and to the position of endodontic files,[5–13] these reports cannot be considered as a comparison of the effect of theoretical spatial resolution on the diagnostic accuracy. Physical properties of a detector, such as dose–response function, modulation transfer function (MTF), detective quantum efficiency (DQE), signal-to-noise ratio (SNR) etc., play a more important role than merely the pixel size in determining the sensor quality. Therefore, a digital detector having a high theoretical spatial resolution does not necessarily show more detective information than a detector with a low theoretical spatial resolution. This may explain why the radiographs scanned at 20 lp mm^{-1} with the Dürr VistaScan® imaging system did not show any benefit in detecting proximal caries in the present study. On the other hand, a theoretical spatial resolution is not always a true representation of the actual spatial resolution of a sensor system.[14]

Another effective factor for detecting image details of an exposed object is the human visual system. For a human observer with normal vision, the perceptible grey levels are, in fact, no more than about 100. This implies that even if an image detector with a high spatial resolution could record more details with small contrasts, the human visual system has no ability to differentiate them from one another. Meanwhile, an artefact could be suggested in such a radiograph. This is known as the vicinity law in perception psychology, which implies that the closer together the image elements, the easier it is to experience these elements as a combined object. Similar results are reported by Zeller.[15]

This study was performed with the radiographs exposed at the same exposure time of 0.16 s in spite of the different scanning resolutions employed. This may have had an effect on the detection of proximal caries since, in theory, an increasing spatial resolution results in a poor signal-to-noise ratio and therefore needs a proportionately increased exposing dose in trying to keep the same image quality obtained at a low spatial resolution. However, for SPP radiographs it is hard to find an optimum exposure because of the wide dynamic range and the automatic exposure control of a SPP imaging system. Even an extremely overexposed SPP radiograph can show a good subjective quality without any apparant loss of image characteristics.[16] To keep the principle of ALARA (as low as reasonably achievable) for patient dose in mind, we employed only one exposure time at which an acceptable subjective image quality was obtained for all radiographs in the present study.

Digora® Optime is the next generation of the Digora® FMX. According to the manufacturer, new image storage phosphor plates have been introduced together with the Digora® Optime. This is shown indirectly by the present study where A_z values for Digora® Optime radiographs are larger than those for radiographs obtained with Digora® FMX.

For the imaging system Dürr VistaScan®, the spatial resolution of 10 lp mm^{-1} was supposed to be the standard resolution. However, the present study reveals that detection accuracy of proximal caries in radiographs scanned at such a standard resolution was just above chance and significantly lower than the detection accuracy for the radiographs scanned at 20 lp mm^{-1} and those obtained with Digora® systems. This suggests that for detection of proximal caries 20 lp mm^{-1} should be the standard spatial resolution for the Dürr

VistaScan imaging system. Meanwhile, the VistaScan at 20 lp mm^{-1} did not perform as well as the Digora Optime, which has much lower theoretical spatial resolutions, although this difference was not significant. Considering the above, we conclude that for SPP radiographs an increased theoretical spatial resolution *per se* is not related to an improved detection of proximal caries.

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