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ORIGINAL ARTICLE

A comprehensive in vitro study of image accuracy and quality for periodontal diagnosis. Part 2: The influence of intra-oral image receptor on periodontal measurements

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Abstract The aim of the study was to determine the image receptors' influence on exposure levels, image accuracy, and quality for periodontal diagnosis. Periodontal defects from cadaver specimens were imaged using two intra-oral conventional films (E-, F/E-speed), four indirect receptors (Digora 8 bit, Vistascan 12 bit with/without filter, Vistascan 16 bit), and two solid-state sensors (Sigma 12 bit, VistaRay 14 bit) at rising exposure (20–160 ms). Three observers assessed the standardized radiographs for alveolar bone measurements (1,732, 31 sites) and for subjective rating of lamina dura, contrast, trabecularization, crater, and furcation involvements. The measurements were compared to the gold standard. For the imaging plates, highest measurement accuracy was found with Vistascan 16 bit (100% within 0.5 mm) and for solid-state sensors with VistaRay 14 bit (100%, 0.5 mm), although the latter are mostly not significantly different. Higher contrast resolution imaging plates require up to 50% less exposure time, but for solid-state sensors, the dose remains unchanged. For the latter, a higher bit depth does seem to provide more accurate depiction of the alveolar crest, counteracting blooming artifacts. The use of a dedicated periodontal filter contributes to higher accuracy at all exposure times ($p<0.05$–0.0001). Accuracy of periodontal diagnosis increases with higher contrast resolution. Digital exposure levels are thus dependent of image receptor as well as X-ray generator.

Keywords Digital image receptor · Contrast resolution · Exposure time · Intra-oral radiography · Periodontal bone height

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Introduction

Many laboratory studies have investigated the physical properties of digital sensors compared to film and described dose savings when using the digital ones [1–3]. Although these tests are very adequate for comparing inherent characteristics of a digital receptor [4–6], they cannot simulate the clinical situation given the diversity in diagnostic tasks of oral diseases. For instance, the spatial resolution of an image receptor may be of importance for the detection of fine endodontic instruments [7], while it may not influence the detection of small carious lesions [8]. It is therefore important to investigate the properties of digital sensors in a clinical simulation or environment for specific diagnostic tasks. In addition, the radiographic chain has many more variables, which should also be included in such investigations.

The two main variables in this chain are the X-ray generator and image receptor. In our previous report, the influence of X-ray generators (producing different waveforms) on periodontal measurement accuracy has been demonstrated using various receptors [9]. However, no distinction between the latter was made except for their main categorization: conventional film, photostimulable storage phosphor (PSP) plates and charged-coupled device (CCD) sensors. These three groups have different inherent properties like sensitivity and dynamic range, which directly influence image quality and the associated required exposure time [9–12]. Nevertheless, besides these major variables, other physical properties of digital receptors and not to forget the opportunity of image enhancement need also to be taken into account when establishing proper clinical protocols. While the receptor's spatial resolution (expressed in line pairs per millimeter (lp/mm)) reflects the ability to discern small details in a radiographic image, its contrast resolution (expressed in bit depth) reflects the amount of gray values that can be imaged (grayscale range), and both are important variables of the final image quality [13]. Although most digital sensors have been found to perform well in terms of spatial and contrast resolution [5], there is a discrepancy between older and newer technology where the latter now reach up to 20 lp/mm (pixel sizes as small as 20 μm) or 16 bit (2^{16}= 65.536 shades of gray) contrast resolution. These differences may influence the diagnostic image quality of intra-oral radiographs [6–8, 14]. For periodontal bone level measurements, adequate contrast may thus be crucial for accurate visualization of the alveolar crest, which can easily be deteriorated by blooming artifacts [9–11]. Furthermore, contrast resolution can often be limited not only by the resolution of the display screen and by ambient light [15] but also by the perception ability of the human eye [16].

In our previous report [9], we demonstrated the differences in exposure time needed when using various receptor types, with up to 50% dose savings when using CCD sensors compared to PSP. Most studies on periodontal diagnosis unfortunately do not take into account the influence on exposure range [17–23] or make use of older generators [19, 24]. In addition, only few studies have described the clinical accuracy of different sensor resolutions and their individual influence on exposure time. One in vitro study from Borg et al. [25] investigated marginal bone loss with a PSP and CCD sensor at a wide exposure range, but it did not describe different sensor resolutions and in addition, a high exposure range was used. Another study from Wenzel et al. [8] described the possible influence of contrast resolution on exposure time but for the detection of small carious lesions. Since for periodontal diagnosis no studies could be found researching this impact, the main aim of this report was to determine the influence of various image receptors on exposure parameters for the visualization of local bone height and for subjective rating of the image quality for periodontal evaluation.

Materials and methods

Periodontal analysis consisted of two main radiographic assessments. Measuring alveolar bone levels of an adult human dry skull and an upper and lower cadaver jaw was the first assessment, while the second one was the subjective evaluation of periodontal landmarks/symptoms including lamina dura delineation, trabecular pattern depiction, crater, and furcation involvement visibility and in addition the evaluation of radiographic contrast.

The maxillary and mandibular bony plates of the dry skull were covered with Mix D [26], a solid synthetic material with similar attenuation and absorption properties as muscle and water, in order to simulate the soft tissues. Mix D, mostly containing paraffin wax and polyethylene, was heated at 180°C for plastic modeling over the jaw bones. Radiopaque gutta percha fragments were glued onto the buccal and oral crown surfaces in order to obtain standardized fiducials for alveolar bone level measurements since the cemento-enamel junctions (CEJs) were faded by dehydration. A central indentation in the fragment allowed not only mesial and distal bone level measurements but also central measurements on both buccal and oral sides. For the cadaver jaws, soft tissues and CEJs were preserved by fixing the specimens in a formalin solution. The cadavers were obtained with permission and ethical approval from the Department of Anatomy at the Catholic University of Leuven, Belgium. Upper and lower incisor and premolar and molar regions were imaged giving a total of 12 regions. The gold standard (GS) of the measurements was obtained by physical measurements of two observers using a digital caliper (Mitutoyo, Andover, UK) with accuracy to the nearest 0.01 mm, prior to Mix D modeling for the dry skull and after radiographic exposures and flap surgery of the cadavers (a more detailed description can be found in our previous report). Of the 72 gold standard measurements, 31 sites, including linear bone loss and angular or infrabony defects, were selected for the assessments, excluding most missing sites on radiographs.

For the intra-oral radiographic protocol, standardized rigid occlusal keys were fabricated by melting green stent over bite-blocks of aiming devices (XCP, RINN Corporation, Elgin, IL, USA), thus obtaining individualized teeth imprints for correct repositioning of the X-ray tube. The paralleling technique was used for radiographic exposure of conventional films and digital image receptors. For this setup, only two types of X-ray generators were further considered (of the three in our previous report) corresponding to low and high frequency X-ray generation, namely the alternating current (AC) IRIX 70 tube (Trophy Radiologie, Marne-La-Vallée, France) and the direct current (DC) Minray tube (Soredex, Tuusula, Finland), both with 30-cm focal-film distance and rectangular collimation.

Exposure settings were 70 kVp and 7 or 8 mA s (DC and AC type, respectively) and an exposure time range of 0.020, 0.040, 0.060, 0.080, 0.120, and 0.160 s for Film or PSP and 0.020 or 0.040, 0.060, and 0.080 s for CCD. In addition to the radiographic assessments, the skin doses (in μGy) for all X-ray tubes were also measured using a Barracuda multimeter (RTI Electronics AB, Mölndal, Sweden) with a solid-state dose detector (R100 dose probe) to evaluate the threshold levels where diagnostic accuracy might be insufficient (cfr previous report).

Image receptors: conventional film, PSP, and CCD

To test the influence of image receptor and its specific properties (contrast resolution), peri-apical radiographs of the subjects (12) were taken at the various exposure times with seven different image receptors using the standardized setup (see Table 1). The conventional films used in this study were Agfa Dentus M2 Comfort E-speed film (Heraeus Kulzer GmbH, Dormagen, Germany) and Kodak Insight F/E-speed film (Carestream Health, Rochester, NY, USA). The indirect digital PSP systems were Digora Optime (Soredex, Tuusula, Finland), Vistascan (12 bit), and Vistascan Perio (16 bit) (Dürr Dental GmbH, Bietigheim-Bissingen, Germany). For the Vistascan 12 bit, both original and images with a dedicated periodontal filter were included for analysis. The direct digital CCD sensors were Sigma (Instrumentarium Dental, Tuusula, Finland) and VistaRay (Dürr Dental GmbH). Conventional films were processed using an automatic film processor (XR24 Nova, Dürr Dental) with Dürr Chemistry (Röntgen Spezial-Set fur Dürr Automat XR24). Two examples of the radiographic setup are given in Figs. 1 and 2: the four PSP configurations (Fig. 1) and the two CCD (Fig. 2) systems exposed at increasing exposure time using the DC unit.

Radiographic assessments: measurement accuracy and subjective evaluation

The intra-oral radiographs from all possible X-ray tube, image receptor, and exposure time combinations were evaluated by three calibrated observers, which specialized in oral imaging, during several sessions with 2-day intervals in the same darkened room to prevent ambient light influence. Conventional films were placed in film mounts (coded random order) to minimize surrounding light and were analyzed with countertop illuminators (Universal Viewer 6 in.×12 in. 240 V with magnifier, Dentsply International, York, PA, USA). The digital radiographs were all exported in tagged image file format for observer assessment without loss of information. The blinded digital radiographs were imported into the Emago advanced, V.3.5.2. software (Oral Diagnostic Systems, Amsterdam, The Netherlands) and displayed in the same darkened room in a random order on three standardized notebooks with 17-in. TFT-based LCD monitors (contrast ratio 750:1) having anti-reflective layers, same screen resolution (1,440×900 pixels) and contrast and brightness levels.

For the alveolar bone level measurements, 31 periodontal sites were measured per image receptor and X-ray tube combination at every single exposure time. The observers measured the CEJ to alveolar bone distance using the measurement tools of the Emago advanced software or for the conventional films, using a digital sliding caliper (Mitutoyo, Andover, UK), both at accuracy to the nearest 0.1 mm. These could then be compared to the gold standard.

For the subjective evaluations, delineation of lamina dura, crater visibility, furcation involvement visibility, depiction of trabecular bone, and radiographic contrast were categorized with an ordinal scale, ranging from 0 to 3 (0=not possible to evaluate the criterion, 1=bad, 2=medium, and 3=good).

Table 1 Overview of image receptors used in this study and the number of periodontal bone level measurements made by each observer for each combination with exposure level

Receptor	Type	X-ray tube		20ms	40ms	60ms	80ms	120ms	160ms	Total
Dentus M2	E-speed film	AC	70 kV	29	29	29	29	29	29	174
Insight	FE-speed film	AC	70 kV	29	29	29	29	29	29	174
Vistascan[a]	12-bit PSP	AC, DC	70 kV	31+62	31+62	31+62	31+62	31+62	31+62	558
Vistascan perio	16-bit PSP	DC	70 kV	31	31	31	31	31	31	186
Digora Optime	8-bit PSP	AC, DC	70 kV	31+31	31+31	31+31	31+31	31+31	31+31	372
Sigma	12-bit CCD	AC, DC	70 kV	27+27	27+27	27+27	27+27	0	0	216
VistaRay	14-bit CCD	DC	70 kV	13	13	13	13	0	0	52
Total				311	89	311	311	244	244	1,732

Differences between combinations are due to missing landmarks on certain radiographs. A total of 1,732 measurements were done by each observer

[a] Images were saved and assessed both in original format and after application of a dedicated periodontal filter (for DC only)

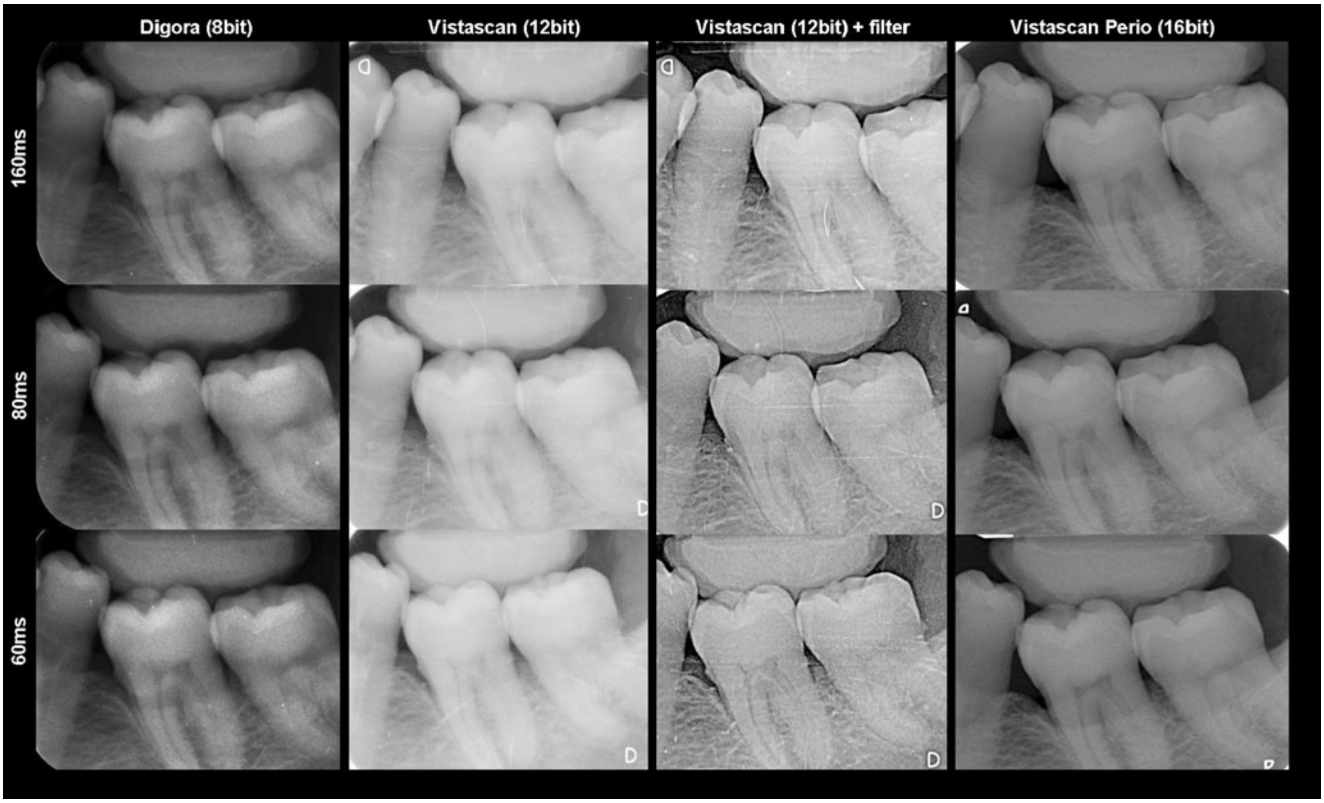


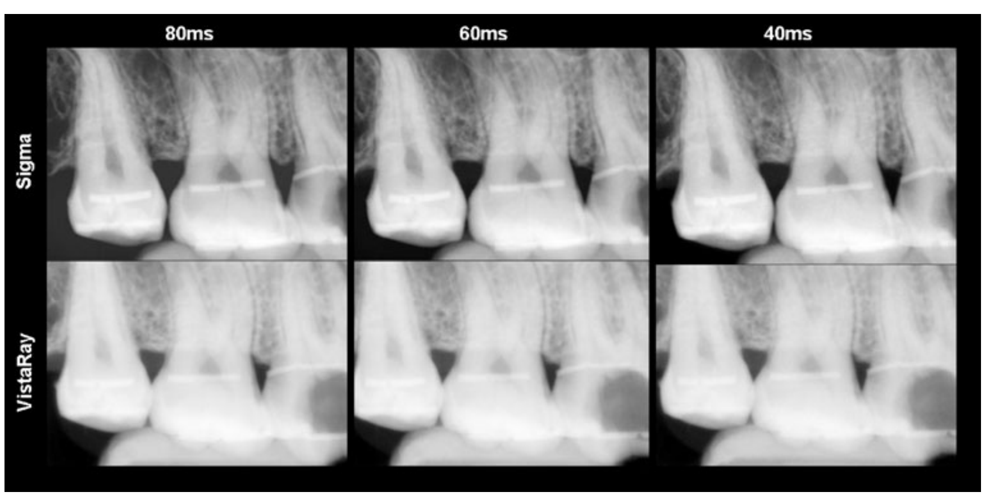
Fig. 1 Standardized PSP radiographs of the cadaver left lower molar region at various exposure times. Digora 8 bit, Vistascan 12 bit with and without a dedicated periodontal filter, and the Vistascan 16 bit were the four PSP groups compared

Statistical methodology

Table 1 gives an overview of the number of measurements per combination of image receptor–X-ray tube and exposure time used in this report. For the conventional AC unit, five groups (two film types, two PSP types, and one CCD sensor) were included in the analysis. For the more modern DC tube, four groups were distinguished for PSP and two for CCD. The subjective ratings consisted of only one measurement or rating per skull for each receptor–tube combination and exposure level.

For accuracy (absolute distance from the GS), comparisons between groups were made at specific mA s levels separately in the main analysis (cfr previous report), cast into a survival analysis framework. In addition, a Cox regression model was used when exposure levels were common to the compared groups. Interaction between both was verified to determine if the differences between groups depended on exposure level.

Fig. 2 Standardized CCD radiographs of the right upper molar area from the dry skull (with gutta percha fragments as fiducials) at decreasing exposure times. The Sigma CCD 12 bit sensor and the VistaRay 14 bit CCD were the two groups included in the analysis



For the subjective measurements, non-parametric tests were used given the lower number of measurements compared to the accuracy analysis. However, the Kruskal–Wallis test followed by the Mann–Whitney for pair-wise comparisons did not take into account the clustered structure of the data, and p values therefore should be interpreted carefully.

In all analyses, p values smaller than 0.05 for accuracy and 0.01 for subjective ratings are considered significant. All analyses have been performed using SAS software, version 9.2 of the SAS System for Windows [27].

Results

Measurement accuracy

Digital receptors

Comparison between the PSP receptors (Digora 8 bit, Vistascan 12 bit without and with periodontal filter, Vistascan 16 bit) and CCD sensors (Sigma 12 bit and VistaRay 14 bit) revealed differences in accuracy depending on the exposure level (p=0.0003). As such, statements about differences between groups should take into account the exposure level. Figure 3 represents the percentage accuracy (percentage of measurements, y-axis) for deviations from the GS (x-axis) for the six groups at various exposure levels. The faster the curve increases, the higher the accuracy. Hence, the lowest accuracy was perceived for the Digora 8 bit, which was significant with almost every group at almost every exposure level, but the strength was more outspoken at lower exposure levels. Table 2 summarizes the significant differences at the different exposure levels.

For the PSP receptors, when restricting attention to ms> 20 and ignoring possible interaction between exposure and group, there was still a significant difference in accuracy between the groups:

– The accuracy of Digora 8 bit was significantly lower than for the three other groups (p<0.0001 compared to Vistascan 12 bit with filter and Vistascan 16 bit, p< 0.05 compared to Vistascan 12 bit).
– The accuracy for Vistascan 12 bit was significantly lower than Vistascan 12 bit with filter (p<0.0001) and Vistascan 16 bit (p<0.01).
– There was no significant difference between Vistascan 12 bit with filter and Vistascan 16 bit (p>0.05).

For the CCD sensors, when ignoring the interaction between exposure time and receptor groups, there was a significant difference between both groups with the highest accuracy for VistaRay CCD 14 bit compared to Sigma 12 bit CCD (p<0.01).

Dosimetric threshold values

The mA s levels of the six groups were associated to their respective skin doses and plotted against their median accuracy (Fig. 4). The results from our previous report were confirmed where accuracy increased for all PSP receptors at rising exposure times and remained constant for the CCD sensors. Table 3 shows the dosimetric threshold values at which measurement accuracy was within 0.5- and 1-mm deviation from the GS. For PSP, a 50% dose reduction could be estimated when using the PSPs with a dynamic range of 12 bit or higher for periodontal bone level measurements at maximum 1-mm deviation. When considering a 0.5-mm deviation as the maximal error margin, the same was true when using Vistascan 12 bit+filter or higher. For CCD, no immediate dose savings could be estimated given the high accuracy at very low exposure times.

Digital receptors vs film (AC tube)

The above results are confirmed when using an AC X-ray tube (see Fig. 5), although the possible dose savings seemed slightly larger than with the DC tube. Table 4 shows between 48% and 78% dose reduction estimates when using Vistascan 12 bit compared to Digora 8 bit and 79–88% when using the 12 bit CCD sensor compared to film or PSP. The threshold skin doses for periodontal bone level measurements using the two films were equal to the ones of the 8 bit PSP system (see Fig. 6). More detailed results on the effect of X-ray tube can be found in our previous report.

Subjective quality evaluation

The mean scores for the PSP and CCD groups are plotted by exposure time for each subjective criterion in Fig. 6. The p values of the Kruskal–Wallis tests per observer for each rating are given in Table 4. For CCD, no significant differences were observed for the different sensors. For PSP however, irrespective the type of rating and observer, the lowest score was systematically given to Vistascan 12 bit without filter (mostly significant with the other groups when using Mann–Whitney) and the highest to Vistascan 16 bit (mostly not significant).

When considering a minimum ordinal score of 2 (=medium visibility) for all variables, estimated dose reductions were comparable to the ones with the bone level measurements (Table 5).

Discussion

For the PSP systems, when ignoring exposure time and investigating the full exposure range between 20 and

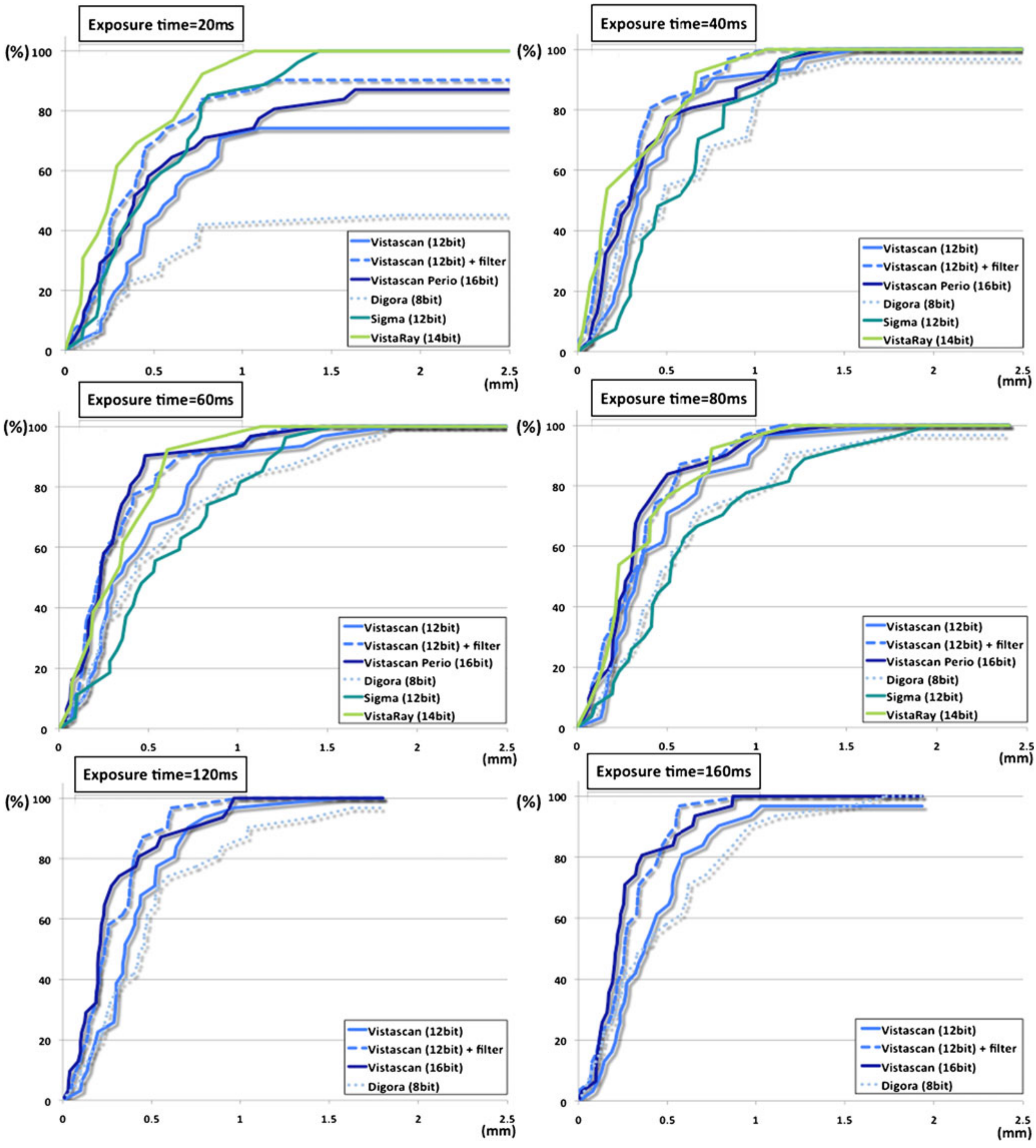


Fig. 3 Graphic representation of the survival analysis framework: The four PSP groups and two CCD groups were plotted by the distance from the gold standard (*x*-axis) and the percentage of bone level measurements within these deviations (*y*-axis). The faster the curve increases for a certain group, the higher the accuracy

160 ms, significant differences were found between the four PSP types namely Digora 8 bit, Vistascan 12 bit, Vistascan 12 bit+filter, and Vistascan 16 bit. When considering exposure time as a contributing factor, significant differences were still found (see Table 2) where the highest accuracy was perceived for Vistascan 12 bit+filter and Vistascan 16 bit. Therefore, when plotting the results by the actual skin dose (see Table 3 and Fig. 5), a 50% lower dose could be estimated when using Vistascan 12 bit+filter or Vistascan 16 bit for a measurement error within 0.5-mm

Table 2 Results of the survival analysis framework with Cox regression

Receptor	Group	Exposure time					
		20ms	40ms	60ms	80ms	120ms	160ms
PSP	Vistascan 12 bit vs Digora 8 bit	*p<0.01*	p>0.05	p>0.05	*p<0.05*	*p<0.05*	p>0.05
	Vistascan 16 bit vs Digora 8 bit	*p<0.0001*	*p<0.01*	*p<0.01*	*p<0.001*	*p<0.0001*	*p<0.001*
	Vistascan 16 bit vs Vistascan 12 bit	p>0.05	p>0.05	*p<0.05*	p>0.05	*p<0.01*	*p<0.01*
	Vistascan 12 bit+filter vs Vistascan 12 bit	*p<0.001*	*p<0.05*	*p<0.001*	*p<0.05*	*p<0.01*	*p<0.0001*
	Vistascan 12 bit+filter vs Digora 8 bit	*p<0.0001*	*p<0.0001*	*p<0.001*	*p<0.0001*	*p<0.0001*	*p<0.001*
	Vistascan 12 bit+filter vs Vistascan 16 bit	p>0.05	p>0.05	p>0.05	p>0.05	p>0.05	p>0.05
CCD	VistaRay 14 bit vs Sigma 12 bit	p>0.05	*p<0.05*	*p<0.05*	p>0.05	x	x
PSP vs CCD	Digora 8 bit vs Sigma 12 bit	*p<0.0001**	p>0.05	p>0.05	p>0.05	x	x
	Digora 8 bit vs VistaRay 14 bit	*p<0.0001**	*p<0.05**	*p<0.05**	p>0.05	x	x
	Vistascan 12 bit vs Sigma 12 bit	*p<0.05**	p>0.05	p>0.05	p>0.05	x	x
	Vistascan 12 bit vs VistaRay 14 bit	*p<0.01**	p>0.05	p>0.05	p>0.05	x	x
	Vistascan 12 bit+filter vs Sigma 12 bit	p>0.05	*p<0.001*	*p<0.01*	*p<0.01*	x	x
	Vistascan 12 bit+filter vs VistaRay 14 bit	p>0.05	p>0.05	p>0.05	p>0.05	x	x
	Vistascan 16 bit vs Sigma 12 bit	p>0.05	p>0.05	*p<0.01*	*p<0.01*	x	x
	Vistascan 16 bit vs VistaRay 14 bit	p>0.05	p>0.05	p>0.05	p>0.05	x	x

The model compares the accuracy between various groups within ranges of exposure level. The significant differences in italics indicate a greater accuracy for the first group vs the second one, except when indicated by [*], which demonstrates greater accuracy for the second group

x missing combinations

deviation. When setting the threshold value at 1-mm deviation, again a 50% dose reduction was seen but this time already when using the 12 bit system or higher compared to 8 bit. This indicated that contrast resolution may play an important factor in the detection of periodontal bone height. Wenzel et al. [8] researched the influence of bit depth of PSP systems on caries diagnosis and did not seem to find any significant differences when using higher bit depths. However, this study described classification of caries rather than bone level measurements, and extracted teeth were used as simulation. No studies could be found describing this for periodontal diagnosis.

For the CCD systems, significant differences were found between the two groups being Sigma CCD 12 bit and VistaRay CCD 14 bit, with highest accuracy for VistaRay CCD 14 bit, especially at higher exposure

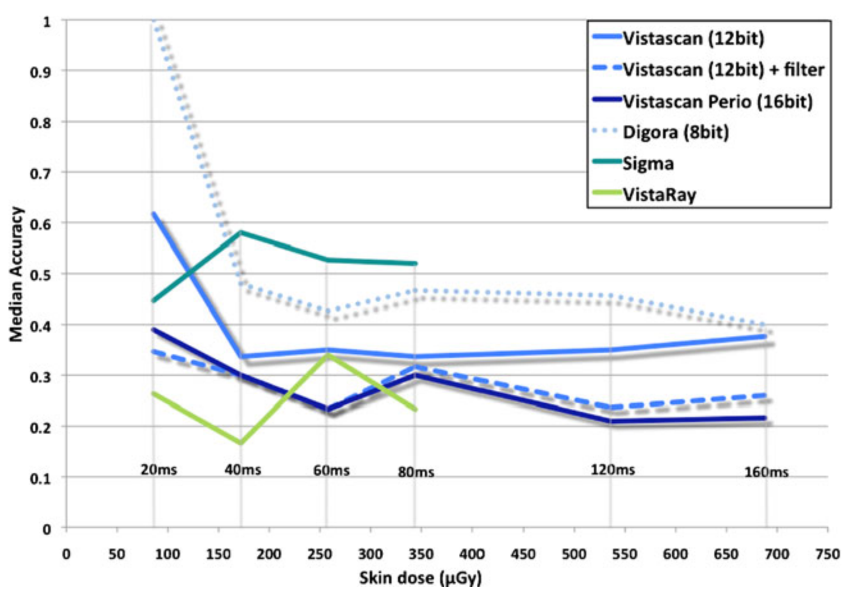


Fig. 4 Median accuracy (absolute distance from gold standard) of the six digital groups plotted by entrance skin dose (exposure time). Outlying median accuracies (medians higher than 1) were given an arbitrary value of 1. The threshold skin dose levels are given in Table 3

Table 3 Dosimetric threshold values for periodontal bone level measurement accuracy at 0.5- and 1-mm deviation from the gold standard

Accuracy	Receptor	Sub-type	DC		AC	
			mAs	μGy	mAs	μGy
0.5 mm	Film	Agfa E-speed	x	x	0.96	444.6
		Kodak FE-speed	x	x	0.96	444.6
	PSP	Digora 8 bit	0.28	176.3	0.96	444.6
		Vistascan 12 bit	0.28	176.3	0.32	133.3
		Vistascan 12 bit+filter	0.14	86.7	x	x
		Vistascan 16 bit	0.14	86.7	x	x
	CCD	Sigma 12 bit	0.14	86.7	0.16	54.5
		VistaRay 14 bit	0.14	86.7	x	x
				0–51%		70–88%
1 mm	Film	Agfa E-speed	x	x	0.64	257.4
		Kodak FE-speed	x	x	0.64	257.4
	PSP	Digora 8 bit	0.28	176.3	0.64	257.4
		Vistascan 12 bit	0.14	86.7	0.32	133.3
		Vistascan 12 bit+filter	0.14	86.7	x	x
		Vistascan 16 bit	0.14	86.7	x	x
	CCD	Sigma 12 bit	0.14	86.7	0.16	54.5
		VistaRay 14 bit	0.14	86.7	x	x
				0–51%		48–79%

At 1-mm deviation accuracy, 50% lower skin doses were found when using systems with at least 12-bit grayscale. For 0.5 mm as error margin, application of a dedicated filter on Vistascan 12 bit or using the Vistascan 16 bit seemed to allow to reduce the required skin dose with approximately 50% for PSP systems, while the CCD sensors did not result in any apparent dose differences. This tendency was also seen when using the AC tube, where the 8-bit PSP system required similar doses as the two film types

times. However, this did not translate in any form of dose savings given the already high accuracy of these solid-state sensors at very low exposure times. It did again indicate that contrast resolution may influence accuracy in the detection of local bone height. Heo et al. [14] examined the influence of CCD sensor bit depth in determination of endodontic file positioning and found that 12-bit images were preferred over 8-bit images. No other studies to our knowledge have investigated higher bit depths with solid-state sensors.

When comparing the use of PSP plates to CCD sensors for these specific periodontal diagnostic tasks, it was found that 50% lower doses were achievable when using the 12- or 14-bit CCD sensors compared to PSP 8 bit (1-mm deviation error margin), but none when using higher PSP bit depths. In our previous report [9], no dose reduction was

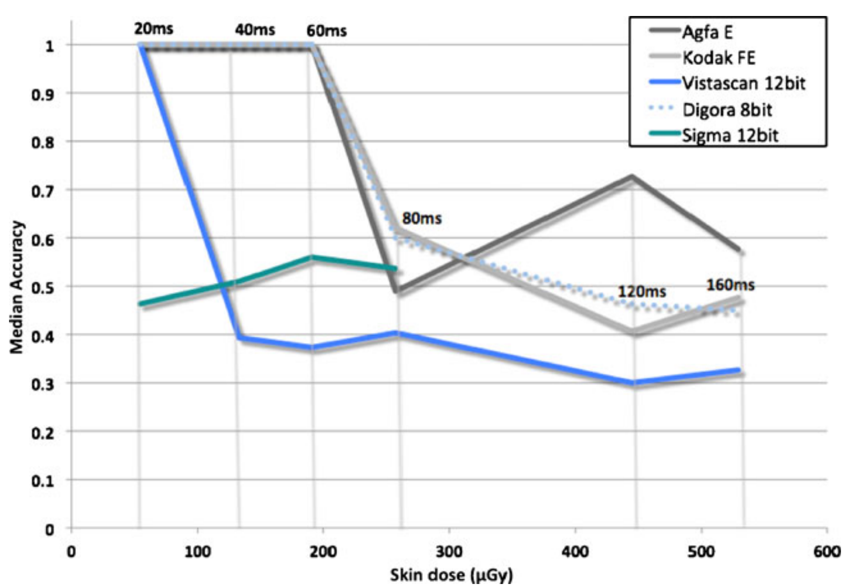


Fig. 5 Median accuracy of Vistascan 12 bit PSP, Digora 8 bit PSP, and Sigma 12 bit CCD in comparison with two film speed types using an AC X-ray generator. The Digora 8 bit PSP behaved similar to the two film types, while the other two digital receptors were more accurate at low exposure times

Table 4 Kruskal–Wallis tests for subjective ratings of lamina dura (LD) and trabecular pattern (BQ) visibility, image contrast perception (C) and crater (CR), and furcation (FU) visibility for each observer

		LD	BQ	C	CR	FU
Obs1	PSP	$p>0.01$	$p>0.01$	*$p<0.01$*	$p>0.01$	$p>0.01$
Obs2		*$p<0.01$*	*$p<0.01$*	*$p<0.0001$*	$p>0.01$	$p>0.01$
Obs3		$p>0.01$	$p>0.01$	*$p<0.001$*	$p>0.01$	$p>0.01$
Obs1	CCD	$p>0.01$	$p>0.01$	$p>0.01$	$p>0.01$	$p>0.01$
Obs2		$p>0.01$	$p>0.01$	$p>0.01$	$p>0.01$	$p>0.01$
Obs3		$p>0.01$	$p>0.01$	$p>0.01$	$p>0.01$	$p>0.01$

The *p* values in italics indicate significant differences for PSP, and further Mann–Whitney tests were used for pair-wise group comparison of the different PSP systems

found when comparing PSP to CCD sensors using a DC tube, but no distinction between different contrast resolutions was made. Therefore, this higher contrast resolutions often attributed to newer technology should be considered for exposure guidelines of digital systems. These results were confirmed when comparing the PSP groups to conventional films using an AC tube (see Fig. 5). Here, the Digora 8 bit PSP behaved like the two conventional film types (see Table 3), and thus, no apparent dose savings could be seen when using this PSP system compared to

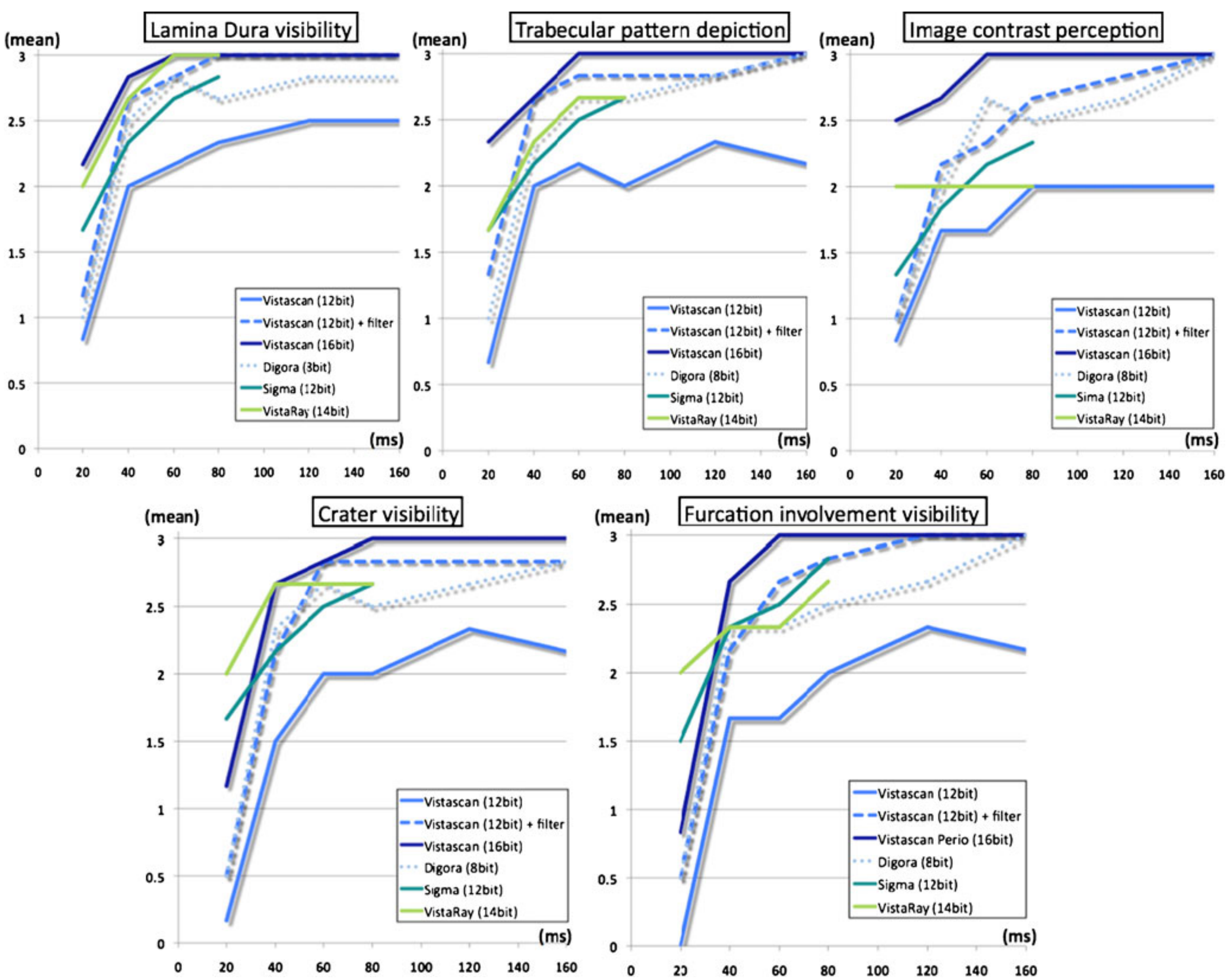


Fig. 6 For each subjective criterion, the means of the ordinal scores of each group were plotted by exposure time. The scores for most subjective ratings are similar for all groups. Non-parametric tests were used to determine any differences between the groups (see Table 4)

Table 5 Threshold skin doses with a minimal ordinal score of 2 for the subjective ratings lamina dura (LD) and trabecular pattern (BQ) visibility, image contrast (C) perception, crater (CR), and furcation (FU) involvement visibility

Variable	Receptor	Sub-type	DC tube	
			mAs	μGy
LD	PSP	Digora 8 bit	0.28	176.3
		Vistascan 12 bit	0.28	176.3
		Vistascan 12 bit+filter	0.28	176.3
		Vistascan 16 bit	0.14	86.7
	CCD	Sigma 12 bit	0.28	176.3
		VistaRay 14 bit	0.14	86.7
				0–51%
BQ	PSP	Digora 8 bit	0.28	176.3
		Vistascan 12 bit	0.28	176.3
		Vistascan 12 bit+filter	0.28	176.3
		Vistascan 16 bit	0.14	86.7
	CCD	Sigma 12 bit	0.28	176.3
		VistaRay 14 bit	0.28	176.3
				0–51%
C	PSP	Digora 8 bit	0.28	176.3
		Vistascan 12 bit	0.56	343.9
		Vistascan 12 bit+filter	0.28	176.3
		Vistascan 16 bit	0.14	86.7
	CCD	Sigma 12 bit	0.42	257.8
		VistaRay 14 bit	0.14	86.7
				0–75%
CR	PSP	Digora 8 bit	0.28	176.3
		Vistascan 12 bit	0.42	257.8
		Vistascan 12 bit+filter	0.28	176.3
		Vistascan 16 bit	0.28	176.3
	CCD	Sigma 12 bit	0.28	176.3
		VistaRay 14 bit	0.14	86.7
				0–66%
FU	PSP	Digora 8 bit	0.28	176.3
		Vistascan 12 bit	0.56	343.9
		Vistascan 12 bit+filter	0.28	176.3
		Vistascan 16 bit	0.28	176.3
	CCD	Sigma 12 bit	0.28	176.3
		VistaRay 14 bit	0.28	176.3
				0–49%

For most ratings of PSP radiographs, only Vistascan 16 bit scored well at lower skin doses (approximately 50% dose savings, in italics). Similarly for the CCD sensors, most criteria seemed to allow lower threshold doses when using the VistaRay 14 bit system. Note that contrast perception scored well at the lowest threshold skin doses for these two systems

conventional film. The 32–56% dose reduction of PSP compared to film in our previous report was therefore also dependent of the PSP resolution [9]. It must be noted that the median accuracy in Figs. 4 and 5 was mostly higher for the PSP systems than the solid-state sensors.

Although contrast resolution may thus influence periodontal diagnosis, other important parameters in the intraoral radiographic chain are the imaging software, the display screen resolution, ambient light [15], and the resolving power of the human eye. While standard computer monitors can only image 256 gray shades, the human eye can also only discern approximately 10 lp/mm or 60 shades of gray at once without any aids [16]. When using higher bit depths, the acquired information can still be imaged using image enhancement algorithms. In addition, medical displays or newer high resolution non-medical computer displays can also image more gray shades [28]. In this study, evaluation of digital images was standardized with same ambient light conditions, while images were exported at maximal bit depth in a standard software for radiographic assessments on LCD monitors with same screen resolution (1,440×900 pixels) and brightness settings. Unfortunately, the screens in this study could only display 8 bit, and window-level adjustments were not allowed (except the application of the dedicated periodontal filter for Vistascan 12 bit). However, for most sensors, prior to display of the radiographic image and right after image acquisition, manufacturer-defined pre-processing algorithms may already influence the actual display of the radiograph in the accompanying software. This can explain why higher accuracies were observed at higher bit depth in this study without the use of window-level functions. Also, when the Vistascan 12-bit images were processed with a dedicated periodontal filter, higher accuracy was perceived comparable to the one of Vistascan 16 bit PSP plates. Baksi [29] found that enhanced PSP images provided better visibility of periodontal structures but resulted in comparable measurement accuracy. However, no details on filter or contrast resolution of the PSP system used were provided. It may well be that dedicated filtering thus only influences accuracy when using higher bit depths. Eickholz et al. [17] and Wolf et al. [23] also did not find any significant differences when using digital enhancement, although they used digitized conventional films with a 10-bit flatbed scanner. Li et al. [21] also did not find any differences for bone level measurements using enhanced images, but exposure time was fixed and additional information is lacking. Further studies should therefore investigate the influence of image processing, especially when using smaller bit depths.

For the subjective ratings of the digital radiographs, the variables lamina dura visibility, trabecular pattern depiction, contrast perception, and furcation and crater involvement visibility seemed to score alike and were comparable to the accuracy measurements. No significant differences were found for CCD, but for PSP, the lowest scores were given to the Vistascan 12 bit, which is different from the accuracy measurements where Digora 8 bit scored the least. However, a non-parametric test does not take into account the clustered datasets used in this study, and only careful assumptions could be made. In general, all receptors score well for the subjective criteria, and a threshold level of 2 on a three-point rating scale is too limited for accurate statements.

Lastly, it is crucial to respect the ALARA (as low as reasonably achievable) principle for periodontal diagnosis especially since it is a discipline where often radiographs or full mouth series (FMX) are required from the patient. Literature still often questions the added value of two-dimensional intra-oral radiographs for periodontal diagnosis [30–32], and three-dimensional modalities have proven to be of significant help when assessing crater and furcation involvements [33, 34]. The low dose of the latter [35] is often even lower than an FMX using E-speed film or when using incorrect radiographic guidelines [36, 37]. Therefore, even though many different technologies are overwhelming the dental market, it is still of utmost importance to establish digital intra-oral radiographic guidelines.

Conclusion

This study is the second part of a comprehensive in vitro study assessing periodontal bone level measurement accuracy and subjective image quality using different X-ray generators and image receptors. In the first report, the influence of X-ray generator on specific exposure settings for conventional and digital sensors has been described. In this second study, the influence of the type of image receptor on exposure levels for periodontal diagnosis was described.

It can be concluded from these results that the type of PSP or solid-state sensor itself played an additional role in the radiographic diagnosis of bone loss. For PSP, 50% dose savings could be estimated when using high contrast resolution systems starting at 12 bit. The use of a dedicated periodontal filter did seem to deliver higher measurement accuracy. The highest accuracy was perceived for Vistascan 16 bit where 100% of the measurements were within 0.5-mm deviation. For CCD, the highest accuracy was found for VistaRay 14 bit, where 100% of the measurements were within 0.5-mm deviation. No dose savings could be estimated between the two solid-state sensors given their high accuracy at low exposure times. The findings seemed to indicate that higher contrast resolution may play an important role in alveolar crest depiction and bone level measurements.

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