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A comparative study of image quality and radiation exposure for dental radiographs produced using a charge-coupled device and a phosphor plate system

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Abstract

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Aim To investigate the quality of periapical radiographic images produced by two digital dental radiography systems, a charge-coupled device (CCD) and a photostimulable phosphor (PSP) image plate system, and to examine the overall radiation exposure when using these systems in a clinical setting.

Methodology Patients were randomly allocated to both systems and the resultant radiographs rated for quality. The expected radiation exposure for an investigation was calculated.

Results Overall, 98 images were acquired using the CCD system and 108 with the PSP system. The PSP system produced significantly higher quality ($P < 0.001$) periapical images compared with the CCD system. The CCD system required significantly more ($P < 0.001$) repeat exposures to obtain a diagnostic image than the PSP system but at a lower expected radiation exposure.

Conclusions The image quality was superior using the phosphor plate system. Although more repeat radiographs were required using the CCD system, the images were produced with a lower expected radiation exposure.

Keywords: dental digital radiography, radiation doses.

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Introduction

Digital radiography is increasingly being used in clinical practice. Two common systems employed use either a charge-coupled device based sensor (CCD) or a photostimulable phosphor (PSP) imaging plate system.

The literature is replete with studies, conducted *ex vivo*, comparing the quality of image between CCD and PSP systems for diagnosis of a specific pathological condition, either naturally occurring or mechanically formed (Lim *et al.* 1996, Borg & Grondahl 1996a, Borg *et al.* 2000, Boscolo *et al.* 2001, de Almeida *et al.* 2003). Subsequently, various advantages and disadvantages of both CCD and PSP systems have been suggested but results tend to show both systems comparable in terms of image quality, with neither significantly superior (Wenzel & Borg 1995, Kang *et al.* 1996, Velders *et al.* 1996, Borg *et al.* 1997, 1998, Cederberg *et al.* 1998, Versteeg *et al.* 1998, Syriopoulos *et al.* 2000). However, within the clinical environment there are many variables that may influence the quality of the image obtained. Few studies have examined the effectiveness of either system for diagnostic purposes *in vivo* (Morner-Svalling *et al.* 2003) .

It is well documented that the optimum individual exposure using the CCD system requires a lower radiation exposure than the PSP systems (van der Stelt 2005), but this does not take into account any repeat exposures that may be necessary. The aims of the study were therefore to investigate whether there were any differences in image quality and radiation exposure

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between a CCD and a PSP digital system for periapical radiography.

Material and methods

The study was approved by the Cardiff & Vale NHS Trust Research and Development Committee (reference number 04-DH-3089), and South East Wales Local Research Ethics Committee. Adult patients, referred to the Radiology Department at the University Dental Hospital, Cardiff, UK and requiring periapical radiographs of at least one individual tooth, were recruited into the study. Written, informed consent was obtained from each patient, by the principal investigator (SF), prior to the radiograph being exposed.

Two digital radiography systems were compared: the Sidexis CCD system (Sirona Dental Systems GmbH, Bensheim, Germany), and the Vistascan PSP system (Dürr Dental GmbH, Bissingen, Germany). The resolution for Sidexis CCD system is measured at <10lp mm^{-1}. For the Vistascan the high resolution setting was chosen which corresponds to a measured resolution of 8 lp mm^{-1} (horizontal) and 10 lp mm^{-1} (vertical) The sensor sizes used were 31 mm × 41 mm and 22 mm × 35 mm for the Vistascan PSP system. For the Sidexis CCD system, the universal sensor which measured 25.4 mm × 36.8 mm × 6.6 mm (11 mm over cable insert) and the full size sensor which measured 29.9 mm × 40.1 mm × 6.8 mm (11.2 mm over the cable insert) were used. The active area of the Sidexis CCD system is 26 mm × 34 mm for the full size sensor and 20 mm × 30 mm for the universal sensor.

Sample size

The primary outcome was identified as image quality assessment rated on a 3-point scale as described later. Assuming 70% excellent, 20% satisfactory and 10% unsatisfactory are the quality assessment scores for one system, and 50% excellent, 20% satisfactory and 30% unsatisfactory are the scores for the other, a sample size of 120 (60 per system) gives a power of 80% to detect this difference. The intention was to increase the total sample size to 240 (120 per system) in order to detect a difference of the order of 15% with a power of 80%. It was planned to use each system uniformly across six areas of the dentition, namely incisors and canines, premolars and molars, in both the maxillary and mandibular arches. Thus, 40 radiographs were to be used in each of the six regions, 20 allocated to each system according to a predetermined concealed randomization scheme. The chief investigator was blind to the system allocation until it was disclosed in the clinical setting. Some patients had requests for more than one tooth to be radiographed. If this was the case, the same digital system was used for all exposures, but only one radiograph formed part of this particular study. This was chosen by the principal investigator, before meeting the patient and taken first.

Radiological process

Each radiograph was taken by the principal investigator using the paralleling technique, using an appropriate sensor holder and beam aiming device. The manufacturers' instructions regarding exposure factors were followed for all examinations (Table 1).

If the resultant image was deemed nondiagnostic by the principal investigator, a repeat exposure was carried out immediately using the same system. In the situation that a patient could not tolerate the sensor and holder, or a repeated intraoral digital image was again assessed undiagnostic, a conventional film based intraoral radiograph or an extraoral radiograph was used to obtain the necessary information. These additional images were not evaluated in the study.

Evaluation of images

The principal investigator evaluated all images immediately after the exposure on a Fujitsu Siemens computer monitor (Hansol Electronics Inc., Jinchon-Kun

Table 1 Exposure factors for the digital systems

Region		mA	kV	Time of exposure (seconds) CCD, Sidexis	PSP, Vistascan
Maxilla	Incisors and canines	7	60	0.05	0.12
	Premolars	7	60	0.06	0.16
	Molars	7	60	0.06	0.25
Mandible	Incisors and canines	7	60	0.05	0.12
	Premolars	7	60	0.06	0.16
	Molars	7	60	0.08	0.25

CCD, charge-coupled device; PSP, photostimulable storage phosphor.

Table 2 Three-point scale for assessment of radiograph quality

Rating	Quality	Basis
1	Excellent	No errors of patient preparation, exposure, positioning, processing or handling
2	Diagnostically acceptable	Some errors of patient preparation, exposure, positioning, processing or handling, but which do not detract from the diagnostic utility of the radiograph
3	Unacceptable	Errors of patient preparation, exposure, positioning, processing or handling, which render the radiograph diagnostically unacceptable

Choongbuk, Korea). Each image was assessed in a systematic fashion, within its own software and enhanced if necessary, and assigned a Quality Score (1–3), based on National Radiological Protection Board (NRPB 2001) guidelines (Table 2).

To assess inter- and intra-observer variability, the set of images was reviewed and any with particularly memorable features were excluded. Then 60 images were selected using a stratified random sampling scheme. Three observers, the principal investigator, an experienced endodontic specialist and a maxillofacial radiologist assigned these a Quality Score (1–3), using the same guidelines and viewing conditions. The specialist endodontist and radiologist were also allowed to enhance the images if necessary. Images were selected equally from both systems, and from all areas of the mouth. Should images chosen be associated with a repeat exposure, this second image was also graded in the same manner. Each observer analysed the images in the same order and no knowledge of the previous quality score was available.

Radiation exposure

The observed probability of requiring a repeat radiograph and the standard exposure times given for the different regions for the two systems were considered. From this both the overall average exposure time and radiation exposure (surface entrance doses) were calculated, with confidence intervals.

Statistical analysis

Chi-squared tests were used to compare radiographic quality scores between the two systems. A 1 degree of freedom χ^2 was used for the binary variable indicating whether a repeat was required, and a 1 df trend component is reported for analyses relating to the 3-point ordinal radiographic quality score. Confidence intervals (CIs) for differences between proportions were calculated using method 10 of Newcombe (Newcombe 1998), and CIs for weighted means of proportions analogously.

Inter- and intra-observer agreement was assessed using quadratic weighted kappa for the 3-point scale (Fleiss & Cohen 1973). For the binary decision as to whether repeat radiography should be performed, Scott's pi was used (Scott 1955, Newcombe 1996), with CIs calculated by the method of Donner & Eliasziw (1992).

Proportions of radiographs rated as excellent, acceptable and unacceptable were compared to NRPB targets using upper and lower tail probabilities based on summation of trinomial probabilities generalizing *P*-values (Newcombe & Farrier 2008).

Results

Sample

In total, 209 patients were included in the study; 108 subjects were male and 101 female, with ages ranging from 17 to 90 years. Table 3 shows the number of radiographs from each of the six areas of the mouth allocated to each system. Ideally 240 images should have been obtained. However, it was not possible to collect the planned numbers of mandibular incisors and premolars in the time available for the study. In total, 206 images from 206 different patients were assessed as three patients could not tolerate the digital sensor.

Quality of the original periapical radiographs

Table 3 shows the quality scores assigned to the 206 images obtained by the principal investigator. A 1 df trend component chi-square indicates a highly significant preference for the PSP system ($\chi^2 = 26.3$, $P < 0.001$), with a very large difference commensurate with what was initially assumed in the power calculation. Clinically the most relevant dichotomization was obtained by combining categories 1 and 2, (excellent and clinically acceptable), in contrast to category 3 (unacceptable, undiagnostic). The proportion of images judged excellent or acceptable was 94% for PSP and 78% for CCD. The estimated difference in the proportions unacceptable is 17% with 95% CI from 8% to 27%.

Table 3 Quality scores for the two radiography systems. These show the numbers of radiographs taken for each area of the dentition, and the quality scores of the original periapical radiographs as assessed by the principal investigator

			Quality score		
Radiography system	Area of dentition	Number of radiographs	Excellent	Acceptable	Unacceptable
CCD	Maxillary incisors	20	6 (30%)	13 (65%)	1 (50%)
	Maxillary premolars	20	7 (35%)	11 (55%)	2 (10%)
	Maxillary molars	20	8 (40%)	6 (30%)	6 (30%)
	Mandibular incisors	7	3 (43%)	4 (57%)	0
	Mandibular premolars	13	6 (46%)	2 (15%)	5 (38%)
	Mandibular molars	18	6 (33%)	4 (22%)	8 (44%)
	Total	98	36 (37%)	40 (41%)	22 (22%)
PSP	Maxillary incisors	20	11 (55%)	7 (35%)	2 (10%)
	Maxillary premolars	20	18 (90%)	2 (10%)	0
	Maxillary molars	20	14 (70%)	5 (25%)	1 (5%)
	Mandibular incisors	10	7 (70%)	3 (30%)	0
	Mandibular premolars	18	11 (61%)	6 (33%)	1 (6%)
	Mandibular molars	20	16 (80%)	2 (10%)	2 (10%)
	Total	108	77 (71%)	25 (23%)	6 (6%)

CCD, charge-coupled device; PSP, photostimulable phosphor.

Repeat required for clinical purposes

Repeat exposures were actually performed for 27 (27%) of 98 radiographs using the CCD system and 8 (7%) of 108 radiographs using the PSP system. This was because the clinician in charge of the patients' care deemed some of the images unacceptable when SF deemed them acceptable and vice versa. Nevertheless, this 20% difference (95% CI 10% to 30%, $\chi^2 = 14.8$, $P < 0.001$) was closely in line with the results shown in Table 3.

Quality of the repeat periapical radiographs

Analyses for the quality scores for the repeat radiographs and whether a further repeat exposure was required were restricted to 34 patients (Table 4). The results of this showed a similar pattern to the original radiographs but statistical significance was not reached due to the very small sample size.

Table 4 Quality scores of repeat radiographs

	Radiography system	
Quality score	CCD	PSP
Excellent	5 (20%)	5 (63%)
Acceptable	14 (54%)	2 (25%)
Unacceptable	7 (27%)	1 (13%)
Total	26	8

CCD, charge-coupled device; PSP, photostimulable phosphor.

Quality scores in relation to area of dentition

Table 3 shows the quality scores of the original periapical radiograph as graded by the principal investigator with regard to the area of the dentition. There were marked differences (>20%) between the two systems in favour of the PSP system, for all areas of the dentition. The greatest differences were for maxillary premolars and molars, and mandibular molars.

The observed overall difference in repeat rates between the CCD and PSP systems needed slight adjustment to allow for the imbalance in numbers of radiographs taken in each area of the dentition. In the maxillary arch the required samples of 20 incisors, 20 premolars and 20 molars were studied. However, in the mandibular arch, this was not the case and fewer subjects used the CCD system than the PSP system. Therefore, a 'balanced scorecard', consisting of equal numbers of radiographs in all areas of the dentition was used to provide a more accurate representation. The projected proportion requiring a repeat periapical radiograph for the CCD system is 27% and for the PSP system 6.8%, a difference of 20.2% (95% CI 10–30%, $\chi^2 = 14.8$, $P < 0.001$). It is therefore reasonable to say that the difference between the two systems is not substantially related to tooth type.

Inter- and intra-observer variability

Weighted kappa for the 3 point scale of quality of the original images ranged from 0.46–0.72 for inter-observer agreement and was 0.98 for intra-observer agreement (SF), with broadly similar results for the repeat radiographs.

For the binary outcome of whether a repeat radiograph was judged necessary, Scott's pi ranged from 0.60 (95% CI 0.30–0.80) to 0.87 (95% CI 0.59–0.96) for inter-observer agreement and was 1.0 (95% CI 0.76–1.0) for intra-observer agreement.

Performance targets

The 3 point quality scores for each system were compared to the minimum target for radiographic quality (≥70% excellent, ≤10% unsatisfactory) suggested by the National Radiological Protection Board (NRPB 2001). It is clear that the results obtained for the CCD system fell short of these targets. Conversely, the results obtained for the PSP system, with 71% excellent and only 6% unsatisfactory, were ostensibly slightly better than the ultimate target performance for quality.

For the PSP system, the probability of observing performance as good as, or better than, the observed proportions of 71% excellent and 6% unacceptable, assuming that in the underlying population the method yields exactly 70% excellent and 10% unacceptable quality of images, may be calculated as a summation of multinomial probabilities. For these results, an upper tail probability $U = 0.058$ was obtained, which represents the probability that results as good as or better than those observed would arise if the true population proportions were 70% excellent, 20% acceptable and 10% unacceptable. A corresponding lower tail probability of $L = 0.64$ was obtained, representing the probability of results no better than those observed. Both U and L use a mid-P accumulation of tail probabilities (Lancaster 1949). A high value of L with a low value of U indicates that the observed results surpass the standard, whereas a high U and a low L indicate results that fall short of the standard.

For the CCD system, $U > 0.99$ and $L < 0.0001$ which indicated strongly that the performance of this system fell short of the target.

Radiation exposure

The physical characteristics of the X-ray machine used (Siemens Heliodent DS, Bensheim, Germany) were measured by the radiation physicist as part of the annual radiation safety survey. The 60 kV machine gave a dose rate at the end of the spacer cone of 5.98 mGy/s. Using this value an entrance doses for the examinations was derived.

Based on a 'balanced scorecard' and disregarding repeat exposures, the mean time of exposure of the CCD system was 0.06 s. The expected additional exposure due to the 27.6% risk of requiring a repeat exposure, based on all areas of the dentition is 0.0171 s, with a 95% confidence interval of 0.0131–0.0232 s. Taking account of the original periapical radiograph and a single repeat if required, the average time for the CCD system was 0.0771 s with a 95% CI from 0.0731 to 0.0832. This translated into an expected 0.46 mGy radiation entrance dose, with a 95% CI of 0.44 to 0.50 mGy.

Similarly, for the PSP system the mean exposure time averaged across the dentition was 0.1767 s. The expected additional exposure due to the ≈ 7.4% risk of requiring a repeat was 0.0122 s, with a 95% CI from 0.0077 to 0.0274. Thus, taking into account the original periapical radiograph and a single repeat if required, the average exposure time with the PSP system was 0.1889 s, with a 95% CI from 0.1844 to 0.2041. This translated into a 1.13 mGy expected radiation surface dose, with a 95% CI of 1.10–1.22 mGy.

Therefore, the difference in average exposure time between the CCD and PSP systems based on the balanced scorecard and taking into account the original radiograph and repeat radiograph if required, was estimated to be 0.1889–0.0771 = 0.1118 s, in favour of the CCD system. The 95% confidence interval for this difference is from 0.1042–0.1275 s. This translated into a 0.67 mGy difference in expected radiation surface dose with a confidence interval of 0.62–0.76 mGy.

Discussion

In this study comparing CCD and PSP systems in the clinical environment, patients were allocated randomly to a digital system and stratification methods used so that each area of the dentition was uniformly examined. The principal investigator, a qualified dentist, was responsible for exposing and assessing all the radiographs and was blind to the system allocation until it was disclosed in the clinical setting to ensure a more fair comparison.

The subjective image quality rating score as described by the NRPB was chosen since it is based on the diagnostic potential of the image produced (NRPB 2001). This rating system is recommended when conducting audits based on the quality of radiographs and is thus familiar and clinically relevant. Since this is an established grading system used in the UK and by its very nature is subjective no calibration of the investigators was performed. Each investigator was familiar with the grading scheme before the study commenced and deemed whether the radiographs were diagnostically acceptable independently.

Various studies have been carried out which suggest that digital equipment may improve the quality of the image, especially if the contrast and density are not optimum (Wenzel 1993, Gotfredsen *et al.* 1996, Yoshiura *et al.* 1999, Svanaes *et al.* 2000, Li 2004). Therefore, manipulation of the digital images was allowed by all observers within the appropriate system software, since this made the study more reminiscent of the clinical environment. The same monitor was used to view both types of image so that confounding screen factors were not introduced. Each image was analysed within its own software and it is possible that this could lead to observer bias. An alternative approach would have been to export the digital images to one common viewing environment, as was done by Berkhout *et al.* (2004), this would have made the observers blind to the identity of the imaging systems. However, a more realistic assessment was desired by enabling the observers to manipulate the image within their own software so as to simulate a true clinical situation. The active areas of the CCD sensor and PSP imaging plates are also different and thus masking the borders would also have been required for all bias to be eliminated. This would have resulted in some of the image from the PSP systems being absent from view, since it has a larger active pixel area and thus some vital radiographic data could be prevented from being viewed and this would have had a direct impact on the relevant quality score.

The overall quality of the PSP system was found to be significantly better than the quality of the images produced with the CCD system. This agrees with Borg & Grondahl (1996b) and Boscolo *et al.* (2001), but is the opposite to that reported by de Almeida *et al.* (2003), however, these studies were *ex vivo* and involved imaging dried specimens with soft tissue equivalents where control of radiographic positioning is more consistent and reproducible. In addition, these studies did not use the NRPB system for grading image quality.

There was a 20% difference between the two systems in favour of the PSP digital system as to whether a repeat image was required (95% CI 10–30%, $P < 0.001$). This is potentially a very important benefit since such a difference could have a marked influence on the patient dose received, the ease at which the process is carried out by both the patient and clinician and the time taken for a successful radiological examination.

Suggested explanations for the improved quality of the PSP images and the less frequent need for a repeat exposure can be sensibly combined. The CCD sensor is far more bulky and stiff than the PSP imaging plates and has a cable attached; it is also associated with a larger sensor holder and beam aiming device. The CCD sensor was found to be more difficult to position than the PSP imaging plates. Patients susceptible to gagging also found the CCD more difficult to tolerate than the PSP sensor.

The active pixel area of the two sensors also differs, which may be a contributing factor to the image quality. The larger active image size of the PSP imaging plates enables more information to be captured and a greater probability that all the relevant information required is actually recorded.

Difficulties in positioning CCD sensors have been reported before (Wenzel & Moystad 2001, Berkhout *et al.* 2002). In two surveys of dental practitioners, there were significant problems with the positioning of CCD sensors with an increase in the number of CCD images taken compared with PSP systems (Wenzel & Moystad 2001, Berkhout *et al.* 2002). In addition, when compared to conventional film it has been shown that there is an increase in the number of unsatisfactory images with the CCD systems (Berkhout *et al.* 2003).

The 'balanced scorecard' allowed for the imbalance in numbers throughout the areas of the dentition and between the two digital systems. This gives a projected difference of 20.2% between the CCD and PSP systems in favour of the PSP system regarding whether or not a repeat radiograph is required.

The CCD system did not reach the suggested NRPB quality targets. The PSP system performed slightly better than the ultimate targets. These performance targets do not take into consideration the radiation dose received by patients in order to eventually obtain the correct diagnostic information.

The mean exposure time and radiation surface dose for the PSP is greater than that for the CCD system by a factor of 2.45. Therefore, despite the CCD system requiring more repeat exposures, the radiation received by the patient is less. In a questionnaire based survey comparing CCD and PSP systems, CCD systems showed a larger dose reduction in comparison to PSP imaging plates (Berkhout *et al.* 2004). However, the authors also raised concerns that the radiation reduction may be less than originally perceived as more CCD exposures were carried out than PSP exposures. In the context of the present study, it might have been possible to reduce the mean exposure time without affecting the quality for the PSP system, since the sensor has a very wide exposure latitude; this is an area for further research. In this study, if conventional radiographs or extraoral radiographs were required because the patient could not tolerate the sensor or there had been two failures using the digital sensor the additional radiation exposure was not included in the calculations.

Another study reported that the dose reduction as a result of shorter exposure times exceeded the increase in doses as a result of the greater number of radiographs with both digital systems (Berkhout *et al.* 2003). However, with the CCD sensors the dose reduction per exposure was almost cancelled out by the increase in the number of radiographs taken. These results are very different to the findings of the present study.

Conclusion

The PSP Vistascan system produced significantly higher quality intraoral periapical images compared with the CCD Sidexis system. The CCD system did not reach the set performance targets of ≥70% excellent and ≤10% unsatisfactory. There was also a significantly higher repeat rate using the CCD system compared to the PSP system. The mean exposure time and radiation exposure for the PSP system is greater than for the CCD system.

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