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Detection of Artificial Occlusal Caries in a Phosphor Imaging Plate System with Two Types of LCD Monitors Versus Three Different Films

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The aim of this study was to determine diagnostic performance of a storage phosphor plate system Digora® Optime (Soredex, Helsinki, Finland) with two types of LCD monitor in the detection of artificial caries when compared to Ultraspeed (D), Ektaspeed Plus (E), and Insight (F) radiographic films. Seventy extracted human molars—with artificial caries—were radiographed under identical standardized conditions using (1) a storage phosphor plate system Digora (Soredex, Helsinki, Finland), (2) Insight, (3) Ektaspeed Plus, and (4) Ultraspeed (Carestream Health Inc, Rochester, NY). All digital images and radiographs were examined by three observers for the presence or absence of artificial caries using a five-point confidence scale. Digital images were evaluated both on a LCD computer monitor (Philips 170S, Holland) and medical monitor—3 megapixel monochrome display (Me355i2, Totoku, Tokyo)—with brightness and contrast enhancement. Observer responses were evaluated using ROC analysis and other measurements for diagnostic accuracy. Storage phosphor images with medical monitor demonstrated higher mean A_z values (0.70±0.08) than digital images with computer monitor and conventional films. Storage phosphor images with medical monitor presented the highest score, 0.97, 0.90, 0.94, for each observer, respectively. Also, true positive observations (0.82) and positive likelihood ratios (2.71) were higher in enhanced storage phosphor images with medical monitor. Caries detection of mechanically created lesions by experienced radiologists is roughly comparable when examining D-speed film images and Digora images on both the computer and medical LCD monitors, and appears to be poorer on E- and F-speed film images.

KEY WORDS: Diagnostic evaluation, digital display, digital imaging

INTRODUCTION

Conventional intraoral radiography is frequently preferred to detect caries. Since faster films are desirable from the standpoint of exposure reduction, manufacturers are developing films with increased sensitivity to radiation.[1]

Eastman Kodak's intraoral film, named Insight, builds on existing emulsion technology used for Ektaspeed Plus film, but has been classified as an E/F-speed film, depending on the processing conditions.[2] Previous studies indicated that the film in speed group F has contrast equal to or greater than Ektaspeed Plus, with an exposure dose reduction of at least 20%.[3–5] Although an increase in speed implies dose reduction for the dental patient, D-speed film is the most preferred one among the dentists.[3,6] Previous studies have been carried out about performance of F-speed film with respect to carious detection and depth measurement.[7–14]

Digital radiographic system was introduced as an alternative to conventional radiography. This system supplies approximately 80% exposure reduction compared to D-speed films.[15–17] Digital images generated with storage phosphor techniques have been shown to be diagnostically comparable to film images for detecting caries.[18,19] Easy access to image processing which may enhance the diagnostic value or facilitate the diagnostic interpretation is one of the advantages of digital radiography.[20–25]

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Several studies have shown that digital contrast enhancement increase diagnostic accuracy for detection of lesions.[20,25–26]

More recently, liquid crystal display (LCD) monitors have been used as a display device for medical digital images, and LCD monitors are currently most common types used in diagnostic radiology systems.[27–31] But to our knowledge, no comparison exists about the effects of LCD monitors on the observer's performance in dentistry. There are studies in the literature on the efficiency of various radiographic systems for the diagnosis of proximal caries which includes the surface of the tooth facing with the adjacent tooth, reporting a wide range of levels of diagnostic performance.[12,13,32] However; there is no information available concerning artificial occlusal caries which includes only the masticator surface.

Thus, this study was carried out to obtain additional information on the diagnostic performance of a storage phosphor plate system Digora Optime® (Soredex, Helsinki, Finland) with two different LCD monitors in the detection of artificial occlusal caries when compared to Ultraspeed (D), Ektaspeed Plus (E) and Insight (F) radiographic films.

MATERIALS AND METHODS

Extracted Teeth and Simulation of Caries Lesions

Seventy extracted noncarious unrestored human molar teeth were used in this study. The teeth had been stored in a 10% formalin solution and the reason of their extraction was unknown. The experimental teeth were randomly divided in two groups. The study sample comprised 50 teeth; standardized occlusal cavities were prepared with 1.5 mm into dentin and 4 mm buccal–palatal and 6 mm mesio-distal diameters. A round bur, 0.7 mm in diameter, was used for preparing a hole on the pulpal surface of the occlusal cavity to simulate an artificial recurrent caries. The locations of the artificial holes on the base of the cavity were produced randomly. After filling the holes of each tooth in the study group with a modeling wax (Kemdent, Tenatex Red,UK), the occlusal restorations were made by using a hybrid composite resin (3M Espe Filtek Z 250,USA). The control group consisted of 20 teeth with only occlusal composite restorations having the same dimensions as the study group. The experimental teeth of the study and control groups were randomly embedded in wax blocks as 35 pairs (each block consisting of two teeth) at the level of cemento-enamel junction (Fig. 1). Each block consisted of additional two teeth which represented neighbors at both ends (premolars, second, or third molars). These teeth were not included in the experiments.

Exposures

A Trophy (Novalix, Croissy-Beaubourg—France) intraoral X-ray unit, operating at 65 kV 8 mA with 2.5 mm aluminum equivalent filtration was used. Table 1 shows the characteristics of the film used and the two displays. To make X-ray projection geometry identical within each specimen, an arrangement was used (Fig. 2). A 15-mm thick polymethylmethacrylate plate was used to simulate soft tissue in the path of the beam at 220 mm from the focal spot. For the positioning, the place of the wax blocks were marked 5 mm from the film holding groove. The resulting focus-to-film distance was 255 mm. Ultraspeed, Ektaspeed Plus, and Insight dental films (Carestream Health Inc, Rochester, NY, USA) were used to image each set of teeth. Exposed films were automatically processed (Velopex Extra-X [Medivance Instrument Limited, London, UK]) using Kodak developer and fixer solutions. To determine the appropriate exposure times, one experimental block was exposed over a wide time range (0.10–1.0 s) with each film type.

Fig 1. Wax block.

Table 1. The Characteristics of the Films Used and the Two Displays

	Medical monitor	Computer monitor	Digora Optime	D-speed	E-speed	F-speed
lp/mm			12.5	20	20	20
Pixel Pitch mm	0.264	0.207				
Contrast ratio	900:1	800:1				
Available resolution	2,048 × 1,536	1,280 × 1,024				
Color	Grayscale	Color				
Maximum luminance cd/m^2	410	300				

An optical densitometer (Gretag Macbeth, TD 932, NY) was used to find the maximum optical density values. Exposure times, which produced a density of approximately 2.0 in background—as recommended by ISO 5799–1991—were selected for each film.[33] The resulting exposure times for evaluated radiographs were 0.40, 0.30, 0.25, and 0.18 s for Ultraspeed, Ektaspeed Plus, Insight, and for Digora, respectively. The exposure times for Digora images were determined subjectively by blind consensus of the observers for optimal diagnostic quality. Consequently, radiographs of 35 blocks were taken with Digora and three types of films.

Evaluation of Radiographs and Digital Images

In the present study, 105 radiographs and 35 digital images were evaluated. The conventional radiographs were mounted on black cardboards with 35 size-adapted windows in randomized order. Three observers having 8, 7, and 5 years experiences as specialists in oral radiology, respectively, evaluated the radiographs in a darkened quite room on a viewing box (50×75 cm) using a ×3 magnifier (Maped, China). Digital images were evaluated both on a LCD computer monitor (Philips, 170S, 1,280×1,024 resolution, Holland) and medical monitor—3 megapixel monochrome display (Me355i2, Totoku, Tokyo) using the toolbox in the same way for each (Digora® software for Windows 2.0®, Soredex) in a darkened quite room, similar environment for evaluating the conventional radiographs. One viewing session was limited to 30 min. Care was taken to ensure that 24 h elapsed between each session. The observers were not informed about film types but they were free to use the brightness and contrast enhancement to be best in their view for digital images. All images and radiographs were assessed by the observers in terms of the visibility of artificial caries on the pulpal surface of the restoration. Visibility was classified on a five-point confidence scale: 1 = definitely no lesion present, 2 = probably no lesion present, 3 = uncertain whether or not a lesion is present, 4 = probably lesion present, 5 = definitely lesion present. The digital images and radiographs were evaluated by the observers for a second time after 1 week.

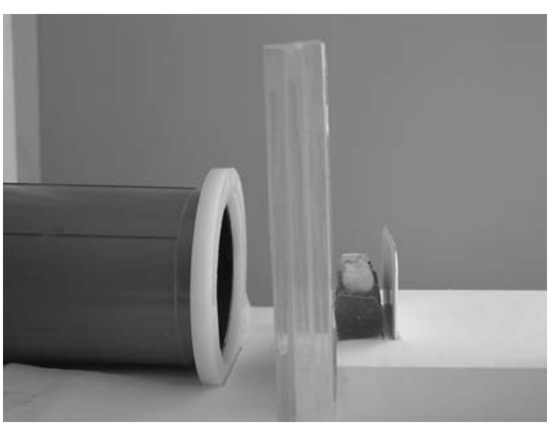

Fig 2. The arrangement for identical X-ray projection.

Statistical Analysis

Statistical analysis was performed using NCSS-PASS 2007 package program (Dr. Jerry L. Hintze & NCSS, Kaysville, UT) and ROCFIT computer program (Metz CE, Chicago, IL). Kappa test was used for detection observer reading and re-reading reliability. A rating of "3" ("uncertain whether or not a carious lesion is present") was accepted as the missing value. Receiver operating characteristic (ROC) analysis was used to evaluate diagnostic accuracy for each radiograph and digital image. Kruskal–Wallis (KW) and Dunn's multiple comparison tests were applied to mean A_z values. To obtain information on a possible overlap, 95% confidence intervals (CI) of the areas beneath the curve (A_z) were included. After converting the confidence ratings into binary data (lesion/no lesion), true positive (TP), false positive (FP), true negative (TN), and false negative (FN) observations were calculated for radiographs and digital images pooled from all observers using all rating categories. Sensitivity (SNT) and specificity (SPF) were computed from these results. Positive likelihood (LR+) and negative likelihood (LR−) ratios were calculated. The LR+ is the ratio of the probability of obtaining a positive test result when the lesion is present to the probability of obtaining a positive test result when the lesion is absent.[34]

RESULTS

In this study, 175 images with two teeth on each radiograph were evaluated. Table 2 shows that observers' readings and re-readings are consistent according to Kappa test (p=0.0001).

Table 3 presents intraclass coefficients and interobserver consistency for radiographs and digital images. These results reflect the reliability of observers with inter-ratings which explains that the observers gave similar ratings within the repeated observations for each image types. Enhanced storage phosphor images with medical monitor presented the highest score, 0.97, 0.90, 0.94, for each observer, respectively. For all film types, all observers gave similar ratings (mean= 0.81).

On the other hand, a clear overlap existed between the 95% CIs of the areas of the radiographs and digital images (Table 4). In Table 3, the ROC curve area for the radiographs and digital images demonstrated that storage phosphor images with medical monitor had higher diagnostic accuracy than others. The mean A_z values were lower for E-speed film. The storage phosphor images with computer monitor, Insight, and D-speed film produced similar A_z results.

Kruskal–Wallis (KW) test results revealed that the mean A_z values have a significant difference between the film types and digital images (p= 0.004; Table 5).

Table 6 shows the comparison of mean A_z values for each film type and digital image. Only the differences between E- ($p<0.05$) and F-speed ($p<0.01$) films, according to the medical monitor, are statistically significant.

According to Table 7, sensitivity–specificity values and the positive likelihood ratio (LR+) were high for storage phosphor images with the medical monitor (0.65, 0.76, and 2.71, respectively). Ultraspeed was the second successful film type while finding artificial caries lesion according to positive likelihood ratio (LR+). Results for Insight and Ektaspeed Plus were similar. The negative likelihood ratio (LR−) was lowest (0.46) for storage phosphor images medical monitor and 0.65 for Ultraspeed.

DISCUSSION

In recent studies, conventional radiographic images were compared with the digital images and no differences were found in the measurement of the images and verified similar performance for the caries diagnosis.[13,35–43] The performance of LCD monitor types is little known. The ME355i2 is a 3 megapixel 20.8″ grayscale display and is widely used by radiologists due to its versatility for multi-modality workstations. This monitor includes luminance uniformity compensation for edge to edge uniformity and is capable of displaying 2,048 shades of gray, simultaneously. The display functions of the LCD medical monitor are much better than a computers'. While the contrast ratio is 900:1, the available resolution is 2,048× 1,536 and maximum luminance is 410 cd/m^2 for

Table 2. Kappa Test Results

	Observer 1	Observer 2	Observer 3
Observer 1	$\kappa_w = 0.65$ $p = 0.0001$	$\kappa_w = 0.43$ $p = 0.0001$	$\kappa_w = 0.43$ $p = 0.0001$
Observer 2		$\kappa_w = 0.74$ $p = 0.0001$	$\kappa_w = 0.49$ $p = 0.0001$
Observer 3			$\kappa_w = 0.67$ $p = 0.0001$

Table 3. Intraclass Coefficiency and Interobserver Consistency

	All film types	D-speed	E-speed	F-speed	Digora® (Computer monitor)	Digora® (Medical monitor)
Observer 1	0.81 (0.76–0.85)	0.73 (0.57–0.83)	0.74 (0.58–0.84)	0.74 (0.58–0.84)	0.84 (0.794–0.891)	0.97 (0.95–0.98)
Observer 2	0.85 (0.81–0.88)	0.82 (0.71–0.90)	0.81 (0.70–0.88)	0.84 (0.75–0.90)	0.82 (0.732–0.882)	0.90 (0.84–0.90)
Observer 3	0.78 (0.72–0.83)	0.73 (0.57–0.83)	0.68 (0.56–0.79)	0.69 (0.57–0.80)	0.84 (0.798–0.873)	0.94 (0.90–0.96)
All observers	0.81 (0.79–0.84)	0.79 (0.68–0.86)	0.74 (0.61–0.83)	0.76 (0.65–0.84)	0.83 (0.795–0.867)	0.97 (0.95–0.98)

the medical monitor; these are 800:1, 1,280 × 1,024 and 300 cd/m^2 for the computer monitor.[44,45]

Tyndall[46] et al. observed that when each observer used the brightness and contrast enhancement, it damaged the image when compared with conventional X-rays and digital image due to lack of skills for handling images. Wenzel[47] suggested that the distinction of the image used incorrectly could reduce the accuracy in the radiographic diagnosis.

In addition, there are studies which reported better results in the evaluation of the digital images with brightness and contrast enhancement.

In the present study, three observers having 8, 7, and 5 year's experiences as specialists in oral radiology, respectively, who have the skills for handling images, evaluated the digital images. It was observed that E- and F-speed films did not show significant differences comparing the quality for diagnosis.[13,38,47,48] Similar to these results, E-speed and F-speed films revealed the same lower SPF when compared to other image types (0.49) in this study. According to these results, a question may be raised regarding the performance of Insight with respect to correct detection of carious lesions. Calculation of both SNT and SPF neglects the confidence of a given observer in his rating. Thus, it is more informative to look at the area under the ROC curve (A_z), which is a measure for accuracy of a diagnostic system. When comparing one ROC curve with another, however, it is important to include information on the 95% CIs of A_z.[34] Our results reveal an obvious overlap of the 95% CIs among radiographs and digital images (Table 3), indicating that the test accuracies of all evaluated images are comparable. This is consistent with the study of Schulze.[7]

In Table 5, the mean A_z scores of E- and F-speed films are similarly lower than the others. Medical monitor has the highest score (mean A_z= 0.70). The D-speed film and computer monitor have similar scores.

Positive (LR+) and negative (LR−) likelihood ratios were included to obtain information on the probability of the respective diagnostic system to obtain a positive or negative test result. The former is called the likelihood of a positive test result, whereas the latter is described as the probability of a negative test result. LR− was 0.46 for digital image with medical monitor. LR+ is also named the diagnostic power of a test.[34] In the present study, it ranged from 1.06 (Ektaspeed) to 2.71 (digital image with medical monitor). For D-speed film and digital image with medical monitor, both values (LR+, LR−) indicate a large overlap of ratings for the carious and noncarious teeth (Table 4). The results of storage phosphor images with medical monitor for artificial occlusal caries diagnosis may be due to its display properties.

Deeper lesions were easier to detect than relatively superficial ones.[49,50] It is natural that

Table 4. Areas Between the 95% CIs

		Asymptotic 95% Confidence Interval	
	Area	Lower bound	Upper bound
D-speed film	0.62	0.53	0.71
E-speed film	0.57	0.48	0.66
F-speed film	0.61	0.52	0.69
Digital images (computer monitor)	0.65	0.56	0.72
Digital images (Medical monitor)	0.71	0.63	0.78

Table 5. Kruskal–Wallis (KW) Test

	Mean A_z
D	0.64 ± 0.06
E	0.5 ± 0.06
F	0.47 ± 0.05
DRC	0.65 ± 0.10
DR	0.70 ± 0.08
KW	17.43
P	0.004

Table 6. Dunn's Multiple Comparison Test

Dunn's multiple comparison test	$A_z(p)$
D/E	>0.05
D/F	>0.05
D/DR	>0.05
D/DRC	>0.05
E/F	>0.05
E/DR	<0.05
E/DRC	>0.05
F/DR	<0.01

cavity depth positively affected the odds of diagnosis; a radiographic image is a record of density difference, and the deeper the caries, the greater the caries–sound tooth ratio.[51] Kang et al.[52] demonstrated that mechanically created defects usually have higher contrast than natural carious cavities. Koistra[12] stated that radiographic diagnosis using an F-speed film significantly underestimated the true clinical extent of Class II carious lesions by 0.66–0.91 mm. In the present study, a round bur, 0.7 mm in diameter, was used to simulate an artificial caries.

According to Metz[53], an A_z value of approximately 0.75–0.80 can be regarded as reasonable for clinical imaging modalities. Borg[54] stated that the highest A_z values were found for the deeper lesion size, which gives a more tunnel-like appearance. Hence, corresponding to our generally low A_z values which may be due to small cavity size, the diagnostic power of E- and F-speed films was low in this investigation. This is perfectly in accordance with the statement of Schulze[7], that the diagnostic power of conventional radiographs was low.

Kang et al.[51] reported that the contrast-enhancing process seemed to make the borders of mechanical enamel defects even clearer when it was applied to Digora images. Mechanical defects were more detectable than natural caries lesions on enhanced images. When attempts were made to discriminate between mechanical defects and natural dental caries, the former defects were easier to diagnose exactly on both enhanced and unenhanced images. This is attributable to both the difference between mechanical defects and natural dental caries with respect to border characteristics and the contrast sensitivity of the human observer's eye.[55] In the present study, contrast- and brightness-enhancing processes were used for all digital images and the correct diagnosis of artificial caries with the medical monitor may be due to its high contrast ratio and resolution.

In conclusion, our results indicate that;

1. Caries detection of mechanically created lesions by experienced radiologists is roughly comparable when examining D-speed film images and Digora images on both the computer and medical LCD monitors, and appears to be poorer on E- and F-speed film images.
2. The positive likelihood ratio is very high for digital images viewed on the medical monitor.
3. Resolution, contrast ratio, and luminance are different between the two LCD monitors and the differences in diagnostic accuracy between the monitors may be related to some of these characteristics.
4. These findings may not be completely applicable to naturally occurring caries under restorations because of the different physical characteristics of bur-created lesions.
5. The large 95% confidence intervals suggest some variation in diagnostic ability of the examiners, but they are consistent in inter-items as indicated by the high kappa scores.

Decrease in patient exposure is a very important goal and alternative imaging modalities should prove their performances in order to be utilized

Table 7. Average Sensitivity, Average Specificity, Positive (LR+) and Negative (LR−) Likelihood Ratios

Film types	Sensitivity	Specificity	LR(+)	LR(−)
D-speed	0.63	0.57	1.47	0.65
E-speed	0.55	0.49	1.06	0.94
F-speed	0.57	0.49	1.11	0.88
Digital images with computer monitor	0.64	0.55	1.39	0.84
Digital images with medical monitor	0.65	0.76	2.71	0.46

routinely in daily practice. This study indicates one more time that usage of accurate equipments with digital imaging systems increases the diagnostic performance of the dentist.

REFERENCES

1. White SC, Pharoah MJ: Radiation safety and protection. In: Rudolph P Ed. Oral Radiology. 4th edition. St Louis: Mosby, 2000

2. Ludlow JB, Platin E, Mol A: Characteristics of Kodak Insight, an F-speed intraoral film. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 91:120–129, 2001

3. Geist JR, Brand JW: Sensitometric comparison of speed group E and F dental radiographic films. Dentomaxillofac Radiol 30:147–152, 2001

4. Goren AD, Lundeen RC, Deahl 2nd, ST, Hashimoto K, Kapa SF, Katz JO, et al: Updated quality—assurance self-assessment exercise in intraoral and panoramic radiography. American Academy of Oral and Maxillofacial Radiology, Radiology Practice Committee. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 89:369–374, 2000

5. Bernstein DI, Clark SJ, Scheetz JP, Farman AG, Rosenson B: Perceived quality of radiographic images after rapid processing of D-, and F-speed direct-exposure intraoral X-ray films. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 96:486–491, 2003

6. İlgüy D, İlgüy M, Dinçer S, Bayırlı G: Survey of dental radiologic practice in Turkey. Dentomaxillofac Radiol 34:222–227, 2005

7. Schulze RK, Nackat D, D'Hoedt B: In vitro carious lesion detection on D-, E-, and F-speed radiographic films. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 97:529–534, 2004

8. Hintze H, Wenzel A: Influence of the validation method on diagnostic accuracy for caries. A comparison of six digital and two conventional radiographic systems. Dentomaxillofac Radiol 31:44–49, 2002

9. Ludlow JB, Abreu M, Mol A: Performance of a new F-speed film for caries detection. Dentomaxillofac Radiol 30:110–113, 2001

10. Gungor K, Erten H, Akarslan ZZ, Celik I, Semiz M: Approximal carious lesion depth assessment with insight and ultraspeed films. Oper Dent 30:58–62, 2005

11. Erten H, Akarslan ZZ, Topuz O: The efficiency of three different films and radiovisiography in detecting approximal carious lesions. Quintessence Int 36:65–70, 2005

12. Kooistra S, Dennison JB, Yaman P, Burt BA, Taylor GW: Radiographic versus clinical extension of Class II carious lesions using an F-speed film. Oper Dent 30:719–726, 2005

13. de Araujo EA, Castilho JC, Medici Filho E, de Moraes ME: Comparison of direct digital and conventional imaging with Ekta Speed Plus and INSIGHT films for the detection of approximal caries. Am J Dent 18:241–244, 2005

14. Akdeniz BG, Gröndahl HG, Magnusson B: Accuracy of proximal caries depth measurements: comparison between limited cone beam computed tomography, storage phosphor and film radiography. Caries Res 40:202–207, 2006

15. Soh G, Loh FC, Chong YH: Radiation dosage of a dental imaging system. Quintessence Int 24:189–191, 1993

16. Horner K, Hirschman PN: Dose reduction in dental radiography. J Dent 18:171–184, 1990

17. Horner K, Shearer AC, Walker A, Wilson NH: Radiovisiography: an initial evaluation. Br Dent J 168:244–248, 1990

18. Wenzel A, Borg E, Hintze H, Gröndahl HG: Accuracy of caries diagnosis in digital images from charge-coupled device and storage phosphor systems: an in vitro study. Dentomaxillofac Radiol 24:250–254, 1995

19. Svanaes DB, Møystad A, Risnes S, Larheim TA, Gröndahl HG: Intraoral storage phosphor radiography for approximal caries detection and effect of image magnification: comparison with conventional radiography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 82:94–100, 1996

20. Shrout MK, Russell CM, Potter BJ, Powell J, Hildebolt CF: Digital enhancement of radiographs: can it improve diagnosis? J Am Dent Assoc 127:469–473, 1996

21. Arenson RL, Andriole KP, Avrin DE, Gould RG: Computers in imaging and health care: now and in the future. J Digit Imaging 13:145–156, 2000

22. Lehmann TM, Troeltsch E, Spitzer K: Image processing and enhancement provided by commercial dental software programmes. Dentomaxillofac Radiol 32:264–272, 2002

23. Wenzel A: Computer-aided image manipulation of intraoral radiographs to enhance diagnosis in dental practice: a review. Int Dent J 43:99–108, 1993

24. Wenzel A: Digital radiography and caries diagnosis. Dentomaxillofacial Radiol 27:3–11, 1998

25. Møystad A, Svanaes DB, Risnes R, Larheim TA, Gröndahl HG: Detection of approximal caries with a storage phosphor system. A comparison of enhanced digital images with dental X-ray film. Dentomaxillofac Radiol 25:202–206, 1996

26. Eickholz HJ, Kolb I, Lenhard M, Hassfeld S, Staehle HJ: Digital radiography of interproximal caries: effect of different filters. Caries Res 33:234–241, 1999

27. Usami H, Ikeda M, Ishigaki T, Fukushima H, Shimamoto K: The influence of liquid crystal display (LCD) monitors on observer performance for the detection of nodular lesions on chest radiographs. Eur Radiol 3:726–732, 2006

28. Kim AY, Cho KS, Song KS, Kim JH, Kim JG, Ha HK: Urinary calculi on computed radiography: comparison of observer performance with hard-copy versus soft-copy images on different viewer systems. AJR Am J Roentgenol 177:331–335, 2001

29. Scharitzer M, Prokop M, Weber M, Fuchsjäger M, Oschatz E, Schaefer-Prokop C: Detectability of catheters on bedside chest radiographs: comparison between liquid crystal display and high-resolution cathode-ray tube monitors. Radiology 234:611–616, 2005

30. Samei E, Seibert JA, Andriole K, Badano A, Crawford J, Reiner B, et al: AAPM/RSNA tutorial on equipment selection: PACS equipment overview: general guidelines for purchasing and acceptance testing of PACS equipment. Radiographics 24:313–334, 2004

31. Badano A: AAPM/RSNA tutorial on equipment selection: PACS equipment overview: display systems. Radiographics 24:879–989, 2004

32. Wenzel A: Current trends in radiographic caries imaging. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 80:527–539, 1995

33. International Organization for Standardization. Photography—direct-exposing medical and dental radiographic film/process systems—determination of ISO speed and ISO average gradient. 2nd ed. 1991

34. Dawson B, Trapp RG: Basic & clinical biostatistics, United States of America: McGraw-Hill, 2004

35. Versteeg KH, Sanderink GC, van Ginkel FC, van der Stelt PF: Estimating distances on direct digital images and conventional radiographs. J Am Dent Assoc 128:439–443, 1997

36. Velders XL, Sanderink GC, van der Stelt PF: Dose reduction of two digital sensor systems measuring file lengths. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 81:607–612, 1996

37. Wenzel A, Pitts N, Verdonschot EH, Kalsbeek H: Developments in radiographic caries diagnosis. J Dent 21:131–140, 1993

38. Møystad A, Svanaes DB, Risnes S, Larheim TA, Gröndahl HG: Detection of approximal caries with a storage phosphor system. A comparison of enhanced digital images with dental X-ray film. Dentomaxillofac Radiol 25:202–206, 1996

39. Hintze H, Wenzel A, Jones C: In vitro comparison of D- and E-speed film radiography, RVG, and visualix digital radiography for the detection of enamel approximal and dentinal occlusal caries lesions. Caries Res 28:363–367, 1994

40. Wenzel A: Computer-aided image manipulation of intraoral radiographs to enhance diagnosis in dental practice: A review. Int Dent J 43:99–108, 1993

41. Wenzel A, Borg E, Hintze H, Gröndahl HG: Accuracy of caries diagnosis in digital images from charge-coupled device and storage phosphor systems: an in vitro study. Dentomaxillofac Radiol 24:250–254, 1995

42. Dove SB, McDavid WD: A comparison of conventional intra-oral radiography and computer imaging techniques for the detection of proximal surface dental caries. Dentomaxillofac Radiol 21:127–134, 1992

43. White SC, Yoon DC: Comparative performance of digital and conventional images for detecting proximal surface caries. Dentomaxillofac Radiol 26:32–38, 1997

44. Totoku. Available from http://www.totoku.com/display. Accessed 26 February 2008.

45. Philips. Available from www.philips.com. Accessed 12 February 2008.

46. Tyndall DA, Ludlow JB, Platin E, Nair M: A comparison of Kodak Ektaspeed Plus film and the Siemens Sidexis digital imaging system for caries detection using receiver operating characteristic analysis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 85:113–118, 1998

47. Hintze H, Christoffersen L, Wenzel A: In vitro comparison of Kodak Ultra-speed, Ektaspeed, and Ektaspeed Plus, and Agfa M2 Comfort dental X-ray films for the detection of caries. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 81:240–244, 1996

48. Ricketts DN, Whaites EJ, Kidd EA, Brown JE, Wilson RF: An evaluation of the diagnostic yield from bitewing radiographs of small approximal and occlusal carious lesions in a low prevalence sample in vitro using different film types and speeds. Br Dent J 182:51–58, 1997

49. Syriopoulos K, Velders XL, Sanderink GCH, van der Stelt PF: Sensitometric and clinical evaluation of a new F-speed dental X-ray film. Dentomaxillofac Radiol 30:40–44, 2001

50. Nair MK, Nair UP: An in-vitro evaluation of Kodak Insight and Ektaspeed plus film with a CMOS detector for natural proximal caries: ROC analysis. Caries Res 35:354–359, 2001

51. Kang BC, Goldsmith LJ, Farman AG: Observer differentiation of mechanical defects versus natural dental caries cavitations on monitor-displayed images with imaging plate readout. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 86:595–600, 1998

52. Kang BC, Farman AG, Scarfe WC, Goldsmith LJ: Observer differentiation of proximal enamel mechanical defects versus natural proximal dental caries with computed dental radiography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 82:459–465, 1996

53. Metz CE: Some practical issues of experimental design and data analysis in radiological ROC studies. Invest Radiol 24:234–235, 1989

54. Borg E, Kallqvist A, Gröndal K, Gröndal HG: Film and digital radiography for detection of simulated root resorption cavities. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 86:110–114, 1998

55. Jaffe CC: Medical imaging, vision, and visual psychophysics. Med Radiogr Photogr 60:1–48, 1984