RESEARCH ARTICLE

Comparison between DICOM-calibrated and uncalibrated consumer grade and 6-MP displays under different lighting conditions in panoramic radiography

^{1,2}S Kallio-Pulkkinen, ^{1,2}M Haapea, ^{1,2}E Liukkonen, ^{3,4}S Huumonen, ^{1,2}O Tervonen and ^{1,2}M T Nieminen

¹Department of Diagnostic Radiology, Oulu University Hospital, Oulu, Finland; ²Medical Research Center Oulu, Oulu University Hospital and University of Oulu, Oulu, Finland; ³Department of Oral Pathology and Radiology, Institute of Dentistry, University of Turku, Turku, Finland; ⁴Department of Diagnostic Radiology, Turku University Hospital, Turku, Finland

Objectives: To compare observer performance in the detection of anatomical structures and pathology in panoramic radiographs using consumer grade with and without digital imaging and communication in medicine (DICOM)-calibration and 6-megapixel (6-MP) displays under different lighting conditions.

Methods: 30 panoramic radiographs were randomly evaluated on three displays under bright (510 lx) and dim (16 lx) ambient lighting by two observers with different years of experience. Dentinoenamel junction, dentinal caries and periapical inflammatory lesions, visibility of cortical border of the floor and pathological lesions in maxillary sinus were evaluated. Consensus between the observers was considered as reference. Intraobserver agreement was determined. Proportion of equivalent ratings and weighted kappa were used to assess reliability. The level of significance was set to $p < 0.05$.

Results: The proportion of equivalent ratings with consensus differed between uncalibrated and DICOM-calibrated consumer grade displays in dentinal caries in the lower molar in dim lighting ($p = 0.021$) and between DICOM-calibrated consumer grade and 6-MP display in bright lighting ($p = 0.038$) for an experienced observer. Significant differences were found between uncalibrated and DICOM-calibrated consumer grade displays in dentinal caries in bright lighting ($p = 0.044$) and periapical lesions in the upper molar in dim lighting ($p = 0.008$) for a less experienced observer. Intraobserver reliability was better at detecting dentinal caries than at detecting periapical and maxillary sinus pathology.

Conclusions: DICOM calibration may improve observer performance in panoramic radiography in different lighting conditions. Therefore, a DICOM-calibrated consumer grade display can be used instead of a medical display in dental practice without compromising the diagnostic quality.

Dentomaxillofacial Radiology (2015) **44**, 20140365. doi: [10.1259/dmfr.20140365](https://doi.org/10.1259/dmfr.20140365)

Cite this article as: Kallio-Pulkkinen S, Haapea M, Liukkonen E, Huumonen S, Tervonen O, Nieminen MT. Comparison between DICOM-calibrated and uncalibrated consumer grade and 6-MP displays under different lighting conditions in panoramic radiography. *Dentomaxillofac Radiol* 2015; **44**: 20140365.

Keywords: digital radiography; display; ambient light; calibration; panoramic radiography

Introduction

One of the major factors affecting the quality of digital radiographs and interpretation is the display.¹ Dentists seldom use medical displays in general practice.² There is limited knowledge on how observer performance is affected by the type of display, greyscale calibration and level of ambient light.^{3–5} Panoramic radiography is a common examination covering the maxillofacial regions. It is often used as the initial radiograph to determine further examinations. In clinical practice, these radiographs are usually viewed on consumer displays without calibration (*i.e.* γ 2.2) and frequently under too bright lighting conditions.^{2,4}

Compared with consumer displays, the medical displays offer significant advantages for diagnostic imaging. Consumer displays offer limited resolution and typically lower maximum luminance. Medical displays offer a contrast (up to 1000:1) that is substantially better than most consumer displays (an average contrast ratio of only 300:1). For many applications, contrast is even more important than luminance. The number of available shades of grey on most consumer displays is limited to 256 (8 bit). Medical displays have a greyscale up to 4096 shades of grey (12 bit). The medical displays also contain look-up tables calibrated for viewing of images, and these systems are supported by the proper configuration and quality control tools.

The American Association of Physicists in Medicine^{6,7} and the Institute of Physics and Engineering in Medicine⁸ have drawn up guidelines regarding greyscale calibration and acceptable illuminance levels of the room used for radiographic interpretation. For practical reasons, these guidelines are rarely met in the dental office, where much higher room illuminance is recommended for clinical work.⁹ In medical radiology, compliance with grayscale standard display function (GSDF), part 14 of the digital imaging and communication in medicine (DICOM) standard (DICOM Part 14 GSDF),¹⁰ which separates diagnostic displays from consumer grade or tablet displays, is considered critical. This standard was developed to ensure the uniform presentation of greyscale of different displays without significant degradation or variation. Furthermore, it ensures that the presentation of greyscale by displays is matched as accurately as possible to the contrast sensitivity of the human eye by means of greyscale calibration.¹¹

It is not known how the windowing improves the visibility of low-contrast details, such as dentinal caries, and periapical and sinus pathology. Furthermore, the same display is often used both for viewing radiographs and for maintaining patient records. To our knowledge, only two studies have evaluated the effect of display type and observer experience on diagnostic performance on panoramic radiographs.^{3,12} Kim *et al*¹² concluded that less experienced observers showed poorer diagnostic ability with a general colour liquid crystal display to

detect inflammatory changes, such as thickened mucous membrane on maxillary sinus floor, in dark room conditions than did oral and maxillofacial radiologists with more than 15 years' experience. Several studies investigating the effect of different displays on caries diagnostic accuracy in intraoral radiographs have been published.^{2,4,5,13–17} However, only one study has investigated the use of tablets³ and two studies the use of medical displays as devices to view panoramic images.^{3,12} It has not been investigated how DICOM calibration in consumer grade displays affect the diagnostic accuracy of observing anatomical structures and pathology in panoramic radiographs. Therefore, the aim of this study was to investigate whether the use of a consumer grade display with DICOM calibration in dim ambient lighting improves the detection of anatomical structures and pathology in panoramic radiographs.

Methods and materials

The panoramic radiographs were selected from the patient archive of the Department of Diagnostic Radiology, Oulu University Hospital, Oulu, Finland. The selection criterion for the 30 radiographs was that the structures to be evaluated had to be clearly visible. Images taken during a 3-month period were selected retrospectively by an oral and maxillofacial radiologist who did not participate in the evaluation. All images were subjected to routine quality standards, and exposure and/or position errors (*e.g.* incorrect head position in the image layer) or movement artefacts were not allowed.¹⁸ Ambient light level was 16 lx. Ambient light was measured from the surface of the display in the direction of the viewer using a luminance meter (Ray-Safe Xi; Unfors, Billdal, Sweden). The selection of radiographs was made using a 6-megapixel (MP) display (Table 1).

All panoramic radiographs were taken by experienced radiographers with Orthopantomograph® OP200 D machine (Instrumentarium Dental, Tuusula, Finland). The exposure parameters used were 66 kV and 9.9 mA. The acquired digital raw data were sent to the picture archiving and communication system server. All images were stored as DICOM format files. The image matrix size was 2976×1536 pixels (0.07×0.07 -mm pixel size at detector). The digital archives system used was neaPACS (Neagen Ltd, Oulu, Finland), and the case selection systems, that is, the radiology information system used were nearIS (Neagen Ltd) and the ESKO patient data system (Oulu University Hospital, Oulu, Finland). The viewer used was an HTML4/5-based software application (neaLink; Neagen Ltd).

For the evaluation of panoramic radiographs, two sets of three identical displays were used for convenience and to save interpretation time. A standard personal

Table 1 Technical specifications of two sets of three identical displays

Display group	Manufacturer	Model	Digital imaging and communications in medicine	Screen size (inches)	Screen type	Colour	Resolution (pixels)	Brightness (lx)	Error (%)	Brightness (lx)	Error (%)	Luminance (cd m^{-2})	Error (%)
Consumer grade 1	Fujitsu	P23T6IPS	No	23.0	LED	Yes	1920 × 1080	510.2	0.00	16.2	1.22	206.2	0.34
Consumer grade 2	Fujitsu	P23T6IPS	No	23.0	LED	Yes	1920 × 1080	510.2		16.4		205.5	
Consumer grade 1	Fujitsu	P23T6IPS	Yes	23.0	LED	Yes	1920 × 1080	510.0	0.22	16.2	0.61	180.0	0.45
Consumer grade 2	Fujitsu	P23T6IPS	Yes	23.0	LED	Yes	1920 × 1080	508.9		16.3		179.2	
6 MP1	Barco	MDCC6130DL	Yes	30.4	CCFL	Yes	3280 × 2048	509.5	0.02	16.3	1.88	391.7	4.54
6 MP2	Barco	MDCC6130DL	Yes	30.4	CCFL	Yes	3280 × 2048	509.4		16.0		374.7	

6 MP, 6 megapixels; CCFL, cold cathode fluorescent lamp; LED, light-emitting diode.

Location of manufacturers: Fujitsu is located at Tokyo, Japan and Barco at Kortrijk, Belgium.

computer (Lifebook S-761 VPro; Fujitsu, Tokyo, Japan; integrated graphic card: Esprimo C5731E, Tokyo, Japan) was connected to the consumer grade displays and a power computer (Fujitsu Celsius R570; Fujitsu; graphic card: Barco 5200, Kortrijk, Belgium) to the 6-MP displays. Prior to the study, comparable maximum luminance was set by adjustments of the displays between identical displays. Constant luminance was adjusted using a luminance meter (Unfors RaySafe Xi). The DICOM calibration of all displays was in accordance with Section PS3.14 of the latest version of the standard.¹⁰ Detailed specifications are given in Table 1.

Altogether seven structures were evaluated from the left side of the jaw: the dentinoenamel junction from the first lower molar, the possible presence of dentinal caries and periapical inflammatory lesions (widening of the periapical periodontal ligament space twice from normal or a radiolucent lesion) from the first upper and lower permanent molars; and the visibility of the border and possible pathological lesions in the maxillary sinus, such as thickening of mucous membrane, fluid level or cysts (Figure 1). Both anatomical structures and pathology were chosen because they provided both low- and high-contrast details.

The panoramic radiographs were independently observed in random order by two observers: an oral and maxillofacial radiologist with 8 years' experience (Observer 1) and a resident in oral and maxillofacial radiology with 2 years' experience (Observer 2). Rating was based on a three-point scaling system used in the analyses: 1, definitely not a finding; 2, uncertain; and 3, definitely a finding. The middle score would require further imaging, such as intraoral or even CBCT.

The observers evaluated 30 radiographs in 3 evaluation sessions under bright and dim lighting conditions during which they were allowed to adjust the brightness, contrast and magnification of the radiographs in the viewing software. Before the evaluation, the observers were instructed how to use the viewing programmes. The uncalibrated consumer grade display was evaluated during the first, the DICOM-calibrated consumer grade display during the second and the 6-MP display during the third evaluation with 3 weeks' interval between the evaluation sessions. Evaluations were made under bright (510 lx) and dim (16 lx) lighting. There was a 1-h delay between the room illuminance settings. Evaluation time of 1 min per image was allowed during which all seven different anatomical structures and pathology were assessed.

A consensus between the two observers, which was considered as a reference, was made within each structure in all 30 panoramic radiographs after 6 months of initial viewing. In the consensus reading session, the 6-MP display was used under ambient lighting of 16 lx (Table 1). Intraobserver agreement was determined by Observer 1 by re-evaluating 15 panoramic radiographs 6 months after the initial viewing using the 6-MP display under ambient lighting of 16 lx (Table 1).

Figure 1 (a, b) Panoramic images from the left side of the jaw showing the structures under evaluation.

Statistical methods

Agreement between both observers and the consensus was calculated as a proportion of equivalent ratings. In order to evaluate the reliability of the ratings, Cohen's kappa (κ) was calculated for dichotomized ratings of dentinoenamel junction and linearly weighted kappa (κ_w) and its 95% confidence interval for other structures. Kappa statistics were interpreted as follows: <0 , poor (less than chance); 0.00 – 0.20 , slight; 0.21 – 0.40 , fair; 0.41 – 0.60 , moderate; 0.61 – 0.80 , substantial; 0.81 – 0.99 , almost perfect agreement.¹⁹ In order to compare the different displays (separately calibrated *vs* uncalibrated consumer grade and calibrated consumer grade *vs* 6 MP) and lighting conditions (bright *vs* dim) κ s were compared using z-scores. Only the images that were evaluated successfully in each display were selected for the comparison of displays, and the images that were evaluated successfully in bright and dim lighting within each display were selected for the comparison of lighting conditions. *p*-values <0.05 were considered statistically significant. Intraobserver reliability was analysed by calculating the κ or κ_w between the 15 ratings that were carried out by Observer 1 in the initial viewing and 6 months after the initial viewing. IBM SPSS® Statistics v. 22.0 (IBM Corporation, Armonk, NY) was used in the statistical analyses.

Results

The number of successful ratings with different displays varied owing to problems with the network connection at the first evaluation and some coding typos. The

numbers of successful ratings for the observers under bright and dim ambient light on different displays are shown in Table 2.

The border of the left maxillary sinus was visible to both observers on all displays. Visibility of the dentinoenamel junction is shown in Table 3. Observer 1 performed reasonably well with consumer grade and calibrated consumer grade displays in bright and dim lighting and with 6-MP display in bright lighting, whereas agreement was poor with 6-MP display in dim lighting ($\kappa = 0.19$). Observer 2 performed better with calibrated consumer grade and 6 MP displays than with consumer grade display in both bright and dim lighting.

Comparison of uncalibrated and calibrated consumer grade displays

Bright lighting: In bright lighting, Observer 1 performed non-significantly better in identifying dental caries in the lower molar and non-significantly worse in identifying periapical lesion in the lower molar with calibrated consumer grade display (Table 4). Observer 2 performed significantly better in identifying dental caries in the upper molar, non-significantly better in identifying dental caries in the lower molar and non-significantly worse in identifying pathological lesions in the left maxillary sinus with calibrated consumer grade display.

Dim lighting: In dim lighting, Observer 1 performed significantly better in identifying dental caries in the lower molar, non-significantly better in identifying periapical lesion in the lower molar and pathological

Table 2 The numbers of succeeded ratings for Observers 1 and 2 under bright and dim ambient lighting conditions in different displays

Display	Observer 1		Observer 2	
	Bright, n (%)	Dim, n (%)	Bright, n (%)	Dim, n (%)
Consumer grade	24 (80)	22 (73)	28 (93)	26 (87)
Digital imaging and communications in medicine-calibrated consumer grade	27 (90)	30 (100)	30 (100)	30 (100)
6 megapixels	30 (100)	30 (100)	29 (97)	29 (97)

lesions in the left maxillary sinus and non-significantly worse in identifying dentinal caries in the upper molar and periapical lesion in the upper molar with calibrated consumer grade display (Table 4). Observer 2 performed significantly better in identifying periapical lesion in the upper molar and non-significantly worse in identifying pathological lesions in the left maxillary sinus with calibrated consumer grade display.

Comparison of calibrated consumer grade and 6-MP displays

Bright lighting: In bright lighting, Observer 1 performed significantly better in identifying dentinal caries in the lower molar and non-significantly worse in identifying periapical lesion in the upper molar with 6-MP display (Table 4). Observer 2 performed non-significantly worse in identifying dentinal caries in the lower molar with 6-MP display.

Dim lighting: In dim lighting, Observer 1 performed non-significantly better in identifying dentinal caries in the upper and lower molars and non-significantly worse in identifying periapical lesion in the lower molar with 6-MP display. Performance of Observer 2 did not differ significantly between calibrated consumer grade and 6-MP displays.

Comparison of bright and dim lighting conditions

There were no significant differences between the κ_w s in bright and dim lighting in identifying any of the structures. Detailed information on the results is found in Supplementary Table A. Owing to the selection of images that were successfully evaluated in both bright and dim lighting, the values are not one-to-one with the results shown in Table 4.

Intraobserver reliability

The intraobserver reliability was moderate at the dentinoenamel junction ($\kappa = 0.59$), almost perfect in upper ($\kappa_w = 0.92$) and substantial in lower ($\kappa_w = 0.74$) dentinal caries, fair in upper ($\kappa_w = 0.30$) and substantial in lower ($\kappa_w = 0.63$) periapical lesions and moderate in pathological lesions in the left maxillary sinus ($\kappa_w = 0.48$).

Discussion

In the present study, the DICOM-calibrated consumer grade display was better than the uncalibrated consumer grade display in bright and dim lighting conditions. The DICOM-calibrated consumer grade display was almost equal in detectability to the 6-MP display in both lighting conditions.

The purpose of greyscale calibration is to ensure optimal presentation and perception of contrast in digital radiography and to ensure that an image is presented “identically” over time and different locations. This standard is in use in medical displays, such as 6-MP displays. These displays are expensive, and the replacement of medical displays with consumer grade displays could translate into cost savings. Many dentists view radiographs on ordinary consumer grade displays without calibration, probably owing to lack of knowledge of how the calibration affects the diagnostic accuracy of digital radiographs. To our knowledge, there are no studies on how DICOM calibration and viewing conditions when using consumer grade displays affect the diagnostic accuracy in panoramic radiography.

Kallio-Pulkkinen *et al*³ compared observer performance in the detection of anatomical structures and pathology in panoramic radiographs using an uncalibrated consumer grade display and a tablet (3G iPad; Apple Inc., Cupertino, CA) under suboptimal lighting conditions (bright lighting) and a 6-MP display under dim lighting. They concluded that compared with a more experienced oral and maxillofacial radiologist, a resident in oral and maxillofacial radiology with less experience in interpreting panoramic radiographs may be more dependent on the high-quality display used under dim viewing conditions to detect anatomical structures and pathology. More specifically, a less experienced observer showed significantly

Table 3. Agreement and reliability of visibility of dentinoenamel junction, separately for both observers and ambient lighting conditions in different displays

Display	Observer 1				Observer 2			
	Bright		Dim		Bright		Dim	
	%Eqv	κ	%Eqv	κ	%Eqv	κ	%Eqv	κ
Consumer grade	79	0.54	77	0.51	68	0.39	69	0.40
Digital imaging and communications in medicine-calibrated consumer grade	82	0.59	80	0.56	87	0.72	90	0.78
6 megapixels	83	0.63	67	0.19	86	0.70	86	0.69

%Eqv, proportion of equivalent ratings; κ , Cohen's kappa.

Table 4 Comparison of agreement in dentinal caries and periapical lesion in upper and lower molars and pathological lesions in left maxillary sinus by different displays under ambient light of 510 and 16 lx, separately for Observers 1 and 2

Pathology/display	Observer 1						Observer 2					
	Bright, n = 21			Dim, n = 22			Bright, n = 27			Dim, n = 25		
	%Eqv	κ_w (SE)	p-value ^a	%Eqv	κ_w (SE)	p-value ^a	%Eqv	κ_w (SE)	p-value ^a	%Eqv	κ_w (SE)	p-value ^a
Dentinal caries, upper molar												
Consumer grade	81.0	0.69 (0.14)		72.7	0.53 (0.16)		40.7	0.31 (0.09)		44.0	0.34 (0.10)	
DICOM-calibrated	81.0	0.71 (0.13)	0.841	63.6	0.33 (0.16)	0.201	66.7	0.53 (0.12)	0.044	52.0	0.42 (0.13)	0.453
consumer grade												
6 MP	76.2	0.60 (0.17)	0.452	72.7	0.55 (0.15)	0.153	63.0	0.45 (0.12)	0.520	68.0	0.53 (0.14)	0.453
Dentinal caries, lower molar												
Consumer grade	76.2	0.63 (0.14)		72.7	0.53 (0.15)		59.3	0.53 (0.10)		60.0	0.58 (0.11)	
DICOM-calibrated	81.0	0.80 (0.09)	0.158	81.8	0.82 (0.08)	0.021	77.8	0.69 (0.12)	0.130	72.0	0.63 (0.13)	0.674
consumer grade												
6 MP	95.2	0.95 (0.05)	0.038	90.9	0.91 (0.06)	0.201	55.6	0.47 (0.13)	0.064	80.0	0.72 (0.12)	0.490
Periapical lesion, upper molar												
Consumer grade	57.1	0.18 (0.13)		72.7	0.54 (0.17)		40.7	0.21 (0.10)		36.0	<0.01 (0.12)	
DICOM-calibrated	52.4	0.22 (0.17)	0.782	59.1	0.32 (0.13)	0.131	59.3	0.22 (0.12)	0.907	60.0	0.31 (0.12)	0.008
consumer grade												
6 MP	71.4	0.50 (0.18)	0.116	68.2	0.34 (0.19)	0.920	51.9	0.16 (0.11)	0.597	60.0	0.37 (0.12)	0.638
Periapical lesion, lower molar												
Consumer grade	71.4	0.54 (0.16)		77.3	0.57 (0.17)		51.9	0.32 (0.13)		60.0	0.39 (0.15)	
DICOM-calibrated	66.7	0.30 (0.17)	0.149	81.8	0.75 (0.11)	0.226	70.4	0.36 (0.16)	0.784	68.0	0.29 (0.16)	0.516
consumer grade												
6 MP	71.4	0.43 (0.21)	0.519	72.7	0.61 (0.14)	0.242	66.7	0.38 (0.15)	0.912	60.0	0.32 (0.16)	0.857
Pathological lesions, left maxillary sinus												
Consumer grade	33.3	0.08 (0.05)		54.5	0.28 (0.13)		29.6	0.25 (0.08)		32.0	0.29 (0.07)	
DICOM-calibrated	42.9	0.15 (0.09)	0.346	68.2	0.42 (0.17)	0.358	33.3	0.16 (0.06)	0.247	40.0	0.17 (0.08)	0.119
consumer grade												
6 MP	47.6	0.20 (0.10)	0.604	77.3	0.53 (0.18)	0.522	40.7	0.21 (0.08)	0.554	36.0	0.15 (0.07)	0.734

%Eqv, proportion of equivalent ratings between the observer and consensus; κ_w , linearly weighted kappa; 6 MP, 6 megapixels; DICOM, digital imaging and communications in medicine; SE, standard error.

^aSignificance of z-score calculated between DICOM-calibrated and uncalibrated consumer grade display (upper p-values) and between 6 MP and DICOM-calibrated consumer-grade display (lower p-values).
p-values <0.05 are in bold.

higher diagnostic ability with a 6-MP display under dim lighting than with a consumer grade display and a tablet under bright lighting in dentinal caries and periapical lesions in the first upper molar and in dentinal caries in the first lower molar. The performance of the more experienced observer was not significantly affected by the type of display. For the more experienced observer, however, the performance increased significantly from uncalibrated consumer grade display to 6-MP display in pathological lesions in the maxillary sinus, which are known to be difficult to detect.¹²

Pollard *et al*²⁰ and the American Association of Physicists in Medicine⁶ have also issued recommendations on advisable low illuminance levels while evaluating radiographs. Earlier, Hellén-Halme *et al*^{4,13} concluded that there was no evidence that room illuminance affected the ability to detect carious lesions in digital intraoral radiographs as long as the display was calibrated in accordance with the surrounding light level. Pakkala *et al*¹⁴ compared an off-the-self colour display, a DICOM-calibrated colour liquid crystal display and a DICOM-calibrated greyscale liquid crystal display in varying room illuminance. They showed that different displays and room illuminance levels did not affect the overall detection of caries lesions in intraoral images. On the other hand, Odum *et al*² concluded that

compared with a consumer grade display, the use of the DICOM GSDF significantly improved the diagnostic accuracy in endodontic and periodontal diagnostics of intraoral radiographs.

In the present study, the DICOM-calibrated consumer grade display was significantly better in identifying dentinal caries in the upper molar (Observer 2) under bright lighting and dentinal caries in the lower molar (Observer 1) and periapical lesions in the upper molar (Observer 2) under dim lighting than with uncalibrated consumer grade display. Compared with DICOM-calibrated consumer grade display, Observer 1 performed significantly better with 6-MP display in identifying dentinal caries in the lower molar in bright lighting. From these findings, it can be concluded that the DICOM-calibrated consumer grade display is adequate for the detection of anatomical structures and pathology also in bright ambient light. On the other hand, in dental practice, the room illuminance level is often >510 lx, and thus, it is recommended that the overall lighting level should be decreased in order to reduce reflections and improve the image contrast.

In the present study, the less experienced observer performed better in identifying high-contrast structures, such as the visibility of the dentinoenamel junction, with DICOM-calibrated consumer grade and 6-MP displays

than with uncalibrated consumer grade display in both lighting conditions. Compared with the consensus the more experienced observer rated the dentinoenamel junction more often visible in 6-MP display in dim lighting. The border of the left maxillary sinus was visible on all displays in both bright and dim lighting for both observers. These high-contrast structures are usually well visualized on panoramic radiographs,^{21–23} which was also confirmed in this study.

Previously, Hellén-Halme *et al*^{13,15} concluded that when ambient light was <50 lx, there was no significant difference in accuracy in detection of approximal caries lesions between a well-adjusted standard colour display, DICOM pre-calibrated colour display and monochromatic display. They also concluded that the diagnostic accuracy of dental caries lesions was significantly higher in ambient

light of <50 lx.¹⁶ In their study, the displays were set at a resolution of 1280 × 1280 pixels. In the present study, the resolution of the consumer grade display was lower than that for the 6 MP display or the matrix size for the displayed panoramic images. The display resolution or matrix size of images and the ambient light level did not affect observer performance in the detection of anatomical structures or pathology in panoramic radiographs with any of the displays studied.

In conclusion, DICOM-calibration may improve observer performance in the detection of anatomical structures and pathology in panoramic radiographs despite the room illuminance level. Furthermore, a DICOM-calibrated consumer grade display can be used instead of a medical display in dental practice without compromising the diagnostic quality.

References

- Krupinski EA, Williams MB, Andriole K, Strauss KJ, Applegate K, Wyatt M, *et al*; ACR; AAPM; Society for Imaging Informatics in Medicine. Digital radiography image quality: image processing and display. *J Am Coll Radiol* 2007; **4**: 389–400.
- Odum N, Spalla G, Van Assche N, Vandenberghe B, Jacobs R, Quirynen M, *et al*. Preliminary display comparison for dental diagnostic applications. Medical imaging 2012: image perception, observer performance, and technology assessment. In: Proceedings of SPIE volume 8318; 4–9 February 2012; San Diego, CA, 2012.
- Kallio-Pulkkinen S, Haapea M, Liukkonen E, Huuonen S, Tervonen O, Nieminen MT. Comparison of consumer grade, tablet and 6MP-displays: observer performance in detection of anatomical and pathological structures in panoramic radiographs. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2014; **118**: 135–41. doi: [10.1016/j.oooo.2014.04.005](https://doi.org/10.1016/j.oooo.2014.04.005)
- Hellén-Halme K, Nilsson M, Petersson A. Digital radiography in general dental practice. A field study. *Dentomaxillofac Radiol* 2007; **36**: 249–55.
- Hellén-Halme K, Lith A. Carious lesions: diagnostic accuracy using pre-calibrated monitor in various ambient light levels: an *in vitro* study. *Dentomaxillofac Radiol* 2013; **42**: 1–7. doi: [10.1259/dmfr.20130071](https://doi.org/10.1259/dmfr.20130071)
- American Association of Physicists in Medicine (AAPM). Task Group 18 assessment of display performance for medical imaging systems. [Cited 20 June 2010.] Available from: <http://www.duke.edu/~samei/th18.html>
- Samei E, Badano A, Chakraborty D, Compton K, Cornelius C, Corrigan K, *et al*; AAPM TG18 report. Assessment of display performance for medical imaging systems: executive summary of AAPM TG18 report. *Med Phys* 2005; **32**: 1205–25.
- Institute of Physics and Engineering in Medicine. *Recommended standards for the routine performance testing of diagnostic X-ray imaging systems. IPEM report no. 91*. York, UK: IPEM; 2005.
- Swedish Standards Institute. *Light and lighting—lighting of work places—part 1: indoor work places. [in English]*. Stockholm, Sweden: Swedish Standards Institute; 2003; SS-EN 12464–1.
- Digital Imaging and Communication in Medicine. DICOM PS3.14 2014-Grayscale standard display function. 2014 NEMA. [Cited 1 July 2014.] Available from: <http://dicom.nema.org/MEDICAL/dicom/current/output/html/part14>
- Barten PGJ. *Contrast sensitivity of the human eye and its effects on image quality*. Knegsel, Netherlands: HV Press; 1999.
- Kim TY, Choi JW, Lee SS, Huh KH, Yi WJ, Heo MS, *et al*. Effect of LCD display type and observer experience on diagnostic performance in soft-copy interpretations of the maxillary sinus on panoramic radiographs. *Imaging Sci Dent* 2011; **41**: 11–16. doi: [10.5624/isd.2011.41.1.11](https://doi.org/10.5624/isd.2011.41.1.11)
- Hellén-Halme K, Petersson A, Warfvinge G, Nilsson M. Effect of ambient light and monitor brightness and contrast settings on the detection of approximal caries in digital radiographs. An *in vitro* study. *Dentomaxillofac Radiol* 2008; **37**: 380–4. doi: [10.1259/dmfr/26038913](https://doi.org/10.1259/dmfr/26038913)
- Pakkala T, Kuusela M, Ekholm M, Wenzel A, Haiter-Neto F, Kortensniemi M. Effect of varying displays and room illuminance on caries diagnostic accuracy in digital dental radiographs. *Caries Res* 2012; **46**: 568–74. doi: [10.1159/000341218](https://doi.org/10.1159/000341218)
- Hellén-Halme K, Nilsson M, Petersson A. Effect of monitors on approximal caries detection in digital radiographs—standard versus precalibrated DICOM part 14 displays: an *in vitro* study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009; **107**: 716–20. doi: [10.1016/j.tripleo.2008.12.011](https://doi.org/10.1016/j.tripleo.2008.12.011)
- Hellén-Halme K, Lith A. Effect of ambient light level at the monitor surface on digital radiographic evaluation of approximal carious lesions: an *in vitro* study. *Dentomaxillofac Radiol* 2012; **41**: 192–6. doi: [10.1259/dmfr/15422221](https://doi.org/10.1259/dmfr/15422221)
- Isidor S, Faaborg-Andersen M, Hintze H, Kirkevang LL, Frydenberg M, Haiter-Neto F, *et al*. Effect of monitor display on detection of approximal caries lesions in digital radiographs. *Dentomaxillofac Radiol* 2009; **38**: 537–41. doi: [10.1259/dmfr/21071028](https://doi.org/10.1259/dmfr/21071028)
- White SC, Pharoah MJ. *Oral radiology: principles and interpretation*. 6th edn. St Louis, MO: Mosby; 2009. pp. 197–8.
- Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; **33**: 159–74.
- Pollard BJ, Chawla AS, Delong DM, Hashimoto N, Samei E. Object detectability at increased ambient lighting conditions. *Med Phys* 2008; **35**: 2204–13.
- White SC, Pharran MJ. *Oral radiology: principles and interpretation*. 6th edn. St Louis, MO: Mosby; 2009. pp. 200–9.
- Haring JI, Jensen L. *Normal anatomy-intraoral films. Dental radiology: principles and techniques*. 2nd edn. Philadelphia, PA: WB Saunders; 2000. pp. 433–4.
- Kaeppler G, Dietz K, Reinert S. The effect of dose reduction on the detection of anatomical structures on panoramic radiographs. *Dentomaxillofac Radiol* 2006; **35**: 271–7.