RESEARCH ARTICLE

Effect of display type, DICOM calibration and room illuminance in bitewing radiographs

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Objectives: To compare observer performance in the detection of both anatomical structures and caries in bitewing radiographs using consumer grade displays with and without digital imaging and communications in medicine (DICOM) calibration, tablets (third generation iPad; Apple, Cupertino, CA) and 6-megapixel (MP) displays under different lighting.

Methods: 30 bitewing radiographs were blindly evaluated on four displays under bright (510 lx) and dim (16 lx) ambient lighting by two observers. The dentinoenamel junction, enamel and dentinal caries, and the cortical border of the alveolar crests were evaluated. Consensus was considered as reference. Intraobserver agreement was determined. The proportion of equivalent ratings and weighted kappa were used to assess reliability.

Results: The proportion of equivalent ratings with consensus differed significantly between uncalibrated and DICOM-calibrated consumer grade display in enamel caries in upper and lower molars in bright ($p = 0.013$ and $p = 0.003$) lighting, and in dentinal caries in lower molars in both bright ($p = 0.022$) and dim ($p = 0.004$) lighting. The proportion also differed significantly between DICOM-calibrated consumer grade and 6-MP display in dentinal caries in lower molars in bright lighting ($p = 0.039$), tablet and consumer grade display in enamel caries in upper molars ($p = 0.017$) in bright lighting, tablet and 6-MP display in dentinal caries in lower molars ($p = 0.003$) in bright lighting and in enamel caries in lower molars ($p = 0.012$) in dim lighting.

Conclusions: DICOM calibration improves the detection of enamel and dentinal caries in bitewing radiographs, particularly in bright lighting. Therefore, a calibrated consumer grade display can be recommended as a diagnostic tool for viewing bitewing radiographs.

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Introduction

In clinical practice, bitewing radiographs are taken to detect and monitor the progression of caries and to assess periodontal status. Radiographs are also an important component in assisting with the appropriate

treatment and follow-up of patients.¹ These radiographs are typically viewed using consumer displays without greyscale calibration (*i.e.* γ 2.2), usually under high ambient lighting. There is limited knowledge of how observer performance is affected by the type of display, level of ambient light or greyscale calibration.^{2,3}

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The American Association of Physicists in Medicine^{4,5} and the American College of Radiology⁶ have provided national guidelines regarding acceptable illuminance levels (25–40 lx) in the room used for radiographic interpretation and greyscale calibration. The basic principle is that the displays show greyscale images over an extensive luminance range according to the digital imaging and communications in medicine (DICOM) part 14: greyscale standard display function (GSDF).^{6,7} This relationship ensures that differences in greyscale are shown optimally to the human eye.⁸ The sensitivity of the human eye to detect contrast increases with brightness of pixel elements. The GSDF curve has been derived from Barten's experiments with human observers, determining their contrast thresholds over the complete greyscale range. The difference between two luminances that the human eye can barely detect is defined as just noticeable difference. For a luminance range 0.05–4000 cd m⁻², there are 0–1023 just noticeable differences as defined by the DICOM PS3.14.⁷ In contrast to medical displays, consumer grade displays and tablets are not adjusted to GSDF, which can cause insufficiency in image interpretation. These guidelines rarely come true in dental clinical practice where bite-wing radiographs are often interpreted using the same display that is used for maintaining patient records. Furthermore, a significantly higher room illuminance is recommended for clinical work.⁹

With new technology, potentially useful mobile devices and radiology applications, such as tablets, have become readily available for the imaging community, including dentists. The manufacturers of tablets claim that they are able to display images with high resolution, enabling assessment of different types of digital images. The size of the tablet display is much smaller (*e.g.* 9.7 inches) than medical displays (*e.g.* 23 inches), meaning that the image cannot be assessed in full size. The medical displays employ look-up tables calibrated for viewing images, and these displays are supported by the proper configuration and quality control tools. These tools are lacking on tablets or consumer grade displays. The US Food and Drug Administration (FDA) has indicated that these applications will allow clinicians to view medical images on mobile devices.¹⁰ Following the FDA report, tablets have recently come to be used in hospitals for different purposes, such as detection of cerebral infarction.^{11,12} Volonté *et al*¹³ considered a tablet device, a tool that is helpful for improving surgical performance as well as for teaching purposes. To our knowledge, only one study has evaluated the use of tablets as devices to detect interproximal caries.¹⁴

Several *in vitro* studies have investigated the effect of varying displays on detecting interproximal caries in digital intraoral radiographs.^{14–21} In these studies, some technical parameters were investigated, *i.e.* the effect of DICOM calibration, ambient light, luminance and monitor contrast and brightness settings. Hellén-Halme *et al*¹⁵ concluded that the diagnostic accuracy of

dental caries lesions was significantly higher in ambient light of <50 lx. Odum *et al*³ reported that the use of the DICOM GSDF significantly improved the diagnostic accuracy in endodontic and periodontal diagnostics of intraoral radiographs. Ilgüy *et al*²⁰ found that the accuracy of the medical display was significantly higher than that of the consumer grade display in detecting artificial caries. Araki *et al*²¹ found that the diagnostic accuracy of the iPad Air tablet (Apple, Cupertino, CA) to be lower than that of the DICOM-calibrated medical display or the consumer grade display calibrated according to American Association of Physicists in Medicine TG-18 QC, especially in the detection of enamel caries, and there were no differences in the detection of dental caries. Otherwise, in these and a few other studies, the authors have reported that overall accuracy of caries detection in intraoral images is not affected by display type, *i.e.* consumer grade, tablet or medical display.^{22–24} Though, interpretation with consumer grade display and tablet is time-consuming compared with interpretation with medical display.²⁵

So far, one clinical study has reported the effect of varying displays under bright indirect lighting in bite-wing radiographs.¹⁴ Shintaku *et al*¹⁴ concluded that iPad 2 can effectively show images comparable with a liquid crystal display (LCD). The area under the receiver operating characteristic curve obtained for the iPad 2 and LCD was >0.70, which is considered reasonable for a clinical imaging system.^{26,27}

The aim of this study was to compare observer performance in the detection of both anatomical structures and interpretation of caries in bite-wing radiographs using various displays under different lighting.

Methods and materials

30 horizontal molar bite-wing radiographs were selected by standard criteria, *i.e.* the structures to be evaluated had to be clearly visible. An oral and maxillofacial radiologist who did not participate in the evaluation selected, retrospectively, images taken during a 3-month period. All images were subjected to routine quality standards, *e.g.* limited overlap of the approximal surfaces of the teeth was allowed, and both upper and lower crowns and the maxillary and mandibular alveolar crests had to be seen. 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 metre (Unfors RaySafe Xi, Billdal, Sweden). The selection was made using a 6-megapixel (MP) display (Table 1).

The images were taken as part of patient treatment at the Department of Diagnostic Radiology, Oulu University Hospital, Oulu, Finland. The bite-wings were taken with a storage phosphor plate system (DürrDental AG, Bietingheim-Bissingen, Germany) on the FocusTM Intraoral X-ray unit (Instrumentarium DentalTM; Palodex

Table 1 Technical specifications of two sets of four identical displays

Display group	Manufacturer/year	Model	Look-up table	Antireflective coating	Frequency of digital imaging and communications in medicine (GSD)			Screen size (inches)	Screen type	Colour	Resolution	Brightness (lx)	Error (%)	Brightness (lx)	Error (%)	Luminance (cdm ⁻²)	Error (%)
					GSD	GSD	GSD										
Consumer Grade 1	Fujitsu (Kortrijk, Belgium)/2011	P23T6IPS	N/A	No	No	No	1 year	23.0	LED	Yes	1920 × 1080	510.2	0.00	16.2	1.22	206.2	0.34
Consumer Grade 2	Fujitsu/2011	P23T6IPS	N/A	No	No	No	1 year	23.0	LED	Yes	1920 × 1080	510.2		16.4		205.5	
iPad	Apple/2012	MD368KS	N/A	No	No	No	No	9.7	LED	Yes	2048 × 1536	513.7	0.57	16.2	0.61	344.8	3.55
iPad	Apple/2012	MD368KS	N/A	No	No	No	No	9.7	LED	Yes	2048 × 1536	510.8		16.3		357.5	
Consumer Grade 1	Fujitsu/2011	P23T6IPS	N/A	No	Yes	Yes	1 year	23.0	LED	Yes	1920 × 1080	510.0	0.22	16.2	0.61	180.0	0.45
Consumer Grade 2	Fujitsu/2011	P23T6IPS	N/A	No	Yes	Yes	1 year	23.0	LED	Yes	1920 × 1080	508.9		16.3		179.2	
6MP1	Barco (Kortrijk, Belgium)/2010	MDC6130DL	10/12	Yes	Yes	Yes	6 months	30.4	CCFL	Yes	3280 × 2048	509.5	0.02	16.3	1.88	391.7	4.54
6MP2	Barco/2010	MDC6130DL	10/12	Yes	Yes	Yes	6 months	30.4	CCFL	Yes	3280 × 2048	509.4		16.0		374.7	

CCFL, cold cathode fluorescent lamp; GSD, greyscale standard display function; LED, light emitting diode; Look-up table, bit in/bit out; MP, megapixels; N/A, not available.

Group Oy, Tuusula, Finland) by experienced radiographers. The KerrHawe Kwik-Bite[®] holder (KerrHawe SA, Bioggio, Switzerland) was used. The central beam of the X-ray was positioned to pass at a right angle to the long axis of the tooth and tangentially through the contact area. The parameters used were 70 kV, 7 mA and 0.32 s. The plates were read by the VistaScan Mini Plus image plate scanner (DürrDental AG). All images were stored as DICOM format files. The images matrix size was 1932 × 1496 pixels (0.02 × 0.02-mm pixel size at detector).

The digital archive system used was the neaPACS (Neagen Oy, Oulu, Finland); the case selection system, *i.e.* the radiology information system used was nearIS (Neagen Oy) and ESKO Hospital information system (Oulu University Hospital, Oulu, Finland). The viewer used was an HTML 4/5 neaLink (Neagen Oy). A laptop PC (Lifebook S-761 VPro, integrated graphic card: Esprimo C5731E, Fujitsu, Tokyo, Japan) was connected to the consumer grade displays. A power computer (Fujitsu Celsius R570, Fujitsu, graphic card: Barco 5200, Kortrijk, Belgium) was connected to the 6-MP medical display.

Two sets of four identical displays were used for convenience and to save interpretation time. Before the study, luminance was adjusted on the consumer grade displays, tablet, and 6-MP displays using a luminance metre (Unfors RaySafe Xi). The tablet was fixed on the table before adjusting the luminance. The DICOM-calibrated consumer grade displays' luminance was set by displays' adjustments in DICOM-mode GSDF.¹¹ The detailed specifications of the displays are given in Table 1.

The bitewing 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 (or not visible), 2 = uncertain and 3 = definitely a finding (or visible).

Altogether ten structures were evaluated: the possible presence of enamel and dentinal caries in the first and second upper and lower permanent molars, and the visibility of the dentinoenamel junction in the first lower permanent molar and cortical border of the alveolar crests. Both anatomical structures and pathology were chosen because they provided low- and high-contrast details.

The observers evaluated 30 bitewing radiographs from four displays. The consumer grade display without DICOM calibration and the tablet were evaluated during the first evaluation, the DICOM-calibrated consumer grade display in the second and the 6-MP display during the third evaluation with 3 weeks' delay 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. The radiographs were displayed in random order at each

evaluation to minimize the memory effect. Evaluation time of 1 min per one radiograph was allowed during which all ten structures were evaluated.

A consensus between the two observers, which was considered as a reference, was made within each structure in all 30 bitewing radiographs 6 months after the initial viewing. In 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 bitewing radiographs 6 months after the initial viewing using the 6-MP display under ambient lighting of 16 lx (Table 1).

Statistical methods

Agreement between the observers and the consensus was calculated as a proportion of equivalent ratings for all structures. Additionally, the number and proportion of positive ratings (when positive in consensus) and negative ratings (when negative in consensus) were calculated. Rating of the dentinoenamel junction and cortical border of the alveolar bone was dichotomized as visible or unable to evaluate (*i.e.* not visible or uncertain). In order to evaluate the reliability of the ratings, linearly weighted kappa (κ_w) was calculated for enamel and dentinal caries.²⁸ Kappa statistics were interpreted as follows: <0, poor (less than change); 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.²⁹ McNemar's test was used to compare the proportions of equivalent ratings separately in bright and dim lighting between (1) uncalibrated and DICOM-calibrated consumer grade displays; (2) DICOM-calibrated consumer grade and 6-MP displays; (3) tablet and other displays; and (4) between bright and dim lighting for all displays. Only the radiographs that were evaluated successfully in all displays were selected for the analyses. *p*-values <0.05 were considered statistically significant. To analyse the intraobserver and interobserver reliabilities, the proportions of equivalent ratings and kappa statistics (κ_w) were calculated for enamel and dentinal caries, and the numbers of radiographs were rated as visible for dentinoenamel junction and cortical border of the alveolar bone. For intraobserver reliability, the initial viewing by Observer 1 using the 6-MP display under dim lighting and the reviewing by Observer 1 were used. For interobserver reliability, the viewings by Observers 1 and 2 using the 6-MP display under dim lighting were used. IBM SPSS

Statistics[®], v. 22.0 (IBM Corporation, Armonk, NY; formerly SPSS Inc., Chicago, IL) was used in the statistical analyses.

Results

The cortical border of alveolar crests was visible on all displays in both lighting. The proportion of equivalent ratings with consensus in visibility of the dentinoenamel junction was the lowest (65%) with consumer grade display in bright lighting and the highest (95%) with 6-MP display in both bright and dim lighting (Table 2). Out of 35 radiographs in which the dentinoenamel junction was rated as certainly visible in consensus, only 23 (66%) were rated as visible with uncalibrated consumer grade display, whereas 34 (97%) were rated as visible with 6-MP display (Table 2).

The proportion of equivalent ratings between observers and consensus was statistically significantly lower in uncalibrated than in DICOM-calibrated consumer grade display in enamel caries in upper and lower molars in bright ($p = 0.013$ and $p = 0.003$, respectively), and in dentinal caries in lower molars in both bright ($p = 0.022$) and dim ($p = 0.004$) lighting (Table 3). DICOM-calibrated consumer grade display had a lower proportion of equivalent ratings than 6-MP display in dentinal caries in lower molars in bright lighting ($p = 0.039$).

The proportion of equivalent ratings was higher in tablet than in consumer grade display in enamel caries in upper molars ($p = 0.017$) and lower than in 6-MP display in dentinal caries in lower molars ($p = 0.003$) in bright lighting and in enamel caries in lower molars ($p = 0.012$) in dim lighting (Table 3).

Uncalibrated consumer grade display worked poorly in interpreting the corresponding findings (Table 4). Overall, none of the displays had high proportions of interpreting dentinal caries.

Consumer grade display was significantly better in dim than in bright lighting in detecting dentinal caries in the upper molars ($p = 0.035$).

The intraobserver reliability was fair in enamel caries in upper ($\kappa_w = 0.36$) and moderate in lower ($\kappa_w = 0.44$) molars, and substantial in upper and lower dentinal caries ($\kappa_w = 0.66$ and 0.64 ; Table 5). On initial viewing,

Table 2 A proportion of equivalent ratings in visibility of the dentinoenamel junction, and numbers and proportions of positive ratings in different displays when rated in consensus ($n = 35$), separately in bright and dim lighting

Display	Bright		Dim	
	%Eqv.	#pos. (%)	%Eqv.	#pos. (%)
Tablet	83.8	29 (82.9)	81.8	29 (82.9)
Consumer grade	64.9	23 (65.7)	78.4	29 (82.9)
Digital imaging and communications in medicine-calibrated consumer grade 6 megapixels	83.8	30 (85.7)	89.2	32 (91.4)
	94.6	34 (97.1)	94.6	34 (97.1)

%Eqv., proportion of equivalent ratings with consensus; #pos. (%), number and proportion of positive findings when in consensus.

Table 3 Comparison of agreement between different displays in enamel and dentinal caries in upper (dd. 26, 27) and lower (dd. 37, 36) molars compared with the consensus rating, separately in bright and dim lighting

n = 74 Pathology/display	Bright				Dim				
	% _{Eqv.}	κ_w (SE)	p-value ^a	p-value ^b	% _{Eqv.}	κ_w (SE)	p-value ^a	p-value ^b	p-value ^c
Enamel caries, upper molars (d26 and d27)									
Tablet	77.0	0.61 (0.09)			70.3	0.48 (0.10)			0.23
Consumer grade	60.8	0.36 (0.09)	0.013	0.017	71.6	0.56 (0.09)	0.58	>0.99	0.08
DICOM-calibrated consumer grade	75.7	0.57 (0.09)	0.17	>0.99	75.7	0.52 (0.10)	0.34	0.45	>0.99
6 MP	85.1	0.70 (0.08)		0.18	81.1	0.58 (0.10)		0.08	0.55
Enamel caries, lower molars (d36 and d37)									
Tablet	85.1	0.71 (0.09)			82.4	0.54 (0.11)			0.79
Consumer grade	75.7	0.49 (0.11)	0.003	0.09	79.7	0.53 (0.11)	0.11	0.77	0.51
DICOM-calibrated consumer grade	90.5	0.83 (0.07)	>0.99	0.39	87.8	0.73 (0.09)	0.18	0.42	0.63
6 MP	91.9	0.77 (0.09)		0.23	94.6	0.84 (0.08)		0.012	0.63
Dentinal caries, upper molars (d26 and d27)									
Tablet	73.0	0.42 (0.11)			79.7	0.54 (0.11)			0.27
Consumer grade	67.6	0.42 (0.09)	0.79	0.48	79.7	0.62 (0.08)	0.73	>0.99	0.035
DICOM-calibrated consumer grade	70.3	0.43 (0.10)	0.42	0.80	77.0	0.54 (0.10)	>0.99	0.75	0.27
6 MP	75.7	0.50 (0.10)		0.79	77.0	0.48 (0.10)		0.77	>0.99
Dentinal caries, lower molars (d36 and d37)									
Tablet	74.3	0.46 (0.11)			75.7	0.39 (0.11)			>0.99
Consumer grade	66.2	0.30 (0.10)	0.022	0.18	68.9	0.31 (0.11)	0.004	0.23	0.75
DICOM-calibrated consumer grade	78.4	0.56 (0.08)	0.039	0.58	81.1	0.50 (0.11)	>0.99	0.29	0.63
6 MP	89.2	0.75 (0.08)		0.003	82.4	0.54 (0.11)		0.23	0.13

%_{Eqv.}, proportion of equivalent ratings; DICOM, digital imaging and communications in medicine; MP, megapixels; κ_w , linearly weighted kappa; SE, standard error.

The p-values <0.05 are in bold.

^aSignificance from McNemar's test between consumer grade and DICOM-calibrated consumer grade (upper p-value), and DICOM-calibrated consumer grade and 6 MP (lower p-value).

^bSignificance from McNemar's test between tablet and other displays.

^cSignificance from McNemar's test between bright and dim lighting.

the dentinoenamel junction and the border of alveolar crests were evaluated as visible in all 15 radiographs, whereas on reviewing, the dentinoenamel junction was once evaluated as an uncertain finding.

The interobserver reliability between the readers was fair at upper and substantial in lower enamel caries ($\kappa_w = 0.29$ and $\kappa_w = 0.63$, respectively), and moderate in upper and substantial in lower dentinal

Table 4 Numbers and proportions of positive and negative findings in different displays in enamel and dentinal caries in upper (dd. 26, 27) and lower (dd. 37, 36) molars when positive or negative finding, respectively, in consensus, separately in bright and dim lighting

n = 74 Pathology/display	Positive findings			Negative findings		
	# _{Cons.}	Bright # _{pos.} (%)	Dim # _{pos.} (%)	# _{Cons.}	Bright # _{neg.} (%)	Dim # _{neg.} (%)
Enamel caries, upper molars (d26 and d27)						
Tablet	24	13 (54.2)	12 (50.0)	48	43 (89.6)	38 (79.2)
Consumer grade		7 (29.2)	12 (50.0)		36 (75.0)	39 (81.3)
DICOM-calibrated consumer grade		15 (62.5)	16 (66.7)		39 (81.3)	38 (79.2)
6 MP		22 (91.7)	17 (70.8)		40 (83.3)	41 (85.4)
Enamel caries, lower molars (d36 and d37)						
Tablet	16	11 (68.8)	8 (50.0)	56	50 (89.3)	51 (91.1)
Consumer grade		7 (43.8)	7 (43.8)		47 (83.9)	50 (89.2)
DICOM-calibrated consumer grade		13 (81.3)	12 (75.0)		52 (92.9)	51 (91.1)
6 MP		13 (81.3)	13 (81.3)		53 (94.6)	55 (98.2)
Dentinal caries, upper molars (d26 and d27)						
Tablet	9	5 (55.6)	6 (66.7)	60	46 (76.7)	50 (83.3)
Consumer grade		3 (33.3)	4 (44.4)		43 (71.7)	52 (86.7)
DICOM-calibrated consumer grade		4 (44.4)	5 (55.6)		45 (75.0)	50 (83.3)
6 MP		7 (77.8)	5 (55.6)		48 (80.0)	50 (83.3)
Dentinal caries, lower molars (d36 and d37)						
Tablet	13	5 (38.5)	3 (23.1)	54	47 (87.0)	50 (92.6)
Consumer grade		2 (15.4)	3 (23.1)		43 (79.6)	45 (83.3)
DICOM-calibrated consumer grade		2 (15.4)	4 (30.8)		50 (92.6)	51 (94.4)
6 MP		8 (61.5)	6 (46.2)		54 (100.0)	53 (98.1)

#_{Cons.}, number of positive/negative findings (*i.e.* certainly a finding/not a finding) in consensus; #_{neg.} (%), number and proportion of negative findings when not a finding in the consensus; #_{pos.} (%), number and proportion of positive findings when a finding in the consensus. DICOM, digital imaging and communications in medicine; MP, megapixels.

Table 5 Intraobserver and interobserver reliability assessed using 6 megapixel display in dim lighting

Pathology	Intraobserver reliability, ^a 30 structures		Interobserver reliability, ^b 56 structures	
	%Eqv.	κ_w	%Eqv.	κ_w
Enamel caries, upper molars (d26 and d27)	86.7	0.36	66.1	0.29
Enamel caries, lower molars (d36 and d37)	90.0	0.44	87.5	0.63
Dental caries, upper molars (d26 and d27)	80.0	0.66	64.3	0.46
Dental caries, lower molars (d36 and d37)	93.3	0.64	85.7	0.60

%Eqv., proportion of equivalent ratings; κ_w , linearly weighted kappa.

^aBetween the initial viewing of Observer 1 and reviewing of 15 radiographs.

^bBetween the viewings of Observers 1 and 2 (28 radiographs successfully rated by both observers).

caries ($\kappa_w = 0.46$ and $\kappa_w = 0.60$, respectively; Table 5). The dentinoenamel junction was evaluated as visible in all 28 radiographs by Observer 1 and in 26 radiographs by Observer 2, and the border of alveolar crests was evaluated as visible in all 28 radiographs by both observers.

Discussion

In the present study, DICOM-calibrated consumer grade display was significantly better than uncalibrated consumer grade display, slightly better than tablet and almost equal to medical displays in the interpretation of enamel and dental caries in bitewing radiographs. Tablet was slightly worse than medical displays in both lighting. Overall, with consumer grade display the proportions of equivalent ratings were higher under dim than bright lighting and were statistically significantly better for the interpretation of dental caries in upper molars. High-contrast structures such as the dentinoenamel junction and the cortical border of alveolar crest were seen almost equally well in all displays under both lighting conditions in bitewing radiographs.

The ability to detect caries lesions on dental radiographs depends on lesion grade. In this study, to mimic clinical conditions, lesion grade was not validated. Deeper lesions are easier to detect than relatively superficial ones.³⁰ Early radiographic detection of caries lesions in the enamel is important, as the probability of cavitation is low and the prospect of interceptive treatment is good. Hellén-Halme *et al*¹⁵ concluded that it was easier to detect dental caries in dim conditions than in bright conditions, whereas with enamel caries, there were no differences between the lighting when the display was adjusted for optimal brightness and contrast. Pakkala *et al*¹⁹ also concluded that different displays and room illuminance levels did not affect the overall accuracy of intraoral radiographs in enamel caries detection. In the present study, DICOM calibration significantly improved enamel caries interpretation as compared with uncalibrated display in bright lighting. 6-MP display was significantly better than tablet in detecting enamel caries in lower molars in dim lighting, whereas tablet was significantly better than consumer grade display in detecting enamel caries in upper molars in bright lighting.

The purpose of the GSDF calibration is to ensure the optimal presentation and perception of contrast in digital radiography and to ensure that radiographs are presented unaltered over time and different locations. This standard is commonly used in medical 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 calibration may affect the diagnostic accuracy of digital radiographs.

Previously, Hellén-Halme *et al*¹⁶ found that there was no difference between bright and dim lighting in the ability to detect caries lesions in digital intraoral radiographs when the display was calibrated to DICOM part 14 standards. McIlgorm *et al*³¹ concluded that standardizing consumer grade display devices to the DICOM part 14: GSDF can improve the presentation of dental radiological images. They also concluded that a DICOM-calibrated consumer grade monitor is capable of displaying an image quality that is equally preferred to a DICOM-calibrated medical grade monitor for 8-bit dental images.³² In these studies,^{31,32} the ambient light level was set between 25 and 40 lx. Recently, Kallio-Pulkkinen *et al*³³ concluded that the DICOM-calibrated consumer grade display is adequate for the detection of anatomical structures and pathology in panoramic radiographs also in bright (510 lx) ambient light.³³ In the present study, the DICOM-calibrated consumer grade display was significantly better for the interpretation of enamel caries in lower and upper molars and dental caries in lower molars in bright lighting and in dental caries in lower molars in both lighting conditions. It can be concluded that the DICOM calibration can improve dental caries detection especially in bright lighting.

According to the FDA, tablets are not intended to replace full workstations and are indicated for use only when there is no access to a workstation.¹⁰ All participants in the FDA Task Group agreed that the device was sufficient for diagnostic image interpretation under the recommended lighting.³⁴ Recently, Shintaku *et al*¹⁴ concluded that the iPad 2 can effectively display images, comparably to the evaluated LCD monitor, for the evaluation of interproximal caries under bright light conditions. Furthermore, Shintaku *et al* concluded that

image size did not affect the ability to identify dental caries on the iPad 2 compared with a 24-inch LCD monitor. Similar findings were made by Cederberg *et al*²³ and Isidor *et al*.²⁴ Cederberg *et al*²³ compared three medical-grade cathode ray tube displays and a laptop for the detection of interproximal caries. The authors did not detect a significant difference in diagnostic accuracy and luminance values, monitor size or resolution between these displays. Isidor *et al*²⁴ compared five LCD displays with different sizes and resolutions for the detection of caries. The authors did not detect statistically significant differences between the displays. In the present study, the resolution of the consumer grade display was lower than that of the tablet and the 6-MP display or the matrix size of the displayed bitewing radiographs. Thus, viewing images on the medical display may have benefitted from the higher resolution. However, the display resolution or matrix size of the images did not affect observer performance in the detection of anatomical structures or interpretation of caries in bitewing radiographs when comparing the calibrated and non-calibrated consumer grade display. Furthermore, the tablet was slightly worse

than medical display and almost equal to the DICOM-calibrated display in interpreting of enamel and dental caries in bitewing radiographs in both lighting conditions.

There are several limitations pertaining to the present clinical investigation. First, instead of measuring the ability to make a correct diagnosis, a subjective method was used to evaluate the underlying differences in image quality between modalities. Second, a real golden standard method was not used; instead, consensus with two observers with the 6-MP display was used as reference. Previously, histology has been used as the gold standard in *in vitro* studies; however, such an approach is of limited value for a clinical setting.³⁵

In conclusion, DICOM calibration improves the detection of enamel and dental caries in bitewing radiographs, particularly in bright lighting. Therefore, a DICOM-calibrated consumer grade display can be recommended as a diagnostic tool with bitewing radiographs. Surprisingly, a tablet display used to view bitewing radiographs can almost equal a DICOM-calibrated display in the detection of enamel and dental caries in both bright and dim lighting. Further research is needed on the clinical use of tablet devices.

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