Quality of 'commercial-off-the-shelf' (COTS) monitors displaying dental radiographs

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RESEARCH

IN BRIEF

- Reports that commercial-off-the-shelf (COTS) computer display monitors for viewing dental images are commonplace.
- Highlights that a computer display monitor used for interpreting dental images should have a maximum luminance of 171 cd/m^2.
- Stresses that early carious lesions in a displayed image could go undetected due to high ambient light levels found in dental surgeries.

Background A computer display monitor used for interpreting dental images should have a maximum luminance of 171 cd/m^2. A monitor used for clinical review should have a maximum luminance of 100 cd/m^2. **Objective** To compare luminance and ambient lighting measurements for a selection of computer display monitors in different locations of a dental teaching hospital to available guidelines. To assess six commercial off-the-shelf (COTS) monitors from the radiology department of the dental teaching hospital after calibration to the Digital Imaging and Communications in Medicine Part 14: Greyscale Standard Display Function (DICOM part 14: GSDF). **Design** Data collection. **Method** Luminance and illuminance measurements were taken for a selection of monitors used for clinical applications throughout a dental teaching hospital. Conformance data were recorded for six COTS monitors from the radiology department following calibration to the DICOM part 14: GSDF. **Results** None of the tested monitors had a maximum luminance value that was appropriate for image interpretation and the ambient lighting in the vicinity of the monitors was also set to inappropriate levels for image interpretation. The quality of conformance to the DICOM part 14: GSDF varied among the calibrated COTS monitors in the radiology department. **Conclusions** It is important that display devices used for dental radiology are quality assured. Consideration should be given to ensure that monitors used for dental radiological interpretation have a maximum luminance that meets available guidelines. These monitors should be standardised to the DICOM part 14: GSDF and the illumination of the reporting environment should be controlled.

INTRODUCTION

The traditional method of displaying diagnostic information in dental radiology has been analogue radiographic film displayed on a light box.[1] Many dental schools and dental practices have now changed to digital radiography and computerised picture archiving and communication systems (PACS). However, some dental schools and dental practices may be unable to afford the widespread installation of high-end medical display systems that are found throughout the large acute hospital sector so it would not be unusual to find a range of commercial-off-the-shelf (COTS) monitors from various manufacturers used for both image interpretation and clinical review in these instances. A recent study reported that the predominant type of monitor used by general dental practitioners was flat panel liquid crystal display (LCD).[2] Most have a display area of 1,024 × 768 pixels, (<1 megapixel), a maximum luminance of approximately 152 cd/m^2, and conform to the eight to eight bit standard personal computer (PC) system architecture allowing the display of 256 shades of grey.[2]

Dental radiology quality assurance systems are an important component of the 'employer's procedures' and each step of the imaging chain must be considered in the process of image optimisation; so it is important to assess the quality of the monitors that are displaying the final images. The Institute of Physics and Engineering in Medicine (IPEM) *Report 91* addresses a number of issues that are important to the quality of the displayed image,[3] and cites the tests and tolerance levels that have been described in the American Association of Physicists in Medicine Task Group 18 (AAPM TG18) document *Assessment of display performance for medical imaging systems*.[4] These levels are based upon fundamental brightness concepts that are optimal for the human visual system.[5]

A high incident luminance on the retinal cones maximises visual acuity, a display monitor used to interpret radiographic images should have a maximum luminance of at least 171 cd/m^2 and a contrast ratio of at least 250:1.[4] A monitor used to review images (after initial interpretation) should have a maximum luminance of at least 100 cd/m^2 and a contrast ratio of at least 100:1.[4]

The luminance presented by the monitor should produce a uniform brightness

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across the screen and should differ by no more than 30% across different areas of the screen.[4]

The greyscale response of the monitor should be adjusted or 'perceptually linearised' so that the maximum number of distinct grey levels identifiable to the human visual system can be utilised.[4,5] This is achieved by calibrating the monitor to the Digital Imaging and Communications in Medicine Part 14: Greyscale Standard Display Function (DICOM* part 14: GSDF).[4–6]

Maintaining the ambient light at a low level can prevent the degradation of low contrast regions of a displayed image,[7] and medical reporting of hard tissues recommends an ambient light level of 25-40 lux.[8]

This study assessed the maximum luminance, contrast ratio, luminance uniformity and ambient light level for a selection of monitors used in different parts of a dental teaching hospital. The study also assessed how well the COTS monitors in the radiology department of the dental teaching hospital conformed to the DICOM part 14: GSDF after calibration.

MATERIAL AND METHODS

Monitors

A random selection of 25% of the 'commercial off-the-shelf' (COTS) flat panel LCD monitors from each of four clinical areas (outside of the radiology department) of a dental teaching hospital (n = 28) as well as two medical grade flat panel LCD monitors in the radiology department were assessed. Within the radiology department all six COTS flat panel LCD monitors used for clinical applications were also included. The COTS monitors were produced by different manufacturers, ranging in age from four to eight years. They were a selection of 15, 17 and 19 inch screen size; all had a resolution of 1,024 × 768 pixels (<1 megapixel). The medical grade monitors both had a resolution of 1,200 × 1,600 pixels (1-2 megapixels) and 21 inch screen size.

*DICOM (Digital Imaging and Communications in Medicine) is an international standard for handling, storing, printing and transmitting information in medical and dental diagnostic imaging. DICOM enables the integration of digital radiographic machines, servers and workstations into a picture archiving and communication system (PACS).

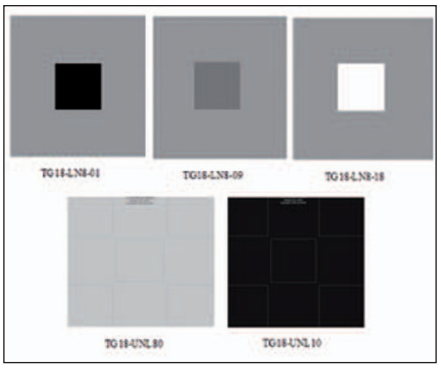

Fig. 1 AAPM TG18 test patterns

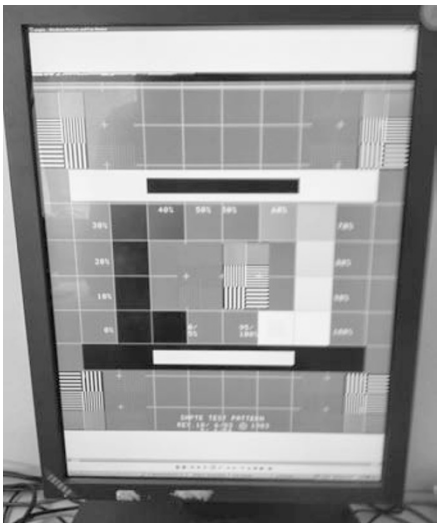

Fig. 2 A Totoku monitor was one of the medical grade monitors assessed. (An advantage of medical grade monitors is that the screen can swivel to present images in portrait or landscape mode, in this photograph the test pattern has been displayed in portrait mode)

All of the monitors had standard graphic display controllers, providing eight bit input to eight bit output, and set to display 24 bit colour.

Physical measurements

All of the monitors had their display surface cleaned by a slightly moistened paper towel and commercial washing up liquid, and then dried with a second paper towel. All monitors were switched on for 30 minutes before testing. No adjustments were made to any of the external controls associated with the monitors at this stage of testing.

Eight bit AAPM TG18 bitmap (bmp) test patterns (Fig. 1) were displayed full screen for the specific measurements.[4] The measurements were taken with a calibrated Unfors Luxi photometer (Unfors Instruments, Billdal, Sweden). Three recordings were taken for each of the

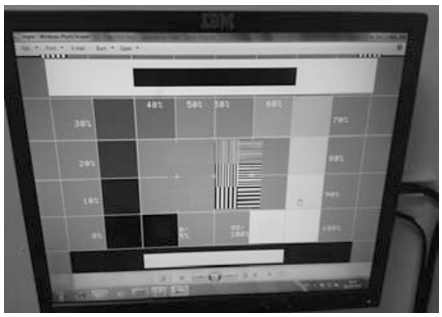

Fig. 3 The IBM commercial off-the-shelf (COTS) monitor that had the best conformance to the DICOM part 14: GSDF calibration[9]

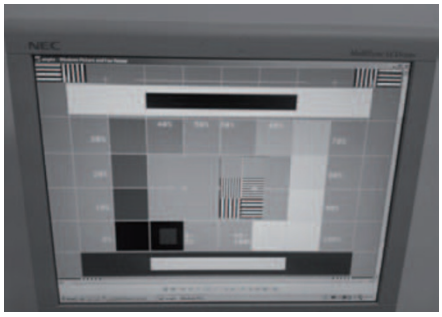

Fig. 4 The NEC commercial off-the-shelf (COTS) monitor that had the poorest conformance to the DICOM part 14: GSDF calibration.[9] (The digital driving levels (DDLs) of the graphics display controller may be unable to achieve any further improvement to the DICOM part 14: GSDF conformance or there could have been backlight degradation as a consequence of age)

measurements. The recordings were taken during the day in the month of August.

The ambient light level was measured by displaying the TG18-LN8-09 pattern and placing the photometer with the focusing cup attachment facing away from the monitor screen.[4] The ambient light level was set to between 25-40 lux in the vicinity of each monitor.[8] The maximum luminance, minimum luminance, contrast ratio and luminance uniformity measurements were recorded according to the AAPM TG18 guidelines using test patterns TG18-LN8-01, TG18-LN8-18, TG18-UNL80 and TG18-UNL10 respectively.[4]

DICOM part 14: GSDF calibration

The ambient light level was set to between 25-40 lux in the vicinity of each of the six COTS monitors in the radiology department.[8] The six COTS monitors had their brightness and contrast controls adjusted so that the best subjective presentations were obtained whereby the perceived contrast of the 5% square and its 0% surrounding was equal to the perceived contrast between the 95% square and its

Table 1 Overall average parameters for COTS monitors assessed in the teaching hospital. (Standard deviation is in parentheses)

Ambient (lux)	Max luminance (cd/m²)	Min luminance (cd/m²)	Contrast ratio (N:1)	Uniformity (%)	Screen size. Median (inches)
270.6 (154.4)	110.3 (23.5)	0.24 (0.07)	566 (232)	11.90 (3.99)	17

Table 2 Average parameters for COTS monitors assessed in the clinical areas (standard deviation in parentheses) as well as parameters for two medical grade monitors

*Area	No of devices	Ambient (lux)	Max luminance (cd/m²)	Min luminance (cd/m²)	Contrast ratio (N:1)	Uniformity (%)
‡Clinic one	9	293.4 (122.9)	108.3 (46.1)	0.27 (0.08)	440.2(211.9)	9.56 (5.61)
‡Clinic two	10	492.9(218.0)	96.81 (28.35)	0.27(0.08)	395.2 (172.3)	9.2 (2.7)
A/E and oral surgery	5	310.7 (110.7)	111.4 (44.8)	0.27 (0.06)	447 (255)	8.4 (3.6)
Oral med	4	167.9 (107.4)	148.5 (75.2)	0.28 (0.07)	586 (315)	17.25 (15.39)
Radiology	6	88.2 (47.2)	86.6 (34.5)	0.1 (0.06)	960 (548)	15.08 (2.67)
Med grade one	1	93.5	40.63	0.05	812.60	9.0
Med grade two	1	130.23	155.6	0.27	576.3	6.5

*One way analysis of variance (ANOVA) used for the clinical areas. Ambient, p = 0.001; Min luminance, p = 0.001; contrast ratio, p = 0.013.
‡Clinics 1 and 2 are areas of the dental hospital where the students carry out restorative, endodontic and prosthetic dental treatment under supervision.

surrounding white square for a displayed Society of Motion Picture and Television Engineers (SMPTE) pattern.[6] The monitors were then calibrated with the Verilum[9] software (version 5.02) and luminance pod (Image Smiths Inc., Bethesda, MD) to conform to the DICOM part14: GSDF standard.[9] The luminance pod measured the separate luminance response at 33 intervals over the complete luminance range of the monitors. This resulted in the software mapping the manipulated digital driving levels (DDLs) to the prescribed look-up table (LUT) and storing them in the graphics video controller of the display systems. The DICOM part14: GSDF transformation could be applied when the gamma correction was enabled on the Verilum software. The calibration software is used as a quality assurance tool for monitors and provides a quantitative measure of the conformance of the monitor to the DICOM part 14: GSDF.[9]

RESULTS

Luminance

The mean maximum luminance (Table 1) for the COTS monitors used for clinical applications throughout the dental hospital was 110.3 cd/m² at 95% confidence interval (102.40, 118.20). A one sample t-test indicated that the maximum luminance of these monitors would not conform to the AAPM TG18 guideline (171 cd/m²) for interpreting purposes, t(35) = -15.5, p = 0.001. Looking at the high contrast ratios (Table 2) for these COTS monitors one could get a false impression that they might be high brightness (luminance) devices, however, the maximum luminance results indicate otherwise. The contrast ratios of the monitors (Table 2) in each of the clinical areas varied significantly (p = 0.013), which may be related to the variations in minimum luminance and the variety of monitors from different manufacturers (Table 3).

Surprisingly, neither of the two medical grade monitors (Table 2) was optimised to a maximum luminance of at least 171 cd/m².[4] The reason for this particular finding is the oversight in acceptance testing for these two monitors. Both devices require the installation of their own calibration software, which can adjust the backlight of the device so that the maximum and minimum luminance can be set to provide an appropriate contrast ratio. These medical grade monitors (Fig. 2) often come with a service level agreement with the manufacturer or supplier who will monitor and maintain adequate luminance parameters, but this was not the case in this dental hospital. The luminance uniformity (Table 2) for the monitors in all of the clinical areas was under the 30% tolerance recommended by AAPM TG18.

Ambient light

The ambient light levels (Table 2) also varied throughout the different clinical areas of the dental hospital (p = 0.001).

The radiology department had the lowest value (88.2 lux). Those areas with high values, especially the supervised student practice area of clinic two (492.9 lux), had large windows and no blinds. These reported statistical variations may need to be treated with some caution as the sample sizes of the monitors in each of the clinical areas varied. However, the quantitative information provides a reasonable 'snapshot' of some important display device parameters associated with COTS monitors used within a dental teaching hospital.

DICOM part 14: GSDF conformance

The column headed 'Just noticeable difference' (JND) per luminance interval (Table 4) gives an indication of how well the discrete grey levels could be detected over the luminance range of the monitor after the monitor has been calibrated to the DICOM part14: GSDF. Large differences between the maximum and minimum values would suggest more of a deviation away from the ideal DICOM part14: GSDF transformation. The column headed 'Root mean square error' (Table 4) shows how well the monitors have been 'perceptually linearised'; the smaller the value the more closely the monitor approximates the ideal transformation with a consistent perceptual response for the observer over the luminance range. It is interesting to note that a monitor with a maximum luminance of 128.10 cd/m² received a rating of 'fair' and a monitor with a maximum luminance of 51.91 cd/m² received a rating of 'good' (Table 4) as to how well they conformed to the DICOM part 14: GSDF calibration process. This quantitative information allows one to make comparisons between the monitors.

DISCUSSION

The human visual system exhibits a natural non-linear contrast threshold that is generally improved with increased luminance.[5] The detection of low contrast features in the presented image is therefore optimal at a higher average luminance level and this should be uniform across the screen of the monitor. Contrast ratio

Table 4 Technical specifications and DICOM part 14: GSDF conformance data provided by the Verilum[9] software application for the six COTS monitors in the radiology department

Monitor	Product type	Year of manufacture	Max luminance (cd/m²)	Screen size (inches)	Just noticeable difference (JND) per luminance interval (min–max)	Root mean square error	Grade
IBM Thinkvision L171 (Armonk, NY)	LCD	2005	67.85	17	1.27 (1.18–1.36)	0.051	Good
HP 1740 (Palo Alto, CA)	LCD	2006	74.35	17	1.44 (1.33–1.55)	0.062	Good
Philips Brilliance 150P2 (Amsterdam)	LCD	2001	127.11	15	1.64 (1.51–1.82)	0.077	Good
HP 1740 (Palo Alto, CA)	LCD	2006	51.91	17	1.55 1.39–1.72)	0.081	Good
Philips Brilliance 150P2 (Amsterdam)	LCD	2001	128.10	15	1.66 (1.47–1.87)	0.119	Fair
NEC Multisync 1550V (Minato, Tokyo)	LCD	2002	63.16	15	1.04 (0.68–1.20)	0.124	Poor

is the ratio of luminance between the brightest white (maximum luminance) and the darkest black (minimum luminance) that can be produced by the monitor. Contrast ratio is a major determinant of perceived image quality.[4] If a monitor has a high contrast ratio, it can present sharper images than one with a lower contrast ratio and the same resolution, since display resolution is a function of the actual size and luminance profile of the pixels displaying the image. To achieve optimal contrast ratio it is important that the black level (minimum luminance) is set accurately; and for a COTS monitor this very often might require some adjustment to the external brightness and contrast controls.[10] However, for most COTS monitors this parameter is usually accepted 'out of the box', though manufacturers tend to cite overly optimistic specifications and users may be unaware that adjustments are required.[10] Reflection of ambient light from the display surface can influence the ability of an observer to detect low contrast objects within the displayed image.[7] This degradation of low contrast structures can be controlled with relatively bright areas of the image under examination (using a high luminance monitor) and low ambient light.[7]

The results from this investigation might suggest that monitors used with dental digital imaging systems that would not meet the AAPM TG18 maximum luminance guideline of 171 cd/m² are common in dental practice. The findings from this dental teaching hospital can be compared to those of Hellén-Halme who found that monitors used in general dental practice were also below 171 cd/m².[2] Cederberg reported that there can be a wide variation in the maximum luminance of monitors used with dental digital imaging systems, with some monitors having a maximum luminance value below 100 cd/m².[11] The monitors in this investigation were predominantly COTS monitors (Figs. 3 and 4) and yet are used to make diagnostic decisions, from caries detection to diagnosing pathological lesions. They are also used for other applications such as accessing electronic dental records and reading and composing letters. They are used in environments where there is a high level of ambient light, which is common in dental surgeries.[10,12]

Medical grade monitors (Fig. 2) are generally considered to be the standard for primary interpretation of most radiographic images. Medical grade monitors are CE marked medical devices and would have added grounding and reduced current leakage. They would also offer some significant advantages over COTS monitors for diagnostic imaging, such as a higher maximum luminance, the ability to offer a higher greyscale resolution, improved viewing angle, and calibration to the DICOM part14: GSDF standard. These options tend to increase the cost of these display devices substantially and manufacturers will often undertake image quality monitoring of their medical grade display devices provided there is a contract for supply and service. However, there have been conflicting reports as to whether there is any difference in image quality and clinical diagnosis between COTs monitors and medical grade displays.[13–15] The continual investment worldwide in COTS display technology, driven by the consumer market to achieve more technically advanced products, will mean further research in this area.

Table 3 Commercial off-the-shelf (COTS) and medical grade monitors assessed in the investigation

Manufacturer of device	Quantity
ACER (COTS)	4
Dell (COTS)	5
Fujitsu Siemens (COTS)	3
HP (COTS)	7
IBM (COTS)	3
LG (COTS)	3
NEC (COTS)	6
Philips (COTS)	3
Totoku (Medical grade)	1
Eizo (Medical grade)	1

There is now a wider range of dental and maxillofacial radiology applications requiring the on-screen soft copy display of images, for example conventional radiographs, computed tomography (CT), cone-beam computed tomography (CBCT), magnetic resonance imaging (MRI) and ultra sound (US). More soft copy dental images are also being shared among practitioners as part of the patient's care pathway, so there is the need to select appropriate monitors for viewing and an increasing expectation that these monitors should adhere to a

standardisation protocol.[16] The concept of 'perceptual linearisation' attributed to the DICOM part 14: GSDF calibration process makes sure that there is a consistent mapping from the image data space of the grey-scale processed image to the human observer's visual sensory space.[5] The practical significance is that distortions in the transferred clinical information between the presented image and the perceived visual sensation are minimised. The DICOM part 14: GSDF standardisation process also allows a quantitative characterisation of the display system to be obtained.[6] The quantitative information provides a better description of the display system (Fig. 4) than just the luminance range of the monitor and this information can assist practitioners in choosing the best display system designs for clinical applications and to assess consistency between monitors (Figs. 3 and 4). With the DICOM part14: GSDF calibration process a digital driving level (DDL) is selected to produce a luminance value nearest the desired luminance on the DICOM part 14: GSDF curve, and in many instances for a 'perceptually linearised' monitor the outcome will depend on discrete samples in the DDL range and the bit depth of the display controller, as well as the luminance range of the monitor;[6] and this conformance must be regularly checked by the user.[17]

This investigation assessed only the luminance quality of monitors. However, there are other important factors such as spatial resolution, colour temperature, image geometry and stability, which can affect image display quality on a monitor. Further studies of these other factors are now needed and guidelines that address these factors may need to be consulted.[3,4]

In conclusion, monitors with a high maximum luminance should be used when interpreting and reviewing dental radiographs. The best possible displayed luminance values that match the contrast sensitivity of the human visual system should also be obtained by calibrating the monitor to the DICOM part 14: GSDF.

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