RESEARCH ARTICLE

DICOM part 14: GSDF-calibrated medical grade monitor vs a DICOM part 14: GSDF-calibrated “commercial off-the-shelf” (COTS) monitor for viewing 8-bit dental images

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Objectives: To investigate whether there is any difference in the presented image quality between a medical grade monitor and a “commercial off-the-shelf” (COTS) monitor when displaying an 8-bit dental image.

Methods: The digital imaging and communications in medicine (DICOM) part 14: greyscale standard display function (GSDF) was verified for both monitors. A visual grading characteristics (VGC) curve was constructed to measure the difference in image quality between the two monitors by comparing radiological structures displayed on each monitor with a DICOM part 14: GSDF-calibrated laptop monitor as reference.

Results: All of the monitors conformed to within the American Association of Physicists in Medicine Task Group 18 10% tolerance levels for the assessment of the DICOM part 14: GSDF. There was no difference in the preferred perceived visual sensation for the displayed image between the two tested monitors with the area under the VGC curve = 0.53 and 95% confidence interval = 0.47–0.59.

Conclusions: A DICOM part 14: GSDF COTS monitor is capable of displaying an image quality that is equally preferred to a DICOM part 14: GSDF medical grade monitor for an 8-bit image file.

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Introduction

Display systems can influence the contrast resolution requirements for clinical applications. The adaptive phenomenon of the human visual system means that one’s sensitivity is increased to small brightness variations when the area of interest is surrounded by bright elements. Barten¹ investigated these brightness variations, and the digital imaging and communications in medicine (DICOM) part 14: greyscale standard display function (GSDF)² was defined, with the distance

between two luminances that the human eye could just about detect called just noticeable differences (JNDs). For a luminance range from 0.05 to 4000 cd m⁻², there are 1023 JNDs as defined by the DICOM part 14: GSDF.² It is also important to remember that the outcome for clinical applications would also depend on the bit depth of the display controller, as well as the luminance range. Most modern flat panel monitors cover a high luminance range that requires >256 or 8-bit JNDs and such displays should be driven with >256 digital driving levels (DDLs). However, most display systems and display controllers still only offer an 8-bit wide video memory and signal pipeline, yielding not more than 256

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available DDLs. A 10-bit DICOM part 14: GSDF-calibrated high-luminance medical grade monitor would allow 1024 shades of grey to be displayed. However, if this 10-bit monitor is connected to a standard 8-bit display controller, 256 luminances closest to the GSDF luminances (JNDs) are selected out of the display shades (0–1023) to display the 8-bit dental image. This allows the display of an 8-bit dental image with “10-bit precision” for the observer, and all of the greyscale information in the 8-bit dental image should be perceived by the observer.³ On the other hand, the normal greyscale precision of most “commercial off-the-shelf” (COTS) liquid crystal display (LCD) monitors connected to a standard display controller is 8 bits and after calibration to the DICOM part 14: GSDF not as many of the luminances (JNDs) of the GSDF are met.

It is often the case that some of the greyscale information in the 8-bit dental image will not be perceived by the observer.³

This investigation uses a visual grading characteristics (VGCs) analysis as a measure of the difference in image quality between two modalities.⁴ Visual grading studies are straightforward to conduct and clinical images are often readily available. Comparing images produced by two test modalities, observers grade the visibility of the structure on the test image relative to that of a reference image using an arbitrary step scale (much worse to much better) with the middle value of the scale meaning a visibility equal to the reference image.^{4,5} The concept behind a visual grading analysis (VGA) is that if the practitioner knows the anatomical landmarks or appearance of a pathological lesion and is presented with a high-quality image, then he/she would be confident to make a diagnosis. The VGA results can then be used to characterize the difference in image quality between the two modalities in the same way as the difference in the response of the observers to the signal and noise distributions are used to characterize the observers in a receiver operating characteristics study. The objective of this investigation was to determine whether there was any preference by the observer in the presented image quality between a DICOM part 14: GSDF-calibrated medical grade monitor and a DICOM part 14: GSDF-calibrated COTS monitor when displaying 8-bit dental images.

Methods and materials

Ethical approval from the Faculty of Health Sciences, Trinity College Dublin, Dublin, Ireland, as well as informed consent from the participating observers was obtained prior to this investigation.

Selection of monitors

A BARCO MDRC1119 LCD 19-inch monitor (Barco, Kortrijk, Belgium) with a native resolution of 1280×1024 (1 megapixel) and a maximum luminance that would be classed as primary (reporting or diagnostic) by the

American Association of Physicists in Medicine Task Group 18 was selected.⁶ The BARCO monitor came with an integral 10-bit DICOM part 14: GSDF look-up table and was stated as being DICOM compliant “out of the box”.

A DELL™ E Series E1913S light-emitting diode (LED) 19-inch COTS monitor (Dell, Round Rock, TX) with a native resolution of 1280×1024 (1 megapixel) and a maximum luminance that would be classed as primary (reporting or diagnostic) by the American Association of Physicists in Medicine Task Group 18 was also selected.⁶ The DELL monitor was calibrated by the investigators using Verilum⁷ v. 5.02 (Image Smiths Inc., Bethesda, MD) software to conform to the DICOM part 14: GSDF luminance response.

The null hypothesis was tested for the following situation:

- There is no difference in the overall perceived visual sensation between the DICOM part 14: GSDF-calibrated BARCO monitor and the DICOM part 14: GSDF-calibrated DELL monitor when displaying an 8-bit image file.

To perform the test, the visibility of a target structure in a presented image on each of the two selected monitors was compared with the corresponding structure presented on a monitor displaying a reference image. An observer would give a score for each of the selected monitors.

The laptop monitor that was used to present the reference image was a 15-inch LCD Fujitsu Siemens Esprimo Mobile V5505 machine (Fujitsu Siemens, Munich, Germany) that had a native resolution of 1280×800 pixels (<1 megapixel) and was also calibrated to conform to the DICOM part 14: GSDF using the Verilum⁷ software application. It should be noted that this monitor had a maximum luminance that would be classed as secondary (review) by the American Association of Physicists in Medicine Task Group 18.⁶ Table 1 presents technical information for the three monitors.

Verification of the digital imaging and communications in medicine part 14: greyscale standard display function: The “out of the box” DICOM part 14: GSDF calibration of the BARCO monitor, as well as the DICOM part 14: GSDF calibration of the DELL and laptop monitors were first verified. The minimum and maximum DDL values are used to verify the calibrated minimum luminance value and the maximum luminance value, respectively. The contrast values normalized to their respective JND are then calculated for the calibrated display devices. A deviation of 10% from the DICOM part 14: GSDF standard is allowed for reporting monitors, while a 20% deviation is allowed for review monitors. The protocol for DICOM part 14: GSDF verification as outlined in a specific National Health Service UK document was followed.⁸ Conformance data were obtained by measuring the luminance output

Table 1 Technical specification of the three monitors

Monitor	Display type	Year of manufacture	Maximum luminance (cd m^{-2})	Screen size (inches)	Resolution
BARCO (clinical)	LCD	2010	187.60	19	1280 × 1024
DELL™ E1931S (commercial off-the-shelf)	LED	2012	186.10	19	1280 × 1024
Fujitsu Siemens Esprimo Mobile V5505 (Laptop)	LCD	2007	160.50	15	1280 × 800

LCD, liquid crystal display; LED, light-emitting diode.

BARCO was obtained from Barco, Kortrijk, Belgium; DELL from Dell, Round Rock, TX; Fujitsu Siemens Esprimo Mobile V5505 from Fujitsu Siemens, Munich, Germany.

of the centre of the squares ranging from 0% to 100% for an 8-bit Society of Motion Pictures & Television Engineers (SMPTE) test pattern.

The measurements were performed using a calibrated Luxi photometer (Unfors Instruments, Billdal, Sweden), capable of measuring both luminance (candela per square metre) and illuminance (lux). The results were then entered into the protocol spreadsheet to obtain the contrast response for the calibrated display device and compared against the DICOM part 14: GSDF standard.^{2,6,8}

Evaluation of images

Four clinical supervisors (one prosthodontist, one orthodontist, one paediatric dentist and one general dental practitioner with a mean of 23 years' experience interpreting dental radiographs) and two final-year dental students (each with 3 years' experience interpreting dental radiographs) carried out the VGA. The method used for the relative VGA was similar to that previously described in the literature.^{9,10} The manufacturers' names on the display devices were obscured, and the ambient lighting was set to between 25 and 40 lux.¹¹ The evaluation of the test monitors was alternated for each observer, and each observer scored one monitor against the reference monitor and then immediately scored the second monitor against the reference monitor; although for this evaluation, the sequence of the displayed images was changed. 15 anonymous dental images for teaching dental radiology were used for the VGA. The 8-bit JPEG images with horizontal and vertical resolution of 96 dots per inch were displayed on a Windows®-based viewing application in slide show mode (Microsoft, Redmond, WA). The image files were displayed as they were saved, having been optimized to facilitate their interpretation during the teaching module. They consisted of nine intraoral images, four panoramic images, one upper standard occlusal image and one lateral cephalometric image. The participants were asked not to alter the display of the images that were scaled to fit the screen of the monitors. They were asked to view the images at 90° to the screen at a distance of between 30 (close inspection) and 60 cm (normal viewing).¹²

The participants were given information on 2 pre-defined criteria relating to target anatomical structures within each of the 15 anonymous 8-bit JPEG dental images. The participants were instructed to score the

display quality of the pre-defined criteria of the target structure on the test image relative to the corresponding landmark on the reference image using the following scoring system:

- (1) Test image is clearly superior to the reference image.
- (2) Test image is somewhat superior to the reference image.
- (3) Test image is equal to the reference image.
- (4) Test image is somewhat inferior to the reference image.
- (5) Test image is clearly inferior to the reference image.

At the end of the grading session, the participants were asked to choose which monitor they would purchase for use in their practice.

Figures 1 and 2 are examples of images that were used.

Criteria for Figure 1. It is a periapical radiograph of extensive carious lesions in the 47 and 48.

- (a) There is a clearly demarcated area of low radio-opacity and high radio-opacity at the root apices of 47 and 48.
- (b) The radiolucency of the radicular canal can be visualized in the middle third of the mesial root of 47.

Criteria for Figure 2. It is a panoramic view of a patient with a large right mandibular swelling.

- (a) The small retained root in the 46 region is covered by a radio-opaque area that extends to just above the mesial cemento-enamel junction (CEJ) of 47.
- (b) The radiolucency that represents the left mental foramen is clearly visible.

Analysis

The VGA scores were analysed in a manner similar to that used in receiver operating characteristic analysis.⁵ A constructed VGC curve described the relationship between the proportions of fulfilled image criteria for the two compared monitors taking into consideration all the possible thresholds for a fulfilled criterion. The area under the VGC curve (AUC_{VGC}) was used as a single measure of the difference in image quality between the two compared monitors. An AUC_{VGC} value >0.5 would indicate that one of the compared monitors

Figure 1 One of the intra-oral images used in the visual grading analysis.

offered a preferred image quality over the other, and an AUC_{VGC} value of 0.5 would indicate that the image quality offered by the two monitors was similar in preference.

Results

All three monitors conformed to within the 10% tolerance levels for the assessment of the DICOM part 14: GSDF. It is interesting to note that the largest deviation (6.8%) was recorded for the BARCO monitor (Figure 3) that was classed as DICOM compliant out of the box. Such monitors usually incorporate their own DICOM part 14: GSDF factory-calibrated look-up table (LUT), and it is also important to remember that an 8-bit test pattern was used for the conformance checking. The other two monitors (DELL and Fujitsu Siemens) had their DDLs actively manipulated by the Verilum⁷ software to a prescribed look-up table that was stored on their respective graphics controllers, which conformed well to the DICOM part 14: GSDF (Figures 4 and 5). The collected VGA data consisted of 180

observations for each of the two monitors (BARCO and DELL). Based on the specific criteria and observers used in this investigation, the quantitative findings (Figure 6) showed that the DELL monitor offered a similar preferred perceived visual sensation for the displayed image to that of the BARCO monitor with the $AUC_{VGC} = 0.53$ and 95% confidence interval = 0.47–0.59, although all of the participants said that they would choose the BARCO monitor for practice.

Discussion

There are differing opinions as to whether medical grade monitors offer any superior diagnostic properties for observers. Doyle et al¹³ found that there was no difference in the accuracy of observer performance for detection of wrist fractures with a personal computer monitor compared with that of a picture archiving and communication system workstation. Geijer et al⁹ did not find any significant difference in image quality between a medical grade monochrome LCD display and a colour LCD display of equal spatial resolution, with either a contrast-detail phantom or a VGA. However, a more recent study by Kuprinski¹⁴ found that the overall, diagnostic accuracy was significantly higher with medical grade displays than with COTS colour displays. Perhaps with the passing of time, medical grade monitors have undergone technical advances that can outperform COTS monitors by presenting superior diagnostic image quality. If this is the case, then with the continual investment worldwide in COTS monitor technology to achieve more technically advanced products for consumers, COTS monitors may soon catch up. Based on the observers and criteria used in this investigation, a high fidelity DICOM part 14: GSDF-calibrated COTS monitor produced an equally preferred perceived image quality to that of the DICOM part 14: GSDF-calibrated medical grade monitor when displaying an 8-bit dental image, and may also suggest that a DICOM part 14: GSDF-calibrated monitor can improve image presentation for the clinical observer.¹⁰ Of course the limitation of visual grading as used in this

Figure 2 One of the panoramic images used in the visual grading analysis.

Figure 3 The luminance response of the BARCO monitor (Barco, Kortrijk, Belgium) expressed as the change in luminance between successive grey levels for a just noticeable difference (JND) (dL/L for a JND), plotted against the digital driving level (DDL). The dashed lines correspond to the +10% American Association of Physicists in Medicine Task Group 18⁶ tolerance for the assessment of the digital imaging and communications in medicine part 14: greyscale standard display function.

investigation is that it is a subjective method to measure the difference in image quality between modalities and not a measure of the ability to make the correct diagnosis.

Whether monitors that can support higher bit depths or calibrating a COTS monitor to the DICOM part 14: GSDF has any effect on clinical diagnosis, particularly with the availability of window levelling and image processing tools that can enhance the presentation of the image for diagnostic purposes,^{15–17} may require further investigation. A recent dental study found that DICOM part 14: GSDF-calibrated display devices made no significant difference to the accuracy of

Figure 4 The luminance response of the DELL monitor (Dell, Round Rock, TX) expressed as the change in luminance between successive grey levels for a just noticeable difference (JND) (dL/L for a JND), plotted against the digital driving level (DDL). The dashed lines correspond to the +10% American Association of Physicists in Medicine Task Group 18⁶ tolerance for the assessment of the digital imaging and communications in medicine part 14: greyscale standard display function.

Figure 5 The luminance response of the Fujitsu Siemens laptop monitor (Fujitsu Siemens, Munich, Germany) expressed as the change in luminance between successive grey levels for a just noticeable difference (JND) (dL/L for a JND), plotted against the digital driving level (DDL). The dashed lines correspond to the +10% American Association of Physicists in Medicine Task Group 18⁶ tolerance for the assessment of the digital imaging and communications in medicine part 14: greyscale standard display function.

approximal caries lesion diagnosis.¹⁸ However, many dental practitioners may be unaware of the ability to apply window levelling to the displayed images in order that all greyscales present in the input image can be visualized sequentially in time by mapping part of the input greyscales to the available grey levels of the display, and window levelling will invariably increase the time needed to analyse a displayed image. There is more of a dependence on the actual monitor to just present the captured digital information itself during the interpretation and review of the displayed image, and very often the specifications and quality of the monitor can be overlooked by the end user.

This investigation provides some useful technical information regarding the soft copy display of dental images. To display an image file with 1024 shades of grey, the entire “pipeline” (application, graphics cards and drivers and the monitor) should all support this 10-bit feature. Therefore, to present accurate coded greyscale modulation information that is >8-bit on a high luminance monitor, a 10-bit pipeline would seem the most sensible option. For a DICOM part 14: GSDF-calibrated high-luminance monitor, an 8-bit input is not really sufficient to dispose of all the discernible JNDs to describe the image, and the display should be driven at a higher bit input if possible.

It is also important to point out that viewing applications have to be specifically written to allow 10-bit per channel output to the higher bit display panel using graphic driver-specific function calls. The 10-bit depth extension technology that was available in the medical grade monitor used in this investigation produces a “pseudo” 10-bit signal in 8-bit signal form, although this type of display panel technology would have the potential to provide the high bit depth luminance output

Figure 6 The 95% confidence interval (CI) of the visual grading characteristics (VGC) curve [area under the VGC curve (AUC_{VGC}) = 0.53] covers 0.5. The digital imaging and communications in medicine part 14: greyscale standard display function (DICOM part 14: GSDF) calibrated BARCO monitor (Barco, Kortrijk, Belgium) and the DICOM part 14: GSDF calibrated DELL monitor (Dell, Round Rock, TX) present an equally preferred image quality. Std Dev, standard deviation; VGA, visual grading analysis.

required for the image receptors currently available in dental practice as long as they are calibrated to the DICOM part 14: GSDF. However, this investigation reflects the current image display practice carried out within the dental community, whereby most available viewing applications and workstation monitors (which are predominantly COTS monitors) present the pixel data with 8-bit shades of grey only.¹⁹ It also highlights the fact that the high luminance monitors that are now available for clinical applications in dentistry as well as COTS monitors that are also used for this purpose should make the best use of the JNDs within their range, and this can be achieved by calibrating them to the DICOM part 14: GSDF.² In an interesting investigation by Hiwasa et al,²⁰ where the greyscale resolution of monitors was investigated by displaying simple test patterns having various grey levels in 8, 10 and 12 bits on a DICOM part 14: GSDF-calibrated LCD monitor, they found that the observers were able to distinguish more grey levels as the bit depth was increased. However, Bender et al²¹ found that even though the higher greyscale resolution results in a more complete visualization of image information, radiologists partially judged this as a lack of

sharpness and contrast and generally preferred the 8-bit display. They went on to make the important point that interobserver heterogeneity and the influence of radiological experience can be interpreted as a strong influence of the individual preference of what a “good” radiological image should look like.

The design of this investigation to measure image quality between two modalities using anatomical images and dental practitioners from diverse clinical disciplines, along with the qualitative finding that all of the observers would purchase the “pseudo” 10-bit monitor, may add some weight to this assumption in the dental setting.

In conclusion, this investigation found that from an observer’s point of view, the DICOM part 14: GSDF-calibrated COTS monitor used in this study was capable of displaying an image quality that is equally preferred to a DICOM part 14: GSDF-calibrated medical grade monitor for an 8-bit image file. However, further research is required to determine what effect viewing software and displays supporting higher bit depths might have on the presentation of dental images.

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