



# **Picture archiving and communication systems (PACS) and guidelines on diagnostic display devices**

**Third edition**

**February 2019**

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**Foreword**

This guidance forms part of a series produced by the Radiology Informatics Committee which aims to highlight rapid developments in information technology in radiology. Diagnostic images are reviewed in multiple settings and the specific requirements for diagnostic display devices are outlined dependent on whether this is primary diagnostic work, clinical review work or mobile review of radiology images. The importance of the viewing environment – physical and ergonomic – should always be taken into consideration alongside the performance of the diagnostic display devices. The current guidance incorporates relevant areas of and supersedes *Picture archiving and communication systems (PACS) and quality assurance, second edition*, which is now withdrawn. Thanks go to Dr Daniel Fascia, the late Dr Dave Harvey and members of the Radiology Informatics Committee and the Professional Support and Standards Board for developing this guidance.

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*Vice-President, Clinical Radiology*

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## 1. Key recommendations

- Primary diagnostic workstations should be equipped with a reliable display with at least three megapixels (MP) resolution, a luminance range of at least 1–350 candelas per square meter ( $\text{cd}/\text{m}^2$ ) which is regularly hardware calibrated such that it remains within 10% of the digital imaging and communications in medicine (DICOM) grayscale standard display function (GSDF).
- Clinical review displays should be at least 2 MP resolution with a luminance range 0.8–250 $\text{cd}/\text{m}^2$  and should be calibrated at least once a year to remain within 20% of the DICOM GSDF. Either hardware or perceptual calibration (using the Task Group 18 [TG18] test pattern) may be used.<sup>1</sup>
- Mobile device displays should mainly be used in the absence of a primary diagnostic display. They should conform to the same standards as clinical review displays.
- When colour displays are used in radiology, they should still meet the grayscale calibration requirements for the given setting. The consistent use of the standard red green blue (sRGB) colour space is recommended to achieve uniformity across workplaces.
- Mammography is regarded as a specialist imaging situation requiring a higher resolution and brighter display unit.
- The viewing environment should be strictly controlled in the primary diagnostic setting. For clinical review, the environment should be controlled as best achievable.
- If consumer off-the-shelf (COTS) displays are chosen, a workplace must also operate and document a regular quality-control and calibration programme.

## 2. Introduction

Digital display monitors are the standard method for viewing radiological investigations, with hard-copy film now being a minority medium. It is therefore of great importance that standards exist to ensure these devices meet quality benchmarks throughout their working lifespans.

Broadly speaking there are three main conventional settings for radiology display devices which have different needs.

**Primary diagnostic work** is usually carried out by a radiologist or other specialist trained healthcare professional to generate a formal and legally binding medical report.

**Clinical review work** is carried out by a vast range of healthcare professionals who wish to view and interpret images to influence clinical management but who do not typically generate a formal radiology report.

**Mobile review of radiology images** is becoming more common and presents a number of challenges in terms of the sheer range of devices available, the varied component displays used and the difficult nature of controlling the reading environment.

The choice of displays suitable for a specific workplace will depend on a number of additional influencing factors such as cost, supplier, departmental preferences and the intended workplace setting.

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### 3. Display device technology

In the past, cathode ray tube (CRT) devices were commonplace but are now regarded as obsolete for medical imaging and should not be used.

Flat panel liquid crystal displays (LCDs) are now ubiquitous in medical imaging and offer the advantages of high spatial resolution, low distortion, high luminance and high contrast ratios. They are also now economical to purchase, and compared to CRT devices, they occupy much less space, and consume much lower amounts of energy. LCDs are found in both static dedicated displays and embedded displays in mobile devices.

Contrary to persisting myth, LCD monitors do not suffer permanent image burn in effects like CRT displays did. However, LCD monitors do have a finite lamp life and should therefore be turned off whenever not in use to prolong life expectancy, reduce persistence effects and ensure long-term colour accuracy. Many devices have built in automatic timed screen-off programmes which should be used. Screen savers should however be avoided with LCD as they will increase lamp hours while the monitor is not in meaningful use and reduce overall lifespan.

In-plane switching (IPS) monitors improve viewing angles of LCD which is useful in medical settings where flexibility of viewing conditions is important (for example, operating theatres or emergency departments).

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### 4. Calibration

Medical monitors must allow custom measurement and adjustment of their colour and grayscale tonal representations to allow for calibration towards recognised reference standards.

For monochrome imaging the DICOM GSDF specifies a means to generate a lookup table to produce a consistent mapping of a monitor's digital driving levels (DDL) to specific perceptible shades of grey. Regular quality-control procedures should be in place to ensure compliance with the GSDF. Note that calibration and conformance to DICOM GSDF does not require or guarantee any specific number of greyscale levels, or any particular resolution – it merely defines the perceptual linearity of the brightness aspect of the display.

No standards have been defined for compliance of mobile display devices, but we would recommend the same reference standard as clinical review displays. Calibration of mobile devices to recognised standards also presents a challenge since it is frequently not possible to load and save custom colour profiles without specialist software or programming experience.

- For primary diagnostic use, formal hardware calibration to within 10% of the DICOM GSDF is required and must be maintained over the lifespan of the display.
- For clinical review use, a display should be calibrated either with hardware or perceptually using the TG18 test pattern.<sup>1-3</sup> Performance variance should be within 20% of the DICOM GSDF.
- Mobile devices cannot always be calibrated but can be used for clinical review. They should be tested for suitability using the TG18 test pattern.<sup>1</sup>

Colour space for medical images has not been previously considered since colour LCD monitors have not thus far been in widespread diagnostic use. However, colour displays are now commonplace in nuclear medicine and ultrasound and are also widely used in areas using advanced image manipulation packages. The use of the same colour space across monitors in a department will ensure consistent reading and interpretation of colour

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images regardless of workstation. The sRGB standard is recommended as a ubiquitous and widely supported colour space, and is now recommended in DICOM although this is in the absence of any formal evidence. (sRGB is an RGB color space that HP and Microsoft created co-operatively in 1996 to use on monitors, printers, and the internet.) The white point should be set to the International Commission on Illumination (CIE) standard D65 of 6500 Kelvin (K).

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## 5. Consumer-grade off-the-shelf (COTS) displays versus dedicated medical displays (DMD)

One of the most frequent questions raised is ‘Do we need medical grade monitors?’

For several years now COTS devices have provided sufficient resolution, contrast and luminance ratios to meet medical imaging standards. Studies have shown them to be of adequate diagnostic quality when compared to DMD.<sup>4,5</sup> However, a number of other factors must be considered.

The lifetime display characteristics are important in the primary diagnostic setting. It is important that luminance and contrast ratios do not deteriorate and that drift from the DICOM GSDF does not occur, creating a misrepresentation of diagnostic data. This risk can be mitigated by a regular quality-assurance and calibration programme but will require extra departmental administrative work. By contrast DMD usually include self calibration and quality control for their expected lifespan.

Choosing a COTS device is also not as simple as choosing a DMD. It will require specialist knowledge of display devices and the ability to accurately compare technical specifications to those set out in this document to ensure performance compliance for the intended use case.

Spatial resolution of any chosen device must be adequate for the intended use case. Plain-film radiography involves images with much higher resolution and grayscale variance than computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound images. Using a device of inadequate resolution introduces error prone interpolation artefacts and requires excessive software zooming to see actual pixel data.

Dedicated features are often available out of the box in DMD which enhance the primary diagnostic and clinical review experience but cannot not be taken for granted in COTS devices. Non-exhaustive examples would include: portrait display rotation, ability to daisy-chain connect multiple displays and temporary luminance boosting to improve viewing sensitivity.

Cost savings by contrast favour COTS devices. Displays are usually much cheaper and can be purchased from consumer retailers rather than dedicated medical representatives. COTS displays usually do not require the additional purchase of dedicated graphics cards. For the clinical review setting, COTS devices are a sensible economical alternative to DMD but more careful consideration is required for the primary diagnostic setting.

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## 6. Recommendations

### Primary diagnostic work

Primary diagnostic work relates to the critical diagnostic reading of medical images to produce a legally binding radiological report.

**Diagnostic displays** should therefore conform to the standards recommended the College.

**The viewing environment** should be carefully controlled. The desirable screen to reader distance is around 60 centimetres (cm) with the screen correctly angulated and placed in plane with the reader's eyes. The centre of the screen should be at reader's eye level. Background lighting ('ambient lighting') should be low, diffused and no brighter than the display but not totally dark. There should be no other directional lighting in the reading room to avoid reflection artefacts on the screen. Desk level controllable 'task lighting' may be required for non-screen based work. Whatever lighting is present should be as consistent as possible, especially if non-auto-calibrating monitors are used, as a DICOM Part 14 greyscale calibration is only valid for a single level of ambient illumination.

While not directly related to the display, the general reading room environment should not be overlooked, with appropriate attention paid to the control of temperature, humidity, seating and desk ergonomics, input devices, noise levels and interruptions to workflow. Each of these factors, along with appropriate displays, has an impact on employee fatigue.

Regardless of the comfort level of the reading environment, users should be advised to ambulate regularly and take appropriate eye rests to prevent strain injury. The most widely suggested strategy by optometrists is the 20-20-20 rule.

*For every 20 minutes of close screen work, take a 20-second break during which you stare at something 20 feet away.*

**Table 1: Recommendations for display standards in primary diagnostic work**

| Feature                         | Plain film X-ray        | CT scan                 | MRI scan                | Ultrasound scan                | Fluoroscopy                    | Nuclear medicine               |
|---------------------------------|-------------------------|-------------------------|-------------------------|--------------------------------|--------------------------------|--------------------------------|
| Minimum resolution (Megapixels) | 2048 x 1536 (3 MP)      | 1600 x 1200 (2 MP)      | 1600 x 1200 (2 MP)      | 1600 x 1200 (2 MP)             | 1600 x 1200 (2 MP)             | 1600 x 1200 (2 MP)             |
| Megapixel resolution            | 3 MP                    | 2 MP                    | 2 MP                    | 2 MP                           | 2 MP                           | 2 MP                           |
| Maximum pixel pitch             | 0.21 mm                 | 0.21 mm                 | 0.21 mm                 | 0.25 mm                        | 0.25 mm                        | 0.25 mm                        |
| Orientation                     | Portrait format         | Portrait/landscape      | Portrait/landscape      | Portrait/landscape             | Portrait/landscape             | Portrait/landscape             |
| Calibration                     | DICOM GSDF $\leq 10\%$  | DICOM GSDF $\leq 10\%$  | DICOM GSDF $\leq 10\%$  | DICOM GSDF or sRGB $\leq 20\%$ | DICOM GSDF or sRGB $\leq 20\%$ | DICOM GSDF or sRGB $\leq 20\%$ |
| Luminance (min/max)             | 1/350 cd/m <sup>2</sup> | 1/350 cd/m <sup>2</sup> | 1/350 cd/m <sup>2</sup> | 0.8/250 cd/m <sup>2</sup>      | 0.8/250 cd/m <sup>2</sup>      | 0.8/250 cd/m <sup>2</sup>      |

Separate guidelines for breast radiology can be found on page 9.

### Clinical review work

With radiology in such widespread and essential daily use, a wide range of non-radiology healthcare professionals now interpret medical imaging and the need for improved quality monitors has grown. Clinical review displays are typically used in short bursts to read radiological images as part of a wider clinical assessment routine.

The viewing environment in the clinical review area is much more varied and difficult to control than in the radiology reading room. Viewing angles may need to be greater in settings such as the operating theatre and emergency room. It is often impossible to reduce background and directional lighting to the recommended diffused, ambient levels. The use of add-on screen shades around displays can help create a micro-environment and improve viewing conditions.

Display calibration should be carried out at least annually to ensure compliance within 20% of the DICOM GSDF. This ensures that sufficiently accurate data is being viewed by all healthcare professionals and that it is consistent with that seen by the radiologist.

### Mobile review work

With high ownership levels of mobile devices such as smartphones, laptops and tablet computers, the viewing of radiological images is inevitable. In common with COTS displays, there is a wide range of embedded display quality variation. The College does not endorse any single device but advises checking of specifications before critically reviewing radiological images.

Some devices have been assessed in clinical trials and have also gained Food and Drug Administration (FDA) approval in the United States of America for the review of medical images when a primary diagnostic display is not available.

When working in a mobile or remote reading environment, the speed of data transfer is often a prime consideration. Data compression is frequently used to improve latency of the viewing experience. It is important to ensure that the highest fidelity images possible are served to any remote device concerned in a clinical decision. Particular attention must be paid to the number of grey levels and amount and type of data compression used. Lossless compression is recommended.

When virtual private networks (VPN) are used to connect to a work environment, it is important not to operate in desktop repeating 'screen sharing' mode because the fidelity of the transmitted image is usually inadequate. Typically, the greyscale palette is very limited and resolution is frequently compromised by lossy compression algorithms. Put simply, real-time screen sharing software is not appropriate for diagnostic radiology use.



**Table 2: Clinical and mobile review display standards**

| Feature                         | All   |
|---------------------------------|---|
| Minimum resolution (Megapixels) | 1600 x 1200 (2 MP)                                |
| Megapixel resolution            | 2 MP  |
| Maximum pixel pitch             | 0.25 mm   |
| Colour/monochrome               | Colour  |
| Orientation                     | Landscape or portrait format                      |
| Calibration                     | DICOM GSDF $\leq 20\%$ or using TG18 test pattern |
| Luminance (min/max)             | 1/250 cd/m <sup>2</sup>                           |

### Breast radiology

Digital mammographic images contain high spatial resolution data and have a natively low contrast resolution due to the composition of breast tissue. Successful interpretation depends on differentiation of small structures from surrounding tissue, notably microcalcifications. It is therefore important that correct specialist displays are used in a well designed viewing environment.

**Table 3. Breast radiology display standards**

| Feature                         | All modalities                             |
|---------------------------------|--|
| Minimum resolution (Megapixels) | 2560 x 2048 (5 MP)                         |
| Megapixel resolution            | 5 MP                                       |
| Maximum pixel pitch             | 0.17 mm                                    |
| Colour/monochrome               | Colour or monochrome                       |
| Orientation                     | Portrait format                            |
| Calibration                     | DICOM GSDF $\leq 10\%$ strictly maintained |
| Luminance (min/max)             | 1/400 cd/m <sup>2</sup>                    |

Due to the size of mammographic images it is common to represent studies at 50% magnification, with a tool to allow interpretation at 100% magnification (that is a 1:1 pixel ratio) as part of each read routine. More unusual fractions of magnification should be avoided to prevent pixel interpolation artefacts.

### Lower resolution monitors and mobile displays

Studies have suggested that interpreting digital mammographic images on displays <5 MP compromises the reading experience such that it is not recommended. Interpretation typically takes longer due to more zooming and panning and, may require specialist software to simulate higher contrast resolution.<sup>6,7</sup>

It has however been suggested that 3 MP monitors with appropriate software can be used for training.<sup>8</sup>

Mobile displays emphatically must not be used for the diagnostic reading of mammograms.

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