



The Royal College of Radiologists

Board of the Faculty of Clinical Radiology

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

This guidance forms part of a series on the developments in information technology in radiology. This is a fast-moving field and developments are occurring rapidly. Consequently, this guidance will be updated regularly and readers should check regularly that they are using the most up-to-date guidance available.

These guidelines are aimed at simplifying the essentials relating to medical display devices (including picture archiving and communication system [PACS] monitors), and deal with the issues of spatial and contrast resolutions, and provide a recommended basic specification table. These guidelines should be read in conjunction with those on the ergonomics of a PACS workstation to appreciate the importance particularly of ambient lighting conditions on digital display devices.

1. Classification of display devices

- 1.1 Medical display devices can be classified as either primary (diagnostic) or secondary (review). Primary display devices are used for the interpretation of medical images. Secondary display devices are used for reviewing medical images, usually in conjunction with the report. It is recommended that all primary display devices undergo acceptance testing and regular performance review.

- 1.2 Specialist 'medical grade' flat panel liquid crystal display (LCD) devices are now preferred to cathode-ray tube (CRT) devices as they can offer superior performance in terms of maximum luminance and linearity, and can also offer such features as automatic calibration and remote quality assurance.

2. Spatial resolution

- 2.1 When first viewing a digital radiographic image, the image data should be interpolated to display the image fully within the maximum available screen area since it is recognised that pattern recognition of non-spatially limited abnormalities can be overlooked if the image is not viewed as a whole. There is insufficient evidence to quantify the clinical risks associated with viewing images interpolated below their acquisition resolution, but it has been shown that any risk can be minimised by a process of systematic magnification.

- 2.2 On a medical imaging workstation, magnification should be achieved by using the software zoom, pan and magnification tools, as closer visual inspection will not overcome the effects of image interpolation. Ideally, images should be magnified to their acquisition resolution or to a whole number magnification factor greater (for example, x2 or x3) to avoid the risk of introducing artefacts due to image interpolation. For example, when an image is too large to be displayed fully on screen, it should be displayed at its acquisition resolution (1:1 pixel matching) and the image panned around the screen until the whole of the image has been viewed. Alternatively, the magnifying glass tool can be used to systematically magnify areas of the image to reveal the full image detail. Studies suggest that there is little reduction in the diagnostic power of using these techniques when compared

to displaying the whole image at 1:1 on higher resolution screens, but there is an increase in the time taken to make a report.

- 2.3 When viewing multiple images, it is recommended that serial images are compared directly, side-by-side, to highlight any difference in appearance. Smaller images, such as those obtained in 'cross-sectional' imaging, can be displayed fully side-by-side on a single screen. Larger images, such as from projection radiography (CR and DR), should ideally be viewed on separate displays to optimise the ratio of the display resolution to the acquisition resolution.
- 2.4 At 'normal' viewing distances, the psychophysical performance of the human eye imposes a limit on the perceived resolution. It has been calculated that at a 60 cm viewing distance, human visual performance is well matched to a screen with 0.25 mm pixels (pixel pitch). This is equivalent to a native screen resolution of 1280 x 1024 (~1.3 MP) on a 42 cm (~17") display, or 1600 x 1200 (~1.9 MP) on a 50 cm (~20") display. Higher resolution display devices enable the user to view the image in greater detail by closer inspection of the screen, but a similar effect can be achieved with software zoom, pan and magnification tools. High fidelity dual screen displays (≥ 3 MP) are recommended in radiology and other areas where large numbers of radiographic images are reported, to reduce reporting times and thereby optimise department workflow.

3. Contrast resolution

- 3.1 The contrast resolution of a display system depends on a number of factors, including the maximum and minimum luminance of the display device, the characteristic (luminance response) curve of the display device, the greyscale bit depth, the background ambient illumination, and the use of application software windowing tools (see below). A useful concept is the 'just noticeable difference' (JND) index. Each JND index step corresponds to a perceivable difference in grey scale resolution. In medical image viewing, it is desirable to optimise the number of JND index steps available
- 3.2 The *contrast ratio* of a display system is defined as the ratio of the maximum to minimum luminance that the device is capable of displaying. In general, the higher the contrast ratio of a display device, the higher the number of JND index steps that can be perceived, and the better the contrast resolution. High fidelity 'medical grade' monochrome LCD monitors are brighter than CRT displays, achieving maximum luminance values >500 cd/m², and contrast ratios $>800:1$. CRT monitors are less bright but typically have significantly lower minimum luminance values, and can thus achieve higher contrast ratios. High fidelity LCD monitors usually perform

better in practice, as CRT monitors are more susceptible to the effects of ambient illumination on low luminance contrast resolution. There is some evidence that high brightness display devices with maximum luminance >500 cd/m² can cause fatigue and impair contrast resolution by their effect on the adaptation level of the human visual system, and the optimum operating level may vary between users. LCD contrast ratio can deteriorate significantly at oblique viewing angles, and it is recommended that all reporting is performed with the user perpendicular to the screen.

3.3 The *characteristic curve* of a display device is a plot of the measured luminance response for each step in the digital driving level (DDL) of the display system. The human visual system has a non-linear response to contrast resolution, with the effect that it is more difficult to perceive contrast differences at low illumination. To compensate for this, a standard curve of luminance versus JND index has been defined within the DICOM Greyscale Standard Display Function (GSDF).¹ Devices calibrated according to the GSDF are said to be 'perceptually linear' in response, and optimised to human visual performance.

3.4 The *greyscale bit depth* of a display device is the number of levels of grey that can be represented by the digital driving level (DDL) of the display device. An 8-bit (per pixel) greyscale display device can represent 256 levels of grey, while a 10-bit device can represent up to 1024 total levels. For colour monitors displaying monochrome images, 24-bit and 32-bit colours are equivalent to 8-bit greyscale. Whether a user is able to perceive all the greyscale bit-depth levels that are represented depends on the maximum luminance, contrast ratio, and calibration of the display device to the GSDF (see above). In practice, a user will typically only see a fraction of the 256 levels of grey represented by a non-calibrated 8-bit display device as the luminance difference between each step in the DDL will not correspond to a 'perceivable difference' in greyscale contrast (JND index step). By comparison, high contrast 10-bit calibrated display devices are capable of displaying >500 perceivable shades of grey (JND index steps).

[Note that the current Windows operating system imposes an 8-bit limit on greyscale image data sent to a display, unless the Windows operating system is bypassed and image data written directly to the graphics card. Even with an 8-bit greyscale input, a 10-bit display device can outperform an 8-bit display device by ensuring all 256 input greyscale levels are represented as perceivable differences in greyscale to the end user.]

3.5 Application software *windowing* tools control the number of simultaneous greyscale values in an image that are presented for display. A DICOM image can encode up to 16 bits greyscale per pixel, but only a fraction of

these are shown at any time. By changing the centre (level) and range (width) of the greyscale values presented, it should be possible to demonstrate all the greyscale data represented in the image. The minimum specification of a display device in terms of contrast resolution parameters is therefore somewhat arbitrary, and depends on how the windowing tools are used during normal workflow. High fidelity display devices are recommended in radiology and other areas where large numbers of images are reported to reduce requirements for windowing images, and thus assist in reporting workflow.

4. Recommended specification

4.1 Table 1 shows the PACS and Teleradiology special interest group minimum and recommended specification for primary diagnostic display devices used for clinical image interpretation. This guidance applies to all workstations where CR, DR, fluoroscopy, ultrasound, CT, MR, nuclear medicine and PET images are viewed (excluding mammography).

Table 1. Minimum and recommended specification for primary diagnostic display devices used for clinical image interpretation

	Minimum ^a	Recommended ^a
Screen resolution ^b (Native pixel array)	≥1280 x 1024 ^c (~1.3 megapixels)	≥1500 x 2000 ^d (~3 megapixels)
Screen size (viewable diagonal)	≥42 cm (~17")	≥50 cm (~20")
Maximum luminance ^e	>170 cd/m ² ^f	≥500 cd/m ² ^g
Luminance contrast ratio (maximum/minimum)	≥250:1 ^{f,h}	≥500:1
Greyscale calibration	Within 10% GSDF ^h	Calibrated to GSDF ^e
Greyscale bit depth	8-bit greyscale (24-bit colour) ⁱ	≥10-bit greyscale
Video display interface	Digital-analogue	Digital video interface (DVI)
Pixel defects ^j ISO 13406-2 classification	Class 2 (2 per million)	Class 1 (0 defects)

Notes

- a: The minimum and recommended specifications for diagnostic display devices are only appropriate if clinical image viewing is performed according to image viewing guidelines. All diagnostic image interpretation should be performed on DICOM images, making use of the application software zoom, pan, magnification, and windowing tools to optimise spatial and contrast resolution.
- b: LCD devices should be run at their native resolution to ensure there is a 1:1 match between screen pixels and screen resolution, and therefore no loss of image quality due to screen interpolation. CRT displays can be run at a variety of resolutions with no loss of display quality; however, care should be taken that the correct aspect ratio is maintained to avoid distortion of the image.
- c: Where the majority of reporting performed on a diagnostic workstation is of cross-sectional imaging, lower resolution landscape style displays (≥ 1.3 megapixels) are considered adequate, providing larger images are interpreted with the aid of systematic magnification.
- d: High fidelity (≥ 3 megapixels) portrait style displays are recommended in radiology and other areas where large numbers of plain radiographic images are reported to reduce requirements for systematic magnification, and thus reduce image interpretation and reporting times.
- e: Display devices may be set initially to operate at a fraction of the maximum luminance in the manufacturer's specification. This can be adjusted to compensate for the decline in performance of the back-light over time while maintaining greyscale calibration.
- f: American Association of Physicists in Medicine TG18 recommendation.²
- g: High luminance displays can increase the number of perceivable greyscale levels (JND index steps) but may have a detrimental effect in user performance through fatigue and the human visual adaptation response. The optimum operating luminance level may vary between users.
- h: Institute of Physics and Engineering in Medicine 91 recommendation.³
- i: 24-bit and 32-bit colours are equivalent to 8-bit monochrome greyscale. Colour display devices are recommended for displaying colour images, but they generally perform less well than monochrome display devices in terms of maximum luminance and contrast ratio.
- j: The number of permissible pixel defects per million is defined by the ISO 13406-2 standard. Class 1 panels should have no defects. Class 2 panels should be replaced if they have >2 whole pixel defects per million. Appropriate use of application software zoom, pan and magnification tools can negate the effect of pixel defects in clinical practice.

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