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

2.5 Medical displays achieve their higher resolution by the use of a smaller pixel pitch, with most display
devices for primary diagnosis being limited to a size of approximately 54 cm (22"). COTS devices tend to
use a larger minimum pixel pitch and high pixel counts are achieved primarily by increasing the physical
size of the screen. The use of very large displays (>70 cm/27") may make achieving adequate ergonomics
difficult, particularly when used in a ‘portrait’ configuration, or when multiple display devices are used on a
single workstation.
2.6 Display devices, especially COTS displays, are increasingly available in ‘wide’ aspect ratios (AR) (for example, 16:9) as opposed to the older aspect ratios (4:3 and 5:4). When comparing the resolution of devices with different aspect ratios, the pixel count may be misleading, as the limiting factor is the absolute number of pixels in the limiting direction. Wide aspect ratios may not be as well suited to most radiographic images with squarer AR. However, a ‘wide’ monitor with the same number of pixel rows provides a greater screen area, so may help workflow by permitting the display of more images side by side.

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 COTS LCD displays, achieving maximum luminance values >500 cd/m², and contrast ratios >800:1. Higher display luminance is useful in maintaining visible contrast in the presence of ambient illumination. 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. It is common for medical LCDs to be specified with maximum luminance significantly higher than the recommended level. This is advantageous in prolonging the life of the display, as the luminance of the light source declines with aging. 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). 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).

[Current operating system software has limited support for handling 10-bit greyscale data. Display of 10-bit data requires the image display application to be written such that it communicates directly with a 10-bit capable graphics card, and that there is a 10-bit capable connection between the graphics card and display device. 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.

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† The luminance of the light source can be reduced electronically to reach the recommended value, but once the light source has degraded and is unable to maintain the recommended luminance, the display has reached the end of its working life.
4 Use of colour displays

4.1 Historically, the performance of colour display technology was insufficient to meet the recommended greyscale performance targets for primary diagnosis. Advances in technology have led to the development of colour display devices that are capable of achieving these standards. Previously, this may have required a segregation of reporting work: dedicated workstations with high performance monochrome displays for high-throughput reporting of projection radiography, and workstations with colour displays for reporting of nuclear medicine or other advanced modality imaging.

4.2 The accurate reproduction of colour images is technically complex and beyond the scope of this document. Unlike the multiple national standards for medical display greyscale luminance and contrast, there are not yet similar standards for colour medical image reproduction. However, commonly used (display and graphics) industry standards for colour calibration and response are incompatible with the DICOM monochrome luminance response meaning that a display cannot be calibrated to both standards simultaneously. Modern computer operating system software (e.g., Windows 7 and Mac OS X) provide a solution by the use of International Color Consortium (ICC) profiles, which inform the system software of the display device's colour response. Colour management capable software can process image colour data, so that the data sent to the display is corrected for the display's response function, and hence should provide near-optimal display regardless of the monitor's calibration (provided that the monitor's response is known, or has been measured). Alternative software-independent solutions to this problem have included display devices that automatically detect monochrome and coloured images, and apply the appropriate calibration to their respective screen regions. Where non-standard solutions such as this are used, their performance should be verified as part of acceptance testing.

‡ In the context of current radiology practice, where foreseeable use of colour is limited to false-colour images and/or coloured annotations, the risk associated with incorrect colour rendering is likely to be lower than that obtained by incorrect greyscale rendering.
5. **Recommended specification**

5.1 Table 1 shows the PACS and Imaging Informatics 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**

<table>
<thead>
<tr>
<th>Minimum(a)</th>
<th>Recommended(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen resolution(b) (Native pixel array)</td>
<td>(\geq 1280 \times 1024^c) (~1.3 megapixels)</td>
</tr>
<tr>
<td>Screen size (viewable diagonal)</td>
<td>(\geq 42) cm (~17&quot;)</td>
</tr>
<tr>
<td>Maximum luminance(e)</td>
<td>&gt;170 cd/m(^2)</td>
</tr>
<tr>
<td>Luminance contrast ratio (maximum/minimum)</td>
<td>(\geq 250:1^f)</td>
</tr>
<tr>
<td>Greyscale calibration</td>
<td>Within 10% GSDF(^h)</td>
</tr>
<tr>
<td>Greyscale bit depth</td>
<td>8-bit greyscale (24-bit colour)(^i)</td>
</tr>
<tr>
<td>Video display interface</td>
<td>Digital (Analogue not recommended for new installations)</td>
</tr>
<tr>
<td>Pixel defects(j)</td>
<td>ISO 13406-2 classification</td>
</tr>
</tbody>
</table>

**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. Displays should be configured such that the correct aspect ratio is maintained to avoid distortion of the image; this will automatically be the case if a 1:1 pixel match configuration is used.

c. Where the majority of reporting performed on a diagnostic workstation is of cross-sectional imaging, lower resolution landscape style displays (\(\geq 1.3\) megapixels) are considered adequate, providing larger (e.g. direct radiographic) images are interpreted with the aid of systematic magnification.

d. High fidelity (\(\geq 3\) 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.\(^4\)

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.\(^5\)

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.

Approved by the Board of the Faculty of Clinical Radiology: 15 June 2012
References


Citation details:
The Royal College of Radiologists. *Picture archiving and communication systems (PACS) and guidelines on diagnostic display devices.* London: The Royal College of Radiologists, 2012.

Ref No. BFCR(12)16 © The Royal College of Radiologists, November 2012

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