65

Quality Control of Medical Imaging Displays

Alisa Walz-Flannigan and Heather Weber

CONTENTS

65.1 Purpose/Introduction .................................................................................................................. 1298
65.2 Quality Goals for the Electronic Display of Medical Images .................................................... 1298
  65.2.1 Maximized Visibility of Image Information .............................................................................. 1298
  65.2.2 Minimization of Misleading or False Information ................................................................. 1299
  65.2.3 Consistent Presentation of Images ......................................................................................... 1299
65.3 QC Philosophy .......................................................................................................................... 1299
65.4 Scope ........................................................................................................................................ 1299
  65.4.1 Primary References ................................................................................................................ 1299
  65.4.2 Different Display Classes and Types ....................................................................................... 1299
    65.4.2.1 Geometrical Accuracy and Spatial Resolution ................................................................. 1300
    65.4.2.2 Display Luminance and Uniformity ............................................................................... 1300
65.5 Display Performance Characteristics Relevant to QC ............................................................... 1300
  65.5.1 Display Matrix and Interpolation ........................................................................................... 1300
  65.5.2 Display Luminance ................................................................................................................ 1300
  65.5.3 Ambient Lighting .................................................................................................................... 1300
  65.5.4 Grayscale Calibration ............................................................................................................. 1301
  65.5.5 Display Color ........................................................................................................................ 1301
  65.5.6 Display Luminance Non-Uniformity and Artifact ................................................................. 1301
  65.5.7 Display Spatial Resolution .................................................................................................... 1301
  65.5.8 Display Noise ......................................................................................................................... 1301
65.6 Testing Tools and Considerations ............................................................................................... 1302
  65.6.1 Photometers: Calibration and Comparisons ........................................................................... 1302
  65.6.2 Test Patterns ........................................................................................................................ 1302
65.7 QC Tests for Medical Image Displays ......................................................................................... 1303
  65.7.1 Display Cleanliness ................................................................................................................ 1303
    65.7.1.1 What Is Done ..................................................................................................................... 1303
    65.7.1.2 How It Is Checked .............................................................................................................. 1303
    65.7.1.3 What Is Expected .............................................................................................................. 1303
    65.7.1.4 Frequency ......................................................................................................................... 1303
  65.7.2 Viewing Environment Assessment ......................................................................................... 1303
    65.7.2.1 What Is Done ..................................................................................................................... 1303
    65.7.2.2 How It Is Checked .............................................................................................................. 1303
    65.7.2.3 What Is Expected .............................................................................................................. 1303
    65.7.2.4 Frequency ......................................................................................................................... 1303
  65.7.3 Settings Check ........................................................................................................................ 1304
    65.7.3.1 What Is Done ..................................................................................................................... 1304
    65.7.3.2 How It Is Checked .............................................................................................................. 1304
    65.7.3.3 What Is Expected .............................................................................................................. 1304
    65.7.3.4 Frequency ........................................................................................................................ 1304
  65.7.4 Qualitative Visual Assessment ............................................................................................... 1304
    65.7.4.1 What Is Done ..................................................................................................................... 1304
    65.7.4.2 How It Is Checked .............................................................................................................. 1304
    65.7.4.3 What Is Expected .............................................................................................................. 1305
    65.7.4.4 Frequency ........................................................................................................................ 1305
65.1 Purpose/Introduction

Electronic displays are an important piece of the process of visual interpretation of medical images done by human beings (see Section IV, Chapters 63 and 64). We know that display properties and utilization affect the visual interpretation of medical information. With these basic notions, it seems obvious that both careful setup and maintenance of displays is an essential component of the imaging infrastructure and warrants our attention.

While initial motivation to implement a display quality control (QC) program may come from the need to meet accreditation standards or regulatory requirements, efficient and effective implementation is probably better supported by a personal understanding of the benefits as well as the costs. In addition, garnering resource support for a quality program may entail being able to convincingly convey relevance to the clinical practice. While we hope to clearly explain this relevance based on experience and data, direct experience of the impact of display quality can be even more convincing. If the reader finds this or himself (or others) at all skeptical of the need for display quality and environmental control, we encourage the reader to conduct their own experiments. For example, software is available that allows a viewer to see the impact of maximum luminance, ambient light, and calibration on the ability to find low contrast objects. One example is the Barco QA Web mobile available for the iPad. After an initial test, the viewer can adjust the tablet to the maximum brightness setting, ensure they are in good ambient lighting conditions, calibrate and then take the test again.

The goal for this chapter is to tie together basic principles for display QC with the display properties that are both relevant for image interpretation and subject to change (and, thus, relevant to monitor). In this way, the reader may gain foundational understanding to more easily adapt to changes in technology and understanding basic needs for imaging. In addition, we hope to provide practical information for designing and implementing a QC program for current technology that meets basic clinical task and accreditation needs, while balancing resource costs.

As much as displays are ubiquitous in our everyday living, this experience may not necessarily convey sufficient knowledge of what is relevant in setup and QC for a medical image display. This confusion about displays can be seen in the displays and software that are often delivered with image acquisition systems, the current variety of QC guidelines and accreditation standards as of 2016 and the variability in the ways practices provide display QC.

A lack of consistency and compliance with display QC may in part be due to the evolving adoption of voluntary programs and changing or multiple conflicting standards; or, perhaps it is a lack of awareness of the relevance to patient care. This lack of awareness is apparent in continued comfort to reference image system quality tolerances in terms of film optical density at least a decade after film utilization has largely disappeared (ACR-AAPM-SIIM 2017). We hope the material provided helps readers feel more competent in managing and executing a QC program to provide standardization of image information. At a minimum, we hope this content provides the background to be able to make better sense of the QC guidelines provided by accrediting bodies or display/PACS (Picture Archiving and Communications Systems) vendors.

65.2 Quality Goals for the Electronic Display of Medical Images

The primary goals for display settings and QC for medical images include: (1) maximized visibility of image information, (2) minimization of misleading or false information, and (3) the consistent presentation of images.

The approach to QC presented in this chapter reflects how these display goals are addressed for diagnostic medical image viewing, with discussion of application to acquisition, QC, post-processing or clinical review workstations.

65.2.1 Maximized Visibility of Image Information

Other chapters discuss the specifics and limitations of translating image pixel data to maximize visual information for human interpretation through grayscale calibration. For images containing 12 bits (4096 values) of grayscale information, image display and visual interpretation can be an information bottleneck. While workstations may provide the ability to window/level and zoom/pan to access additional information, it is logically desirable to minimize additional effort. Display limits on the range of image information may also hamper visual search, a factor that could be especially important where acquisition is guided by visual feedback, as in the case of fluoroscopy.
65.2.2 Minimization of Misleading or False Information

Display non-uniformities, dirt or other artifacts are not only annoying, but they might also obscure image information or confound findings by mimicking image information. An example of this is dirt on a mammography display seen as a low contrast blob (sometimes referred to as mura) near where the chest wall of a mamogram would be displayed. This artifact may not be visible on a clinical image, but clearly seen on a uniform test image during QC testing. Such an artifact would be deemed a risk for confounding diagnosis and the display replaced.

65.2.3 Consistent Presentation of Images

Image optimization relies on the standardization of displays. If images are presented differently at different points in the image chain, this can confound image quality optimization efforts and influence what is perceived. Consistency of presentation is affected by the software, video cards, and display. However, to use the same equipment on everything from the acquisition unit, to PACS workstation, to clinician workstation is often not possible (or appropriate) and is likely too costly. It is important to think about which workstations require consistency between them, what kind of consistency (e.g., resolution, contrast) and how to best achieve targets and tolerances that are meaningful as well as cost effective.

65.3 QC Philosophy

QC helps maintain equipment in line with quality goals. Efficient application of QC efforts is based on the following principles:

1. Test properties that can change over time.
2. If known or applicable, test at a frequency relevant to the rate of change (such that the properties are ideally maintained within an acceptable range or anticipated failure range).
3. Test to tolerances that are plausibly clinically relevant and reasonable for the display capability.
4. Meet accreditation or other regulatory requirements.

For acceptance testing of purchased equipment or evaluation for equipment selection, additional tests may be desired for things that may not change over time, but may vary between different displays. Acceptance testing helps in display selection and in ensuring that a display meets warranty specifications and has been properly configured. Evaluation testing can help discriminate between general properties of different display models. For example, a test such as one for noise or quantitative uniformity may not be as relevant for QC, but may be helpful in establishing which type of display would be good to purchase.

65.4 Scope

65.4.1 Primary References

So as not to add to further confusion with the already varying recommendations and standards for display settings and QC, this chapter is generally written to be consistent with the ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging (ACR-AAPM-SIIM Technical Standard) (ACR-AAPM-SIIM 2017). At its last publication, it represented a good balance between what is easily achievable with current technology and what is relevant for the human visual system. This report also contains helpful information on display selection for medical imaging that is not covered in this chapter.

In addition, in depth descriptions of display measurements and test patterns referred to in this text may be found in Task Group Report 18 from the American Association of Physicists in Medicine (AAPM) (AAPM TG18 2005). This Task Group Report is frequently referenced in accreditation guidelines and technical standards, as well as manufacturer QC guidelines.

Ultimately, the person responsible for ensuring compliance with any accreditation or regulatory requirements (in the case of mammography) needs to be familiar with those specific guidelines. This chapter will not address specific program requirements but gives tools for the reader to comprehend them.

65.4.2 Different Display Classes and Types

Many reports (AAPM TG18 2005; ACR-AAPM-SIIM 2017) have differentiated target settings and test control limits based on class system of displays, including Primary (for diagnostic use) or Secondary (QC, acquisition), Clinical Support or electronic medical record (EMR) display. This stratification often aligns well with accreditation requirements, which are also often written with regard to specific display utilization. However, classification as “Secondary” may unintentionally understate needs for consistent presentation. While not advocating for putting costly solutions in areas of questionable need, in this chapter, we work from the perspective of the stated goals for image display and how they are addressed through settings and QC. Test settings and test targets will be provided that match the ACR-AAPM-SIIM Technical Standard recommendations for the primary class of displays. Considerations for deviations from these targets and tolerances, if needed for cost effectiveness, will be mentioned in terms of needs for consistency in image presentation or other factors.

Displays sold for medical imaging are typically designed to meet recommended standards and guidelines for radiology. They may be differentiated in display image noise, maximum luminance, luminance stability, uniformity and the tools used to support calibration and QC. While grayscale calibration and testing software may be applied to “consumer off-the-shelf” displays for cost savings, there are typically fewer options in that market that can meet the suggested luminance characteristics recommended for diagnostics and, correspondingly, would be challenged to provide consistency in image presentation (with radiologist workstations).

Understanding the basics of what creates an electronically displayed image, what can change and what an end user is able to control can help create both meaningful evaluation criteria and a meaningful display QC program. Some tests relevant for the largely obsolete cathode ray tube (CRT) display no longer pertain to Liquid Crystal Displays (LCDs); likewise, some LCD relevant tests may be less relevant for Organic Light Emitting Diode (OLED) displays. This chapter will only touch on display properties relevant for both LCD and OLED displays.
OLEDs differ from LCDs in that each pixel is created from a separately addressable light source. LCDs rely on bulbs (cold cathode fluorescent lamp, CCFL, or light emitting diodes, LED) and a diffuser panel to create a uniform backlight that is then modified by LCD shutters to create a pixelated image (Badano et al. 2004). In the current market, when a display is advertised as an LED display it is still an LCD display that strives for a uniform backlight that is modulated by LCD pixels. These hardware distinctions have the following impact on display QC.

### 65.4.2.1 Geometrical Accuracy and Spatial Resolution

LCD and OLED displays have fixed matrices, as opposed to a CRT that bends and focuses electron beams with magnets and may deviate from desired spatial targets. There should be no deviation in geometrical accuracy for LCD or OLED displays. Also, unless there is a change in glare or panel blur, the spatial resolution should not change, at least we are not aware of any reports in the literature of this occurring.

### 65.4.2.2 Display Luminance and Uniformity

LCDs use a common light source(s) to illuminate all pixels, whereas OLEDs have many light sources (one for each pixel). As such, there can be correlated brightness changes in an LCD display that can be spot checked during QC with a small area luminance reading or by continual backlight monitoring. OLEDs do not have the same mechanism for correlated declines in brightness as LCDs, having independent light sources for each pixel. However, common effects of aging could create coincident decline in OLEDs. The cause of non-uniformities between LCDs and OLEDs may differ as well, although both may be susceptible to them.

### 65.5 Display Performance Characteristics Relevant to QC

#### 65.5.1 Display Matrix and Interpolation

Images are affected by display software, graphic controller and the display itself. These systems work together to translate a source image of a given matrix size into a displayed image, which may be of different or reduced size. The mapping from one matrix to another can introduce artifacts if not done well, including blurring, stair-stepping or edge halo (Kagadis et al. 2013). The ACR-AAPM-SIIM Technical Standard states that “cubic spline and cubic polynomial interpolation algorithms are commonly used for high quality interpolation, with the graphic controller providing acceleration so that images are presented with negligible delay” (ACR-AAPM-SIIM 2017, p. 7).

The displayed image created by the graphics controller should match the native display matrix. Since graphic controller or display settings can alter interpolation settings, verification of display settings and visual inspection for related artifacts is a relevant objective in display QC, this is further described in Section 65.7.4.

#### 65.5.2 Display Luminance

How much light is emitted from a display for a given image presentation value is perhaps the most obvious display property to set and monitor. Luminance, as measured in candelas/meter$^2$ (cd/m$^2$), refers to the amount of light emitted from an area in a given direction. For LCD monitors, the maximum and minimum luminance is set during calibration and affected by the output of the backlight and LCD panel opacity range. Luminance values between the maximum and minimum are also set by grayscale display calibration. Many current display systems provide an 8-bit grayscale or 256 possible unique luminance values during grayscale calibration. For the consistent presentation of images, the luminance values (taking into account ambient light) of displays should match.

The luminance and grayscale calibration conformance may change over time because of backlight dimming in the case of LCDs (Walz-Flannigan et al. 2012) or the results of OLED display aging (Yu et al. 2008). Aging related changes in the sensors used to stabilize display output or changing opacity of display panel structures can also affect luminance output and grayscale calibration over time. Because luminance output can be variably set and change over time, it should be monitored in a QC program.

#### 65.5.3 Ambient Lighting

The ambient light that reflects from a display adds to the light emitted from it and can alter or obscure the images displayed. This is well appreciated by anyone who has tried to read an emissive display, like that of a smartphone, outside on a sunny day. Ambient light is measured in terms of illuminance, with units of lux or lumens/m$^2$, and describes the amount of luminous flux hitting a particular area from all directions.

The impact of ambient light can be variable. Specular reflections create mirror-like images of their source. If one wears a white lab coat in front of a reflective display, it is likely you can see an image of the coat. These reflections are hard to quantify and control, they superimpose images on top of the desired image display. While specular reflection is not a relevant measurement for QC, this should be considered in selection of display (i.e., less shiny front panels) and user education (i.e., by reducing the presence of bright objects in front of the display).

Displays also create diffuse reflections that are the product of ambient illumination ($L_{\text{amb}}$) and the diffuse reflection coefficient of the display, adding to the luminance output of the display. Diffusely reflected ambient light should be accounted for in the grayscale calibration of the display and considered in the setting of the minimum luminance ($L_{\text{min}}$) and is especially important for darker areas of the image that are more strongly impacted by the presence of ambient light.

In order to maintain recommended luminance ratios, $LR = \frac{L_{\text{max}}}{L_{\text{amb}}}$, the product of ambient light and the diffuse reflection coefficient ($L_{\text{amb}}$) need to be constrained, otherwise the maximum luminance output required to maintain the luminance ratio may exceed the maximum luminance available from the display. High diffuse reflection coefficients mean less tolerance of ambient illumination.
While the diffuse reflection coefficient is a fixed property of the display (and information that should be available from the display manufacturer), the amount of ambient light incident on a display may be highly variable, set by user preference or even affected by what the viewer is wearing. For that reason, quantifying ambient light during QC testing is only meaningful as a means to assess whether reasonable ambient light conditions are achievable in the viewing environment. Viewing systems can also be enabled with tools or test patterns that allow end users to assess the impact of ambient lighting or measure the ambient light and compare it to a reference level that does not degrade image quality. Tools for the end user to evaluate the ambient lighting may be particularly of help for use in mobile or portable viewing situations where ambient illumination is higher or more variable.

65.5.4 Grayscale Calibration

As described in the previous chapter, an image pixel value is translated to a presentation value, which is mapped to display digital driving levels (DDLs). Displays are calibrated to provide a unique luminance output for each DDL. This mapping is called the grayscale calibration, and the standard for medical image display calibration is given by the DICOMSM (Digital Imaging and Communications in Medicine) GSDF (Grayscale Standard Display Function) and should include an anticipated ambient contribution to the luminance (National Electrical Manufacturers Association 2004; AAPM TG18 2005). As mentioned before, the luminance of displays can change and should be monitored with QC testing.

Other types of calibration, such as those that are currently available with mobile devices, can be created specifically for the particular end user and the current viewing environment. These sorts of calibrations may best achieve the goals of perceptual linearity and maximization of visual information; however, they require an end user to provide the setup and execute QC testing. While this type of calibration may be the most pragmatic for mobile viewing, unless available on all platforms it does not address a need for consistent presentation of images.

65.5.5 Display Color

While color is becoming more frequently used in radiology, it is an artificial image attribution, referred to as pseudo-color. True color images contain real-life color information such as the visual appearance of skin rash. In the case of pseudo-color, the primary goals are reasonable consistency with expected color representations and consistency in the gray tone (“white point”) between adjacent displays on the same workstation. Subtle variations will likely go unnoticed between workstations and has not been shown to be relevant for diagnostic use (Krupinski et al. 2007).

For monochrome displays, the color of the white point originates with the backlight and is not something that can be changed. Should the white points of different monochrome displays drift apart over the lifetime of the displays, this cannot be corrected by calibration. If it causes user concern, the only course is to replace one or both displays to create a matched pair.

Color displays can be calibrated to create different white points and can be measured with a consumer grade colorimeter that is commonly available with photometers provided by medical display vendors. The ACR-AAPM-SIIM Technical Standard recommends that monitors be set to a white point corresponding to the International Commission on Illumination (CIE) daylight standard D65 white point. This corresponds to a color temperature of about 6500 degrees K (ACR-AAPM-SIIM 2017). Color change of the white point is something that can change over time and should be considered for QC testing (Walz-Flannigan et al. 2011). Further discussion of color consistency across gray values is discussed in a forthcoming report from AAPM task group 196 (Badano et al. 2016).

65.5.6 Display Luminance Non-Uniformity and Artifact

Typically, display luminance (maximum and minimum values) and grayscale calibration measurements for QC are generally acquired at a single location (e.g., the center) on a display that may differ from other locations. Uniformity of luminance values across a display is generally not something that can be controlled by the end user. It may be a property of the display panel itself or a property of uniformity calibration that was done by the manufacturer. Unacceptable uniformity would be a cause for display replacement. The AAPM suggests tolerances for luminance uniformity for flat-panel displays to be within ±15% (AAPM TG18 2005). It is possible for uniformity to change over time related to panel aging or other development of defects and, thus, is relevant for evaluation with QC testing. It may be just as practical to do a qualitative assessment of non-uniformity as one does other image artifact assessments, weighing the cost of replacing a display against the probability of confusing image interpretation.

65.5.7 Display Spatial Resolution

As previously mentioned, inherent display resolution is not something that is expected to change over the lifetime of LCD or OLED displays and is not relevant for QC testing, with the following exceptions.

Changes in graphics controller or display software related to image interpolation can degrade the displayed resolution of an image. It is also possible that the addition of protective or privacy screens may degrade spatial resolution. This can also be assessed as part of a qualitative visual assessment.

65.5.8 Display Noise

Pixel by pixel luminance variation on digital displays adds to image noise similar in texture to quantum noise and can obscure the visibility of low contrast, smaller features in an image. It can be a differentiating factor between different displays that can be assessed as part of a purchase evaluation. Quantitative evaluation specific to noise can be tricky and requires expensive charge coupled device (CCD) cameras and complicated analysis, as described in AAPM TG report 18 (AAPM TG18 2005). Qualitative noise evaluation can also be used for evaluation, as described in that same report.
65.6 Testing Tools and Considerations

65.6.1 Photometers: Calibration and Comparisons

Luminance is measured with a photometer that integrates luminous flux from a given direction over a photodetector’s surface. Photometers used for display QC can be classified as an external handheld photometer, as seen in Figure 65.1a, or an integrated photometer that is attached to the display and can monitor the luminance emitted at a small region near the display bezel, as seen in Figure 65.1b. Most handheld photometers and all integrated photometers are designed to record surface contact measurements of the luminance emitted from the display and do not include ambient light.

Spot photometers are external, handheld photometers that can be used to measure both light emitted from the display and ambient contributions. They are held offset from the display and use a baffle to restrict the reflected ambient light to that originating in a particular direction from the area being measured. With regards to the previous discussion on ambient light, while these photometers can be used to measure the net impact of a particular ambient light setting, given the variable nature of ambient illumination, they may be of less value to QC testing. Specific photometers designed for measuring ambient illumination (used with the display off) may be more practical.

Handheld photometers require in-person visits and access to the display for testing. Integrated photometers are generally sold with systems that allow remote access. This may enable quantitative luminance measurements to be performed at off-hours with minimal clinical disruption and less human effort.

Photometers require calibration, including on-board photometers. Information about the expected stability of the calibration should be available from the manufacturer. Integrated on-board photometers can often be recalibrated using a calibrated external photometer and correlated to the luminance output of the center of the display.

65.6.2 Test Patterns

Test patterns referred to in this chapter were created by AAPM TG18 (2005), published in that report, are available for download and can be used for quantitative measurements (AAPM Test Patterns 2006). Many of these test patterns are available with display QC software that is sold with “medical grade” displays or available from third party vendors. Some of these test patterns contain features that are not relevant for LCD or OLED displays.
Test patterns are available for quantitative luminance measurements, qualitative assessments of grayscale calibration (including ambient light), noise and image artifact analysis.

65.7 QC Tests for Medical Image Displays

65.7.1 Display Cleanliness

65.7.1.1 What Is Done

A regular program for display cleaning is recommended to remove fingerprints and other material which may obscure viewing from the front panel. Additionally, it is suggested to provide cleaning material conveniently next to displays so that users may easily access them and are less likely to damage a display with inappropriate cleaning materials.

65.7.1.2 How It Is Checked

A display of a bright and dark image such as AAPM TG18 test patterns UN-10 and UN-80 can help in visualizing streaks and residue on a display (AAPM TG18 2005).

65.7.1.3 What Is Expected

There should be no visible residue or debris on the display.

65.7.1.4 Frequency

Displays should be cleaned weekly or as needed. For displays with touch screens or in patient care areas, more frequent cleaning may be needed.

65.7.2 Viewing Environment Assessment

65.7.2.1 What Is Done

The purpose of this test is to assess environmental factors, as described in the AAPM-ACR-SIIM Technical Standard or Electronic Practice that impact viewing, including:

- Ambient lighting levels are achievable that reflect what is compensated for in the grayscale calibration, typically 20–40 lux.
- Displays should be set at a good viewing distance (approximately 60 cm for desktop workstations).
- Displays should be angled to best achieve direct viewing. For most displays, image contrast degrades with off-angle viewing.
- Check that no new panel protectors have been put on the display.

65.7.2.2 How It Is Checked

The ability to achieve reasonable ambient light levels may be assessed using a photometer placed in front of the display and facing outwards (with the displays off). Some displays have built-in ambient light sensors that can be accessed during in-person evaluation. Measurement of ambient lighting is further described in AAPM TG 18 (AAPM TG18 2005). End users can also test to see if their particular lighting has caused image degradation from ambient lighting with a visual test pattern such as TG18-AD shown in Figure 65.2; and the evaluation description is provided in the AAPM TG18 report.

If a new protective panel has been placed on a display, this may change the output or reflectivity. It should either be removed or the display should be recalibrated with a handheld photometer. A spot photometer may need to be used to accommodate unknown changes in reflectance into the calibration.

65.7.2.3 What Is Expected

A previous chapter discussed recommendations for ambient illumination. The ACR-AAPM-SIIM Electronic Practice Technical Standard recommends 20–40 lux in the workspace environment, with uniform illumination (ACR-AAPM-SIIM 2017). Windows and non-regulated natural light sources should be shielded from the display. This can be challenging to achieve in clinical areas or for portable imaging. System design, user education, and placement of displays for image viewing may be modified to better enable images to be seen with less degradation from ambient illumination.

65.7.2.4 Frequency

This is recommended as part of an annual in-person evaluation for fixed workstations or when a workstation is moved or a room is renovated. For portable equipment or mobile devices this must be part of user training for continual efforts to support practice needs.

![FIGURE 65.2](https://example.com/image.png)

The AAPM TG-AD test pattern can be used to evaluate the impact of ambient illumination on subtle contrast features in the darker parts of an image. The test pattern, as shown, has been enhanced to show detail (AAPM TG18 2005).
65.7.3 Settings Check

65.7.3.1 What Is Done

Displays should be checked for the expected on-screen display (OSD) settings that can usually be accessed through display buttons (e.g., calibration mode, display connector settings, OSD lockout). In general, OSD settings should be locked-out whenever possible, as display calibration may be corrupted if users have access to brightness and contrast settings through the OSD tools. It should also be confirmed that the graphics controller settings are appropriately compatible with the display.

65.7.3.2 How It Is Checked

- The OSD lockout must be checked in person.
- Graphics controller settings may be checked within the operating system or video card software display settings. The Extended Display Identification Data (EDID) can be read by an EDID utility to see that the display properties match the graphics controller settings.
- Power management schemes may be checked with operating system or display control settings. However, a more reliable assessment would be to look at the backlight hours used for a given period of time compared to anticipated usage. Backlight hours are often viewable with vendor display management tools.
- Calibration and automated quality check controls (if available) may be found on display software settings, either as a local client or on server based controls.

65.7.3.3 What Is Expected

- The display matrix set out in the graphics controller matches the native resolution of the display.
- Any automated calibration or QC checks are scheduled and performed as expected.
- The desired power management schemes are being utilized as desired. Displays for medical imaging can be quite costly and it is cost effective to turn them off when they are not in use.

65.7.3.4 Frequency

- Assessments requiring in-person evaluation may be made during an annual visit.
- Assessments that may be made remotely can be run more frequently or at a frequency that is useful to catching problems.

65.7.4 Qualitative Visual Assessment

65.7.4.1 What Is Done

Some display tests require visual inspection of the display itself or are, perhaps, most effectively accomplished through a visual inspection. Visual assessment includes inspection for artifacts related to panel defect or display settings, luminance non-uniformity within a display, color non-uniformity within a display or color differences between displays.

If grayscale calibration is not checked quantitatively, it can be checked qualitatively with a test pattern to check the visibility of distinct DDL or for perceptual linearity of the calibration. As a tool for validating consistency of presentation between workstations, it is not ideal. Visual assessment of the grayscale is redundant to the quantitative measurement, and both should not be required.

65.7.4.2 How It Is Checked

- AAPM Test Patterns TG18-UN80 and TG18-UN10, shown in Figure 65.3, are useful for artifact assessment, including non-uniformities, dead pixels, surface dirt or visible color differences (AAPM Test Patterns 2006).
- Features in the following test patterns can be viewed to inspect for reduced resolution or artifacts from inappropriate display matrix settings: IEC 62563-1 TG18-OIQ, SMPTE or AAPM TG18-QC (IEC62563-1 2016, SMPTE, AAPM Test Patterns 2006). The visualization

![Figure 65.3](image_url) The AAPM TG18 UN-10 and UN-80 test patterns are helpful for evaluating display artifacts including defects, dirt and luminance or color non-uniformities (AAPM TG18 2005).
of the test pattern should match specified expectations. Description of qualitative visual assessment for grayscale calibration using TG18-QC is described in the AAPM TG18 Task Group Report (AAPM TG18 2005).

- Assessment of the DICOM grayscale calibration conformance can be assessed through the visibility of features in the AAPM TG18-QC, PQC pattern, as described in the AAPM TG 18 report (AAPM TG18 2005). If features are not visible, appropriateness of ambient light should be evaluated prior to recalibration.

Images of the test patterns not previously mentioned are shown in Figure 65.4.

65.7.4.3 What Is Expected

The display is free from visible non-uniformity or artifact or color differences between adjacent displays. All low contrast squares are visible.

If artifacts or non-uniformities are found that relate to the display panel itself and they are found to interfere with its clinical use (this is a judgment call with the radiologist or qualified medical physicist), then the course of action is to replace a display. If color differences are seen between color displays, the displays can be recalibrated to the target white point. For bar pattern artifact or reduced resolution, graphics controller settings can also be checked to make sure they are appropriate.

65.7.4 Frequency

The ACR-AAPM-SIIM Technical Standard recommends visual quality checks monthly (ACR-AAPM-SIIM 2017). However, we have found an annual visual inspection, alongside a regular cleaning program and quarterly quantitative checks, to be sufficient for maintaining quality.

65.7.5 Quantitative Testing

65.7.5.1 What Is Done

Since grayscale calibration independently sets the luminance values for each DDL at least once for a given monitor type and firmware or calibration software version, it should be established that each of the DDLs are set as expected. Having established that the system can be properly calibrated, it is sufficient to spot-check the calibration for QC purposes to test for drift.

As part of QC, it is recommended to regularly check a subset of the DDLs to see that the displayed luminance is as expected. The sampling points should include the maximum and minimum luminance. Because display luminance is known to change over...
time, rather than wait for failure, it is recommended to use a pro-
active strategy to recalibrate the displays on a regular basis.

For multi-display workstations, many photometers pro-
vided by medical image displays also act as colorimeters. Conformance with expected white point value or quantitative color difference with the white points of adjacent displays can be checked. It can also be checked that maximum luminance values of adjacent displays match sufficiently so that a visual difference is not seen.

65.7.5.2 How It Is Checked

Whether assessed with a handheld contact photometer or an integrated photometer, luminance values are measured in a particular spot on the display, ideally centrally for handheld photometers. Grayscale conformance over the rest of the display is evaluated by visual assessment of uniformity with the area that was quantitatively tested. Contact photometers do not include ambient light in their measurements, so an ambient contribution for an assumed illuminance and known diffuse reflection coefficient must be added to each luminance measurement that is made (often this is done automatically by display QC software if “ambient light correction” is selected).

For handheld photometer measurements, test patterns with different luminance patches for measurement are available from AAPM TG 18 (AAPM TG 18 LN-1,18) or in the SMPTE (Society of Motion Picture & Television Engineers) test pattern.

65.7.5.3 What Is Expected

The following suggestions for luminance and grayscale calibration are written to be consistent with the ACR-AAPM-SIIM Technical Standard (ACR-AAPM-SIIM 2017).

- For displays for diagnostic use, the minimum luminance \( L_{\text{min}} \) should be at least 4-times the ambient luminance \( L_{\text{amb}} \) and \( L_{\text{min}} = L_{\text{min}} + L_{\text{amb}} \) and should be at least \( 1.0 \text{ cd/m}^2 \). For displays not used for diagnosis (where consistent presentation is not required), a \( L_{\text{min}} \) of \( 0.8 \text{ cd/m}^2 \) is ok.
- The maximum luminance should be set so that the Luminance Ratio, \( LR = (L_{\text{max}} + L_{\text{amb}})/(L_{\text{min}} + L_{\text{amb}}) \) should be at least 350 for diagnostic displays. For other monitors, a LR of at least 250 is sufficient. The \( L_{\text{max}} \) of diagnostic monitors used for interpretation should be at least \( 350 \text{ cd/m}^2 \) and, for mammography, this should be at least \( 420 \text{ cd/m}^2 \). Brighter monitors should be calibrated to keep the same target LR. For displays to be consistent in presentation with diagnostic displays, they should have the same LR and \( L_{\text{max}} - L_{\text{max}} \) values from displays attached to the same workstation do not vary by more than 10%.
- Luminance values between \( L_{\text{max}} \) and \( L_{\text{min}} \) should conform to the values set by the DICOM GSDF. Contrast response conformance with the GSDF, as defined in the AAPM TG 18 Task Group Report, should be within 10% for primary diagnostic displays over all DDL. For other monitors, the contrast response should be within 20%.
- Color differences should not be visible between displays. A recommended white point for standardization corresponds to the CIE daylight standard D65 white point.
- Mammography displays may have other specific calibration targets and tolerances required of them by the mammography equipment QC manual, followed as specified by the ACR (American College of Radiology) and MQSA (Mammography Quality Standards Act).

65.7.5.4 Issues and Remediation

- If maximum luminance values can no longer be reached, the display or backlight will need to be replaced.
- If the grayscale calibration does not conform adequately to the GSDF, the display should be recalibrated until it passes or another source of fault is found.
- If color differences are found, color displays should be recalibrated. For monochrome displays, if the color difference cannot be accommodated, one or more displays will need to be swapped.

65.7.5.5 Frequency

Testing or calibration frequency should be relevant to change and effort required. Minimally these tests should be done annually. For displays without luminance stabilization, quarterly measurements may better address keeping the displays in conformance.

We have established a testing routine that occurs on a quarterly basis. Since we automatically conduct remote quantitative tests utilizing an integrated photometer, it includes less effort than an in-person qualitative assessment. Thus, we conduct quantitative tests more frequently and our in-person visits are limited to annual qualitative evaluation. If the effort balance was different (as it might be if you must utilize a handheld photometer), one might do more frequent in-person qualitative evaluations and less frequent quantitative evaluations. In either case, quarterly assessments should be adequate to keep displays in good conformance.

The exception to this is mammography displays, which have specifically stated calibration and testing frequencies required by the ACR and MQSA through vendor provided QC manuals.

65.8 QC Program Management

65.8.1 Organizing Your QC Program

When considering management of a QC program, it is important to evaluate what resources are readily available, how the program and data will be documented and reviewed and the way in which the program will be actively managed on a day to day basis.

The first step of a management program is to determine the manner in which compliance will be tracked. While tracking compliance on a display by display basis may be possible, the decision to track QC based on the workstation and its associated displays may be more manageable for a large fleet. In either approach, it is important to document the decision and the way results will be tracked and managed.
Display QC management software can make program management easier, especially for a large fleet. Utilizing integrated photometers with management software provided by the display manufacturer can provide great advantages for automated data acquisition, recording and analysis. This type of management software can run remotely off a server or the “cloud” and may rely on a locally installed program to run the automated QC activities. Some caution should be exercised with such software programs, to ensure that the entire fleet is accounted for and that data are not lost if a workstation or display is disconnected or has issues in communication. For this reason, we use both vendor cloud-based management for execution of the QC tests and calibration and a separate record to ensure that all workstations and displays are fully managed.

When neither automated programs nor on-board sensors are available, it is necessary to develop a separate method to record data and schedule testing. In some instances, the medical facility may have a computerized maintenance or inventory management system in which the workstations can be entered, tracked and scheduled for preventative maintenance. This may also lend the opportunity to record and store QC data within the management system.

### 65.8.2 Setting up Test and Tools

For displays utilizing QC management software for testing or calibration, test sets must be designed and scheduled that meet the needs of the QC program. In some instances pre-developed test sets may be available through the vendor of the display or workstation product. In this scenario, it may also be possible to adjust the control limits and criteria measured in each test to meet program needs.

For automated testing, scheduling off-hours or having a presence sensor can ensure that no one is currently using the workstation during testing. The QC management software can also be used to locally trigger and display the test patterns needed for qualitative tests, or to access them on demand, as well as to record the results locally or to the server or cloud-based database.

In instances where pre-developed tests are not available you may need to utilize the QC software or another source of test patterns in order to execute either quantitative or qualitative tests. Some vendors, for example, provide SMPTE patterns (SMPTE 1991): that can be used to measure luminance if pan/zoom functionality is possible.

Validation and calibration of measurement devices should also occur at specified frequencies. External sensors can be calibrated by a vendor or replaced with new sensors. Manual comparison of multiple devices against a known calibrated device can also assist with keeping measurement devices reliable. For systems with integrated sensors, a correlation between an external calibrated device and the integrated sensor should be conducted. The vendor may have a specified frequency and control limit for this activity.

### 65.8.3 Program Oversight and Reporting

QC management software generally retains a database of test results and failures and can provide a report for documentation of QC activity which may be needed for accreditation purposes. A program review should occur at a specified frequency. This review should confirm that all workstations have been tested within the program frequency, the resolution of any failing displays, trends which identify a potential issue with the fleet and, potentially, information relating to the expected lifetime of the fleet, as it may be beneficial for budgeting purposes. These reviews, along with the QC records, should be archived and available for review and for inspection purposes. Minimally, this review should occur annually.

When setting up new test sets or learning about the stability of new systems, it may be worthwhile to test a smaller subset of displays at a higher frequency than the rest of the fleet, if the fleet is large. In this way, if failures are discovered, such as an on-board sensor failure, issues with automated tests being run or control limits that may be too restrictive for the capability of the display, they can be evaluated and corrections can be developed and reapplied to a smaller volume of workstations before making the change to the rest of the fleet.

Automated QC management software may offer the ability to receive alerts when a display is not meeting control limits. These systems may also offer alerts of new display installations, displays which have gone offline, display lifetime notifications and more. With a large fleet of displays it may be advantageous to assign a specific team to receive and manage these alerts, in addition to ongoing management.

### 65.9 Summary

Along with motivation to provide QC for displays used for medical imaging, it is hoped that the reader may feel confident to set up, execute and manage a QC program that meets their clinical practice needs through greater understanding of both why and how tests may be done.

### REFERENCES


Society of Motion Picture & Television Engineers. 1991. SMPTE Report 133-1991, Specifications for Medical Diagnostic Imaging Test Pattern for Television Monitors and Hard-Copy Recording Cameras. SMPTE.

