ACR–AAPM TECHNICAL STANDARD FOR DIAGNOSTIC INTERPRETATION DISPLAYS

The American College of Radiology, with more than 40,000 members, is the principal organization of radiologists, radiation oncologists, and clinical medical physicists in the United States. The College is a nonprofit professional society whose primary purposes are to advance the science of radiology, improve radiologic services to the patient, study the socioeconomic aspects of the practice of radiology, and encourage continuing education for radiologists, radiation oncologists, medical physicists, and persons practicing in allied professional fields.

The American College of Radiology will periodically define new practice parameters and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice parameters and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice parameter and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review and approval. The practice parameters and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice parameter and technical standard by those entities not providing these services is not authorized.

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care[1]. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the practitioner considering all the circumstances presented. Thus, an approach that differs from the guidance in this document, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in this document when, in the reasonable judgment of the practitioner, such course of action is indicated by variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to the guidance in this document will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The purpose of this document is to assist practitioners in achieving this objective.

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1 *Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, 831 N.W.2d 826 (Iowa 2013) Iowa Supreme Court refuses to find that the "ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures (Revised 2008)" sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, Stanley v. McCarver, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.*

I. INTRODUCTION

This technical standard was developed collaboratively by individuals with recognized expertise in medical physics, and, representing the American College of Radiology (ACR), and the American Association of Physicists in Medicine (AAPM).

This technical standard defines the personnel, quality management, quality assurance, and quality control methods for diagnostic interpretation display performance management. It applies to all displays that are used for the primary interpretation of medical images, including mammography. These displays may also be referred to as primary displays [1-4] or diagnostic displays [5] on other standards and reports.

II. QUALIFICATION AND RESPONSIBILITIES OF PERSONNEL

A. Qualified Medical Physicist

A Qualified Medical Physicist is an individual who is competent to practice independently in one or more of the subfields in medical physics. The American College of Radiology considers certification, continuing education and experience in the appropriate subfield(s) to demonstrate that an individual is competent to practice one or more of the subfields in medical physics, and to be a Qualified Medical Physicist. The ACR strongly recommends that the individual be certified in the appropriate subfield(s) by the American Board of Radiology (ABR), the Canadian College of Physics in Medicine (CCPM), the American Board of Science in Nuclear Medicine (ABSNM), or the American Board of Medical Physics (ABMP).

A Qualified Medical Physicist should meet the ACR Practice Guideline for Continuing Medical Education (CME).

The appropriate subfield of medical physics for this technical standard is Diagnostic or Nuclear Medical Physics. This pertains to (1) the diagnostic applications of x-rays, or gamma rays from sealed and unsealed sources, of ultrasound, of radiofrequency radiation, of magnetic fields, (2) the equipment associated with their production, use, measurement, and evaluation, (3) the quality of information and images resulting from their production and use, and (4) associated patient and personnel radiation safety issues.

The ACR shall review all appropriate guidelines and technical standards to ensure that each contain this definition of Qualified Medical Physicists where indicated; 1996, 2006, 2008, amended 2012, amended 2022 (Res. 41-f).

The Qualified Medical Physicist is responsible for the test protocols, test methods, and acceptability criteria. The Qualified Medical Physicist may be assisted by properly trained individuals in obtaining data in accordance with applicable regulations and relevant guidance (eg, AAPM medical physics practice guideline 7.a [6]). Medical physics students, medical physics residents, and medical physicists-in-training may assist the Qualified Medical Physicist based on their training and at the discretion of the Qualified Medical Physicist [7]. These individuals must be properly trained and approved by the Qualified Medical Physicist such that they have knowledge about the techniques of performing tests, functions and limitations of the equipment and test instruments, reasons for the tests, and the importance of the test results. The assisting individual shall be under the general supervision[1] [8] of the Qualified Medical Physicist during all surveys. The Qualified Medical Physicist is responsible for all surveys and must review, interpret, and approve all data as well as provide a signed report with conclusions and recommendations [8].

For this standard:

1. The Qualified Medical Physicist shall have knowledge of display technology, relevant test tools, and software.

2. The Qualified Medical Physicist shall understand the digital imaging chain aspects that affect image quality, including conditions that could generate artifacts.

3. The Qualified Medical Physicist shall be aware of all relevant regulatory and accreditation requirements for diagnostic interpretation displays.

4. The Qualified Medical Physicist should remain current on industry standards, recommendations, and

requirements for diagnostic interpretation display performance.

[1] For the purposes of this standard, general supervision means all procedures are performed under a Qualified Medical Physicist's overall direction and control. The Qualified Medical Physicist's presence is not required during the procedure but must be available by phone (or other real-time communication method) to provide assistance and direction if needed. The training of the personnel who perform the procedure and the maintenance of the necessary equipment and supplies are the responsibility of the Qualified Medical Physicist.

II. QUALIFICATION AND RESPONSIBILITIES OF PERSONNEL

B. Physician

As display end-users, a physician is uniquely suited to provide information on the quality and performance of diagnostic interpretation displays. A physician may work under the direction of a Qualified Medical Physicist to perform tests and procedures as part of a quality assurance program. They may also submit feedback on any issues that may arise outside the normal testing schedule.

For this standard:

1. The physician shall demonstrate qualifications as delineated in the appropriate ACR practice parameter or technical standard for the particular diagnostic modality being interpreted.
2. The physician shall be trained or approved by a Qualified Medical Physicist to perform any test or procedure under general supervision for which data will be used to demonstrate diagnostic interpretation display performance or compliance.
3. The physician should have a working knowledge of the digital imaging chain aspects that affect image quality and may generate artifacts.

II. QUALIFICATION AND RESPONSIBILITIES OF PERSONNEL

C. Medical Physicist Assistant

A Medical Physicist Assistant (MPA) is an individual who has the necessary didactic education and practical physicsknowledge to work under the supervision and responsibility of a Qualified Medical Physicist [6,9]. As outlined in AAPM medical physics practice parameter 7.a, an MPA is an individual who is not a Qualified Medical Physicist but extends to a Qualified Medical Physicist through a formal chain of authority.

For practices with large display installations (both in number of displays and/or geographic locations), the MPA is likely to be a valuable member of the quality management team and make the feasibility of a robust quality management program much easier.

For this standard, the MPA shall be trained and/or approved by a Qualified Medical Physicist to perform any test or procedure under general supervision for which data will be used to demonstrate diagnostic interpretation display performance or compliance.

II. QUALIFICATION AND RESPONSIBILITIES OF PERSONNEL

D. Information Technology/Imaging Informatics Professional

An Information Technology/Imaging Informatics (IT/II) Professional is an individual who is responsible for, or aids in, the management of display systems and their associated hardware. In the context of this technical standard, an IT/II professional works to ensure that all hardware and software associated with diagnostic interpretation displays are installed and functioning as intended.

Many modern diagnostic interpretation displays use vendor-supplied software to set the operating levels and perform automated or semiautomated testing procedures. An IT/II professional may work with a Qualified Medical Physicist to establish and oversee the ongoing use of vendor-supplied software and to ensure proper

functionality of any instrumentation that may interface with the display hardware or connected computer hardware.

For this standard,

1. The IT/II professional shall be trained and/or approved by a Qualified Medical Physicist to perform any test or procedure under general supervision for which data will be used to demonstrate diagnostic interpretation display performance or compliance.
2. The IT/II professional shall be trained by a Qualified Medical Physicist on the proper performance settings of any display software or hardware installed or managed by the IT/II professional and used in the quality management of the diagnostic interpretation display.

III. QUALITY MANAGEMENT

A. Quality Management Team

The quality management team defines the individuals who are responsible for and involved with diagnostic interpretation display quality at a site. As defined in II.A., the Qualified Medical Physicist has primary responsibility and oversight for display testing protocols, methods, and criteria. As such, the quality management team should be led by the Qualified Medical Physicist. The quality management team should also include MPAs and IT/II professionals who participate in the quality management aspects of diagnostic interpretation displays. Although, many physicians may be involved in the routine gathering of quality data (eg, reviewing test patterns), the participation of all physicians on a quality management team is likely unnecessary. A small group of physicians, and as few as one, should participate on the quality management team so they may provide physician and end-user input to quality processes.

The quality management team led by the Qualified Medical Physicist should meet at regular intervals, (eg, quarterly, semiannually, or annually) to review issues, discuss upcoming activities, and perform general review of past quality assurance and control results. In addition, such meetings provide an opportunity to discuss any necessary updates to the quality management components discussed later in this section.

The quality management team should be the group responsible for providing the greatest input on purchasing decisions for new or replacement diagnostic interpretation displays and the associated accessory hardware and software. A consistent quality management approach to display hardware and software simplifies the requirements associated with the ongoing quality assurance and control measures.

As described in II.A., the Qualified Medical Physicist may be assisted in the collection of data, subject to all applicable regulations and relevant guidance. The Qualified Medical Physicist and the quality management team should define the required training and approval process for those individuals deemed qualified for assisting under the general supervision of the Qualified Medical Physicist. This technical standard recommends that all annual testing is performed either by or under the general supervision [8] of the Qualified Medical Physicist and all testing at more frequent intervals under the oversight or direction of the Qualified Medical Physicist.

III. QUALITY MANAGEMENT

B. Records of Display Devices and Tools

Quality management of diagnostic interpretation displays requires accurate and complete installation records of the displays and their environments. At a minimum, the quality management team should establish an asset management methodology to track the number, location, manufacturer, model, date of manufacture, and unique identifier of all diagnostic interpretation displays within their site. This should include both onsite and offsite locations (including for remote interpretation). The asset management system should serve as either the repository for, or link to, the permanent storage for quality performance records and reports.

The asset management system for tracking displays may be software provided by the medical display manufacturers, which often interfaces easily with that manufacturer’s own displays to simplify many of the quality

management tasks. For sites with many different display manufacturers, such asset management software may not exist to easily integrate all diagnostic interpretation displays. Sites may choose to use third-party or in-house solutions to customize the asset management system for their specific needs.

In addition to diagnostic interpretation displays, the quality management team should maintain accurate records of the tools used to perform quality control tests. These records should include tool description or type (eg, contact photometer, telescopic colorimeter), manufacturer, model, date of manufacture, and unique identifier. The calibration, calibration schedule, and/or intercomparison history and schedule of the applicable tools should be kept with these records to ensure compliance.

The quality management team should include a review of the asset management system as part of its regular meetings. Individual members of the team should be assigned specific data points of interest to oversee. The more detailed and automated the asset management system, the easier the delineation of the data for the quality management team members.

III. QUALITY MANAGEMENT

C. Display Quality Policies

Effective quality management requires a comprehensive set of policies and guidelines to address all aspects of display quality. This subsection lists those aspects of display quality that should be included in such documentation.

1. Specifications for display calibration targets: The quality management team shall determine the appropriate calibration targets for the luminance and chromaticity values evaluated as part of the quality control tests described in V.A.1. The calibration targets should be specific to each diagnostic interpretation display model within the fleet and be based on the clinical use of the display (eg, mammography versus general radiology), regulatory requirements, scientific guidelines, and physician preferences. Within the quality control tests described in V.A.1, this technical standard provides recommended values based on current display technology and professional guidance. These limits are meant to provide minimum standards for quality control and may differ from the calibration targets for a specific site.

2. Specifications for diagnostic interpretation display and workstation setup: The quality management team should establish the appropriate hardware (eg, displays, graphics cards, cables) and software (eg, operating system, display quality support software) for each physician interpretation workstation configuration. The number of configurations of workstations for each site may vary depending on the typical use. For example, three workstation configurations may be defined for a site: general workstations, mammography workstations, and remote general workstations. In this example, creating standard configurations simplifies the oversight and may aid the local IT department in maintaining the desired consistency between workstations. For recommendations on display performance capabilities, appropriate graphics cards, cabling, and other aspects of workstation configurations, refer to the ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging [4].

3. Medical-grade versus. consumer-off-the-shelf (COTS) displays: As part of establishing appropriate hardware, the quality management team shall determine whether all interpretation workstations are to be equipped with only medical-grade displays (ie, displays specifically designed and marketed for use in medical image interpretation) or if COTS displays may be used for certain configurations. This technical standard discourages the use of COTS displays for medical image interpretation due to the typical lack of internal control hardware and software to maintain luminance and luminance response function stability. COTS displays may perform acceptably under initial settings with appropriate support from the Qualified Medical Physicist, though ongoing maintenance and quality control may be challenging, often requiring use of extra resources to prevent unsatisfactory display performance.The decision on whether COTS displays are used must also consider applicable regulations that may not permit the use of COTS displays for certain types of interpretation (eg mammography).

4. Summary of quality control and assurance frequencies – For each diagnostic interpretation display type or interpretation workstation configuration, the quality management team shall create documentation specifying the required frequency for the quality assurance activities in section IV and the quality control tests in section V. Both section IV and V provide recommended minimum frequencies, although these may differ from the needs of a particular site. The documentation should also include the frequencies for calibration or cross-comparison of tools used to perform the tests.

5. Vendor-supplied vs. vendor-independent software – As discussed in IV.B, vendor-supplied software for diagnostic interpretation displays should undergo periodic performance verification. The quality management team should document both the frequency with which the verification should occur and in what capacity the vendor-supplied software should be used for ongoing quality evaluation activities. This technical standard recommends incorporating the vendor-supplied software for automated checks and calibration of diagnostic interpretation displays, but not as the sole source of quantitative assessment. The quality management team should also document the vendor-independent software (and related tools) that are to be used in ongoing quality management.

6. Review of applicable regulatory and accreditation rules: A site's documentation for the quality management of diagnostic interpretation displays should include a comprehensive summary of all applicable regulatory and accreditation rules for all defined display and workstation types. Many sites are subject to numerous agencieswhose rules for diagnostic interpretation display testing may vary drastically. The applicable rules should serve as the basis for both the tests and their frequencies. When establishing the quality management program, these rules and this technical standard should serve as a guide for the quality management team. In the case in which there are no applicable rules, the tests and frequencies provided in sections IV and V may serve as this basis.

7. Requirements for repaired or replaced diagnostic interpretation displays and hardware – Along with documented frequencies for the ongoing quality assurance and quality control activities, the quality management team should specify the requirements for testing when displays are repaired, replaced, or modified. This should include any changes to the display-related hardware (eg, graphic cards, OS upgrades, vendor software upgrades). In addition, the documentation should specify the level of Qualified Medical Physicist oversight required. This technical standard suggests relying on the input from the Qualified Medical Physicist for final determination of what is required for a given event. However, identifying a list of common occurrences can aid in expediting and standardizing this response.

8. Personnel roles: The quality management team should clearly define each member's role in ongoing quality assurance and quality control. In addition, the team should define the personnel who may not be on the quality management team but are involved with the maintenance of displays. If the quality management team does not have IT/II members, then it should work directly with the IT department to ensure the IT department understands the importance of the quality management team's role in ensuring high-quality interpretation of medical images for patient care. A policy or guideline that specifies the expectations for the personnel working on diagnostic interpretation displays, and how to communicate any required input from the members of the quality management team shall be established.

9. User responsibilities: The quality management team should create a policy or guideline that provides specific expectations for users of the displays and workstations used for diagnostic interpretation. These expectations should summarize each user's responsibility for ensuring that the displays and workstations continue to operate at the required performance level. This policy or guideline may include items such as responsibilities for cleaning, liability for broken components, obligations for reporting issues, requirements for maintaining ambient conditions, and expectations for performing ongoing quality control activities. These expectations may vary by workstation type and are especially useful in managing a fleet of diagnostic displays across multiple sites (some of which may be in private homes).

10. Reporting criteria for quality evaluation activities – The documented policies and guidelines should include a component for the reporting of quality assurance and quality control activities. This includes the timeframes for when activities must be documented. For example, activities performed annually are

expected to be completed and reported by the end of the same calendar month as the previous year. The specifics for each activity are likely guided by the regulatory and accrediting agencies overseeing the site, and documentation of these expectations provides support to the quality management team when performing audits of a site's diagnostic interpretation display quality program.

III. QUALITY MANAGEMENT

D. Display System Architecture

Modern healthcare systems typically have large, complex networks for the electronic communication of medical images and data. Many sites may be connected across large geographic areas to a centralized PACS and electronic medical record (EMR) (or several PACS/EMR), and image interpretation may occur at great distances from where the images were acquired. The quality management of diagnostic interpretation displays should incorporate interoperability checks, although the details of these checks are dependent on the specific configuration of each healthcare system. This technical standard recommends a simplified approach to interoperability verification. It recommends against quality control tests requiring verification of unique connections between each display and modality. For example, the practice of reviewing an acquired phantom image following a repair to the mammography system on every diagnostic interpretation display attached to the PACS is unlikely to reveal display quality issues and is a poor utilization of resources. In this example, so long as the interoperability between the mammography system and the PACS is confirmed, the previously established interoperability can be assumed to remain unchanged.

Readers are referred to the ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging [4] and AAPM Report 248 – Interoperability Assessment for the Commissioning of Medical Imaging Acquisition Systems [10] for a full description of the recommended commissioning and quality assurance and control practices for modern electronic medical imaging environments.

III. QUALITY MANAGEMENT

E. Structure for Reporting Issues

Effective quality management requires a robust communication framework for the members of the quality management team and other partners of the healthcare infrastructure. Physician end users and members of the IT support team should have a clear understanding of how to report quality-related issues to the quality management team for support. This reporting mechanism may be incorporated into the quality management system used to record display information or may be as simple as a shared e-mail address. As part of the documentation responsibilities for users and IT support personnel, the reporting tools should be clearly defined. The quality management team should use their regularly scheduled meetings to review trends in user issues to verify there are no systematic issues with the diagnostic interpretation display fleet.

IV. QUALITY ASSURANCE

A. Calibration of Measurement Devices

Measurement devices (eg, photometers, colorimeters) should be regularly calibrated or cross-referenced with calibrated devices to ensure the quality of their readings. Calibratable devices should be calibrated once every two years, or less often if following the recommendations of the device manufacturer. Devices that cannot be calibrated should be cross-referenced with calibrated devices at a frequency determined by the quality management team. This technical standard recommends a period of two years between cross-referencing for such devices, although the frequency should be determined based on the expertise of the quality management team and documented history of a given device's stability.

The Qualified Medical Physicist or quality management team should evaluate quality control tests for measurement device errors. Outlier measurements may be the result of device failure or may represent the need for device recalibration or cross-referencing to ensure the device's accuracy. This technical standard recommends

that non-calibratable devices agree with a calibrated device to within 5% over the luminance range expected from the diagnostic interpretation displays on which it will be used.

IV. QUALITY ASSURANCE

B. Vendor Software and Built-in Photometer Accuracy

A key feature of many displays designed and marketed for diagnostic interpretation of medical images is the availability of vendor-supplied software for performing quality control tests and monitoring display performance. Medical grade displays often include built-in photometers for directly measuring the output luminance of the display or the incident illuminance at the display surface. This functionality allows the display to automatically adjust the internal settings to maintain an established operating level and remain stable over the life of the display. This stability and functionality make ongoing quality control and assurance activities more manageable, especially for large healthcare systems or those systems with limited resources.

Built-in photometers are typically positioned at the edge of the display and are either permanently fixed in place or deployed at the time of quality control testing. These photometers are responsible for the automatic calibration and quality control tests that are incorporated into the vendor-supplied software. Because they measure the luminance of the display at the edge, their readings are typically different from the luminance output at the center of the display due to luminance non-uniformity across the display. To address this, many display vendors supply external photometers (or allow for the use of other external photometers) to correlate the built-in photometer's edge reading with a corresponding reading at the center of the display. This correlation should be performed at the initial setup of a diagnostic interpretation display, and then at the recommended frequency of the display vendor. AAPM Report 270 – Display Quality Assurance recommends performing the correlation with an external device every 10,000 backlight hours to ensure the internal device remains accurate and can perform the automatic functions to give appropriate results [5]. In the case in which the built-in photometer fails to correlate with an external device within acceptable limits, the Qualified Medical Physicist and quality management team should verify measurements annually with the external device. The use of the internal device should be discontinued.

This technical standard discourages the sole use of the built-in photometers and vendor-supplied software for verification of display performance. The Qualified Medical Physicist and quality management team should design the quality control testing to include the use of external, independently controlled photometers and colorimeters on a periodic basis.

IV. QUALITY ASSURANCE

C. Periodic Review of Diagnostic Interpretation Display Settings

As part of the ongoing quality assurance of diagnostic interpretation displays, the Qualified Medical Physicist andquality management team should review the latest recommendations from professional societies and scientific literature. The calibration targets and test frequencies for the diagnostic interpretation displays at a site should be adjusted accordingly with advancements or changes in best practice, unless those adjustments do not follow applicable regulatory or accreditation requirements.

V. QUALITY CONTROL

The quality control (QC) activities described in this section are broadly separated into two categories: quantitative and qualitative. Quantitative quality control tests require the use of measurement tools to provide numerical data that are analyzed and compared against passing criteria. For displays, this typically involves illuminance, luminance, or chromaticity measurements using a series of test patterns. Section V.A describes the recommended quantitative QC testing for diagnostic interpretation displays. Qualitative quality control testing involves the use of standard test patterns or images and a subjective reviewer to determine the performance of a diagnostic interpretation displays. Section V.B describes the recommended qualitative quality controls tests for diagnostic interpretation displays. Robust quality management of diagnostic interpretation displays should include a

combination of both quantitative and qualitative testing.

V. QUALITY CONTROL

A. Quantitative Display Performance Testing

1. Display Luminance

a. Ambient Luminance (L_{amb}) and Ambient Illuminance (E)

The ambient lighting of a diagnostic interpretation display shall be measured at the initial setup and annually thereafter under the general supervision of the Qualified Medical Physicist. If there are changes to a reading environment in the time between annual evaluations, the effect of the changes shall be evaluated by the Qualified Medical Physicist. This technical standard recommends an ambient illuminance of 25-75 lux [4,5] and an ambient luminance of less than ¼ of the minimum luminance setting [4,5] unless the environment is stable and the ambient luminance can be incorporated into the luminance response calibration. If L_{amb} can be incorporated into the luminance response calibration, the value may approach but should not exceed the minimum luminance setting.

To maintain consistency between reading environments, diagnostic interpretation displays used for similar purposes should be set up using similar conditions between the reading environments. For environments with stable conditions, L_{amb} should be incorporated into the luminance response function. This will allow for a more accurate calibration to the DICOM (Digital Imaging and Communications in Medicine) GSDF (Grayscale Standard Display Function). If L_{amb} is not incorporated into the luminance response function, the perceived contrast within the darker regions of the image will not be consistent with other luminance levels. If L_{amb} remains below ¼ of the minimum luminance, this effect will not be severe, butmay result in failures to the luminance response function quality control test if using fine sampling (eg, measuring every one or five gray levels).

The ambient illuminance may be measured automatically using built-in photometers at more frequent intervals using the vendor-supplied software. In the event of the illuminance check failing, the ambient conditions of the diagnostic interpretation display environment should be verified to ensure that no significant changes have occurred.

b. Minimum Luminance (L_{min}, L'_{min}) and Maximum Luminance (L_{max}, L'_{max})

The minimum and maximum luminance of a diagnostic interpretation display shall be measured at the initial setup and annually thereafter under the general supervision of the Qualified Medical Physicist. If using a contact photometer, the ambient luminance L_{amb} is combined with the measured luminance to calculate the minimum combined luminance L'_{min} and maximum combined luminance L'_{max}. If a telescopic photometer is used, the measured value is the combined value and no summation with L_{amb} is required. Each value shall be compared against the calibration target for the display based on clinical use.

This technical standard recommends that diagnostic interpretation displays used for mammography use an L'_{min} of at least 1.2 cd/m^2 and that displays used for other medical image interpretation use an L'_{min} of at least 1.0 cd/m^2. Note that the technical standard recommends these as *minimum* values, meaning that lower values should not be used for the minimum luminance settings. This is consistent with the recommendations provided by AAPM Report 270 and the ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging [4,5] which are based on avoiding mesopic vision of the human visual system's response at lower luminance levels. The measured L'_{min} should be within 10% of the calibrated L'_{min} target.

AAPM Report 270 and the ACR-AAPM-SIIM Technical Standard for Electronic Practice for Medical Imaging both recommend a maximum luminance based on a desired luminance ratio, defined as L'_{max}/ L'_{min}, of 350 (with a range of 250-450) [4,5]. This recommendation is based on the approximate luminance ratio of a typical chest film displayed on a light box and is meant to limit the dynamic range of the image to not

exceed the limitations of the human visual system [5]. Based on this relationship, L'_{max} should be at least 420 cd/m^2 for mammography displays and 350 cd/m^2 otherwise. The measured L'_{max} should be within 10% of the calibrated L'_{max} target.

For diagnostic interpretation displays with calibration targets greater than the proposed levels, the luminance ratio may no longer be the most appropriate means of maintaining the perceived contrast for a medical image. For displays in this category, this technical standard recommends using a fixed number of just noticeable differences (JNDs) as defined by the DICOM Standard [11] to maintain perceived contrast across displays with different calibration targets [12]. For the thresholds described above, the total number of JNDs is approximately 600.

c. Luminance Response Function

The luminance response function of a diagnostic interpretation display shall be measured at the initial setup and annually thereafter under the general supervision of the Qualified Medical Physicist. Using 18 equally spaced measurement points (every 15 gray levels on an 8-bit system), this technical standard recommends that the maximum error from the DICOM GSDF for the luminance response function is ±10%. The methodology for determining the DICOM GSDF conformance is described in detail in AAPM Report 270 – Display Quality Assurance [5].

Evaluating the luminance response function at finer intervals (eg, using 52 equally spaced measurement points) may better reveal issues with the luminance response function's calibration [5]. However, finer sampling also decreases the averaging benefit of coarser sampling, making the 10% threshold more difficult to reach. Such evaluation may be used in a troubleshooting environment or when evaluating a vendor's calibration, but a separate passing criterion may be needed. This technical standard only provides the 10% criterion for the 18-point measurement.

As described in IV.B, the vendor-supplied software and hardware may provide automatic calibration and measurement of the luminance response of a display. Although this technical standard supports the use of this software, the annual quality control testing should rely on an external photometer for data collection. However, this technical standard acknowledges this may not always be feasible and the use of a built-in photometer may be used instead.

d. Chromaticity and Gray Tracking

Most modern diagnostic interpretation displays are capable of full color display for medical image review. The chromaticity of the display at full brightness and the gray tracking shall be measured at the initial setup and should be measured annually thereafter under the general supervision of the Qualified Medical Physicist. AAPM Report 196 – Gray Tracking in Medical Color Displays [13] and IEC 62563-2 [3] describe the methodology for measuring and calculating gray tracking metrics.

Many photometers are capable of reporting both luminance and chromaticity values simultaneously. In this case, the addition of color metrics to the annual testing routine should not increase the measurement burden of the person performing the evaluation. If this functionality is not available, then the chromaticity should be verified at initial setup and then again if there are suspected issues with a displays color performance.

The chromaticity of diagnostic interpretation displays used for the same clinical purpose should be consistent across all systems. This technical standard recommends the use of the standard illuminant D65, which is consistent with the recommendations of AAPM Report 270 and the ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging [4,5]. The chromaticity of a diagnostic interpretation display should be within 0.01 of the standard target chromaticity when measured in the CIE 1976 color space (ie, chromaticity described using (u',v') coordinates).

Gray tracking using the AAPM Report 196 methodology [13] may be characterized using several metrics

described in detail within the report. This technical standard recommends a threshold of 0.01 for $??_{1,max}$ (referred to as the greyscale chromaticity in IEC 62563-2 [3]).

V. QUALITY CONTROL

A. Quantitative Display Performance Testing

2. Display Luminance Uniformity

Quantitative measurement of display uniformity requires measuring the luminance across different regions of a display and comparing the values. Small variations in the luminance across the surface for a uniform gray level is a low-spatial-frequency effect and is unlikely to negatively impact the clinical interpretation of medical images. In addition, modern display systems have much better uniformity compared with cathode- ray tube (CRT) displays and first-generation LCDs. Therefore, this technical standard recommends that display luminance uniformity only be measured at initial setup under the general supervision of the Qualified Medical Physicist. It may be measured again as a troubleshooting test if there are user-reported issues of nonuniformity, or if the qualitative uniformity test patterns described in V.B.b reveal substantial issues. If measured, either the Maximum Luminance Deviation or Luminance Deviation from the Median (depending on which is used) value should be less than 15%. If the value is greater than 15%, the Qualified Medical Physicist should work with the physicians using the diagnostic interpretation display to determine the possible clinical impact and necessary next steps.

V. QUALITY CONTROL

B. Qualitative Display Performance Testing

1. Test Patterns

a. Display Luminance

A test pattern designed to evaluate the display luminance performance shall be reviewed at least quarterly by a person under the direction of the Qualified Medical Physicist. This may be a technologist, physician, MPA, or IT/II professional. The testing shall take place for each diagnostic interpretation display under typical viewing conditions. The test pattern used may vary depending on what is available on the workstation or PACS for review. This technical standard recommends either the TG270-sQC pattern or TG18-QC/TG18-OIQ pattern. The difference between the TG18-QC and TG18-OIQ pattern is the presence of CRT-specific features in the TG18-QC version. This technical standard discourages the use of the SMPTE pattern due to the lack of features to provide meaningful display quality assessment, agreeing with the recommendations of AAPM Report 270.

If using the TG270-sQC pattern, all low-contrast bar patterns shall be visible in each gray level step and the perceived contrast should remain approximately the same over the full luminance range. The grayscale ramp along the bottom of the pattern shall be smooth with no discontinuities, scalloping, or other issues. The high-resolution patterns in the lower right corner shall both be fully visible, with alternating pixel rows/columns "on” (ie, white) and "off” (ie, black).

If using the TG18-QC/TG18-OIQ pattern, each gray level step shall be distinct from those around it. In addition, the small squares in the corner of each gray level step shall be visible at all levels. The grayscale ramps along the sides should both be smooth with no discontinuities, scalloping, or other issues. Finally, the highest frequency high-contrast pattern shall be clearly visible in all regions of the pattern with alternating pixel rows/columns "on” (ie, white) and "off” (ie, black).

This technical standard discourages the use of the SMPTE-type "5% box-in-a-box” regions of the pattern (such as those present in the TG18-QC/TG18-OIQ pattern) as a meaningful quality control evaluation. All diagnostic interpretation displays should easily display 5% contrast (which is roughly 13 gray levels on an 8-bit display), making it generally useless for quality control of modern systems. The low contrast bar patterns

in the gray level steps of the TG270-sQC pattern and low contrast squares in the corners of each gray level step of the TG18-QC/TG18-OIQ pattern each provide a more complete qualitative tool to determine if the same contrast appears approximately the same throughout the full luminance range.

b. Uniformity

Test patterns designed to evaluate the display luminance uniformity shall be reviewed at least quarterly by a person under the direction of the Qualified Medical Physicist. This may be a technologist, physician, MPA, or IT/II professional. The testing shall take place for each diagnostic interpretation display under typical viewing conditions. The test patterns used may vary depending on what is available on the workstation or PACS for review. This technical standard recommends either the TG270-ULN patterns or TG18-UN patterns. For the TG270-ULN patterns, the user should review three patterns: one low gray level, one medium gray level, and one high gray level. AAPM Report 270 recommends TG270-ULN8-200, TG270-ULN8-100, and TG270-ULN8-020, though any three will work so long as they cover an appropriate range. The TG18-UN patterns include the TG18-UN10 and TG18-UN80 versions, the first of which is set to approximately 10% of the maximum luminance and the second of which is set at 80%.
Regardless of which pattern set is used, the person performing the evaluation should examine each test pattern for clinically significant nonuniformities. As discussed in AAPM Report 270, small- or medium-sized nonuniformities (eg, mura, bad pixels) are likely to interfere with clinical interpretation of medical images more than large nonuniformities [5]. Uniform gray levels are also likely to reveal any external marks (eg, fingerprints, spray marks, pen marks, etc.) that may be easily resolved by cleaning. The Qualified Medical Physicist should review all non-uniformities found on this quality control test, and, if necessary, discuss their clinical significance with the interpreting physician. The threshold for what makes an artifact clinically significant may vary depending on the clinical usage of a diagnostic interpretation display. Diagnostic interpretation displays shall have no clinically significant nonuniformities.

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