ACR–AAPM–SIIM TECHNICAL STANDARD FOR ELECTRONIC PRACTICE OF MEDICAL IMAGING

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 has been revised by the American College of Radiology (ACR), the American Association of Physicists in Medicine (AAPM), and the Society for Imaging Informatics in Medicine (SIIM).

For the purpose of this technical standard, the images referred to are those that radiologists would normally interpret, including transmission projection**,** tomographic and cross-sectional X-ray images, ionizing radiation emission images, and images from ultrasound (US) and magnetic resonance (MR) modalities. In general, similar images generated as part of radiation therapy would benefit from the same considerations outlined in this technical standard. Research, nonhuman, and visible light images (such as dermatologic, histopathologic, or

endoscopic images) are out of scope, although many of the same principles are applicable.

This technical standard defines goals, qualifications of personnel, equipment guidelines, specifications of data manipulation and management, and quality control and quality assurance (QA) procedures for the use of digital image data that should result in high-quality radiological care. A glossary of commonly used terminology (Appendix A) and a reference list are included.

This technical standard is applicable to any system of digital image data management, from a single-modality or single-use system to a complete picture archiving and communication system (PACS) to the electronic transmission of patient medical images from one location to another for the purposes of interpretation and/or consultation. Where other modality or examination-specific practice parameters or technical standards exist, they continue to apply.

In general, digital mammography is outside the scope of this technical standard (see ACR–AAPM–SIIM Practice Parameter for Determinants of Image Quality in Digital Mammography [1]). However, given the constant evolution of display technology and quality control, this technical standard does make suggestions on those areas that are not fully addressed in other technical standards or practice parameters.

The goals of the electronic practice of medical imaging include, but are not limited to:

1. Acquisition or generation of accurately labeled and identified image data
2. Transmission and storage of images and image data with appropriate format, fidelity, and compression
3. Timely retrieval and display of images and image data for formal interpretation, review, and consultation
4. Timely retrieval and display of available prior imaging studies for comparison with a current study
5. Distribution of images and image data to remote sites for consultation, review, or formal interpretation
6. Archiving of data to maintain accurate patient medical records in a form that:
    a. Meets applicable facility, state, and federal regulations
    b. Maintains patient confidentiality
7. Promoting efficiency and quality improvement in radiology workflows
8. Facilitating the interpretations of images, selection of key images, and/or annotated images to referring providers
9. Supporting telemedicine by making medical image consultations available in medical facilities without on-site medical imaging support
10. Providing supervision of off-site imaging studies
11. Providing timely availability of medical images, image consultation, and image interpretation by:
    a. Facilitating medical image interpretations in on-call situations
    b. Providing subspecialty support as needed
12. Minimizing the occurrence of poor image quality
13. Providing/assuring data security and preventing data theft ("breach"), in accordance with Consensus, Frameworks, and Best Practices in A Review of Cybersecurity and Privacy Standards in Medical Imaging [2]
14. The ability to electronically review, audit, and transfer imaging protocols

Appropriate database management procedures applicable to all of the above should be in place.

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

A. Physician

1. The physician must demonstrate qualifications as delineated in the appropriate ACR practice parameter or technical standard for the particular diagnostic modality being interpreted.
2. For the purpose of electronic practice, physicians using the image data management system for official interpretation[2] should understand the basic technology of image acquisition, transmission, manipulation, retrieval, and display, including the strengths, weaknesses, and limitations in the use of the image viewing equipment. Where appropriate, the interpreting physician must be familiar with the principles of radiation protection, the hazards of radiation, and radiation monitoring requirements as they apply to both patients

and personnel. The physician performing the official interpretation must be responsible for the quality of the images being reviewed and understand the elements of quality control of digital image management systems[3].

3. The physician should have a working knowledge of those portions of the digital image chain from acquisition to display that affect image quality and potential artifact production.

[2] The ACR Medical Legal Committee defines official interpretation as that written report (and any supplements or amendments thereto) that attach to the patient's permanent record. In health care facilities with a privilege delineation system, such a written report is prepared only by a qualified physician who has been granted specific delineated clinical privileges for that purpose by the facility's governing body upon the recommendation of the medical staff.

[3] The ACR Rules of Ethics state: "It is proper for a diagnostic radiologist to provide a consultative opinion on radiographs and other images regardless of their origin. A diagnostic radiologist should regularly interpret radiographs and other images only when the radiologist reasonably participates in the quality of medical imaging, utilization review, and matters of policy which affect the quality of patient care."

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

B. Qualified Medical Physicist

A Qualified Medical Physicist is an individual who is competent to practice independently 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 Physicists in Medicine, 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 Parameter for Continuing Medical Education (CME) [3].

The appropriate subfields of medical physics for this technical standard are Therapeutic Medical Physics, Diagnostic Medical Physics, and Nuclear Medical Physics (previous medical physics certification categories including Radiological Physics, Therapeutic Radiological Physics, Medical Nuclear Physics, Diagnostic Radiological Physics, and Diagnostic Imaging Physics are also acceptable). (ACR Resolution 17, adopted in 1996 – revised in 2008, 2012, 2022, Resolution 41f)

Within the electronic practice of medical imaging, the Qualified Medical Physicist should:

1. Understand how the informatics and display components discussed in the equipment specification section of this document function and verify interoperability, as appropriate.
2. Take an active role in the QA and control procedures of the devices that produce the electronic images to ensure all relevant quality standards are met.
3. Participate or consult in the design and execution of a QA and control program for display systems.
4. Ensure appropriate radiation dose information is stored as part of imaging studies, using the relevant format for each modality (eg, Digital Imaging and Communications in Medicine (DICOM) Radiation Dose Structured Reports (RDSRs)).
5. Understand the regulatory and accreditation implications for the electronic practice of medical imaging within their institution and participate as appropriate.
6. Remain apprised of standards-setting organizations and changes with how electronic image information may be created, transmitted, or stored.
7. Be familiar with the processes and requirements of imaging protocol management.
8. Verify the management of imaging data to preserve data fidelity for the life of the data.

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

C. Non-Physician Radiology Provider (NPRP)

NPRPs are all Non-Physician Providers (eg, RRA, RPA, RA, PA, NP, ...) who assist with or participate in portions of the practice of a radiologist-led team (Radiologists = diagnostic, interventional, neurointerventional radiologists, radiation oncologists, and nuclear medicine physicians). The term “NPRP” does not include radiology, CT, US, NM MRI technologists, or radiation therapists who have specific training for radiology related tasks (eg, acquisition of images, operation of imaging and therapeutic equipment) that are not typically performed by radiologists.

The term 'radiologist-led team' is defined as a team supervised by a radiologist (ie, diagnostic, interventional, neurointerventional radiologist, radiation oncologist, and nuclear medicine physician) and consists of additional healthcare providers including RRAs, PAs, NPs, and other personnel critical to the provision of the highest quality of healthcare to patients. (ACR Resolution 8, adopted 2020).

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

D. Radiologic Technologist

See the ACR–AAPM–SIIM–SPR Practice Parameter for Digital Radiography [4]. Additional specific qualifications and responsibilities include:

1. The technologist must
    a. Be certified by the appropriate registry and/or possess unrestricted state licensure
    b. Meet the qualification requirements of any existing ACR practice parameter or technical standard for acquisition of a particular examination.
    c. Be trained to properly operate those portions of the image data management system with which the individual must routinely interact. This training should include as appropriate:
        i. Image acquisition technology
        ii. Image processing protocols
        iii. Proper selection of examination specific options.
        iv. Image quality evaluation and remediation
        v. Radiation dose indicators
        vi. Patient and personnel safety procedures
        vii. Quality improvement methodology
        viii. Quality assurance workflows

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

E. Imaging Informatics Professional

The Imaging Informatics Professional should be qualified to assess problems and provide input to solutions, initiate repairs, and coordinate system-wide maintenance programs that will assure system functioning and availability to high-quality images and image data. The responsibilities and experience of an Imaging Informatics Professional include:

1. Maintenance of all relevant informatics systems, such as radiology information system (RIS), PACS, speech recognition report generation systems, advanced postprocessing systems, machine/deep learning and AI point-of-care tools, image archives, database servers, business continuity and disaster recovery systems, computer servers, and desktops.
2. Maintenance of the integrity and security of systems to ensure continuous and accurate operation of the informatics systems. This includes, but is not limited to, routine updates, software patches, etc.
3. Coordination of the interaction/functionality of all data entry and management systems with the necessary radiology applications, programs and databases. This includes the maintenance of interfaces and integrations with other applications.
4. Knowledge of computer systems using common operating systems (eg, Windows, Unix/Linux, macOS), data communications standards and equipment, network protocols, database management, internet protocols, and systems analysis methods and design.

A Qualified Imaging Informatics Professional is an individual who is competent to practice independently in the areas of informatics listed above and discussed in the section on Informatics Workflow. The individual should

have a minimum of a bachelor's degree in computer science or equivalent and continuing education and experience in imaging informatics to demonstrate that the individual is competent to practice as an Imaging Informatics Professional. Certification through the American Board of Imaging Informatics (ABII) or PACS Administrators Registry and Certification Association (PARCA) can be used as validation of the individual's qualification as a Qualified Imaging Informatics Professional.

III. EQUIPMENT SPECIFICATIONS

Specifications for equipment used in digital image data management will vary depending on the application and the individual facility's needs, but in all cases it should provide image quality and availability appropriate to the clinical needs whether that need be official interpretation or secondary review. The equipment must also be capable of maintaining the security and privacy of patient information in accordance with the Health Insurance Portability and Accountability Act (HIPAA) and other regulations as described in the Consensus, Frameworks, and Best Practices in A Review of Cybersecurity and Privacy Standards in Medical Imaging [2]

Compliance with the DICOM standard, the Integrating Healthcare Enterprise (IHE) Radiology Technical Framework, and, where applicable, the IHE-Radiation Oncology Technical Framework (IHE-RO) is strongly recommended for all new equipment acquisitions, and consideration of periodic upgrades incorporating the expanding features of that standard should be part of the ongoing quality control program. The ability to integrate in-context with text-based applications such as electronic medical records (EMRs), report generation systems, and clinical decision support systems using the Health Level 7v2 Fast Healthcare Interoperability resources (HL7v2 FHIR) standard is strongly recommended.

III. EQUIPMENT SPECIFICATIONS

A. Acquisition or Digitization

Initial image acquisition should be performed in accordance with the appropriate ACR modality or examination practice parameter or technical standard.

III. EQUIPMENT SPECIFICATIONS

A. Acquisition or Digitization

1. Direct image capture

The image data set created by the modality for diagnostic interpretation should be transferred to the image management system with full spatial resolution (image matrix size) and contrast resolution (pixel bit depth). The DICOM Standard is to be used for image transactions with the image management system.

III. EQUIPMENT SPECIFICATIONS

A. Acquisition or Digitization

2. Scanned radiographic films

Although films from prior patient studies may be digitized using modern film scanning systems, scanned films should be used only when access to digital-originals are not available.

When used, the pixel pitch of the scanner should be small enough to capture the limiting resolution of the film. For general purpose radiographic films, the scanner should use a sample pitch of 200 µm or finer and have a limiting spatial resolution of 2.5 line pairs/mm or cycles/mm or better. For high resolution film or mammography, the scanner should use sample pitch of 100 µm or finer and have a limiting spatial resolution of 5.0 line pairs/mm or cycles/mm. The scanner should be capable of recording film optical densities up to at least 3.2 for general purpose radiographs and 4.0 for high resolution radiographs and mammograms. The digitization should have at least 12 bits of precision (0 to 4,095) and produce either DICOM presentation values or values proportional to film density. Avoid using photographic cameras because of their inherent distortion and possible optical artifacts.

III. EQUIPMENT SPECIFICATIONS

A. Acquisition or Digitization

3. Video digitizer acquisitions

Traditional fluoroscopy systems have used video recording cameras to acquire images from the output phosphor of an image intensifier. Recordings may be of individual spot exposures, pulsed fluoroscopic sequences, or continuous fluoroscopic frames. Analog video cameras produce a time varying voltage signal corresponding to a raster scan of the image. Analog to digital conversion systems are used to convert these signals to digital images formatted according to the DICOM standard. These systems are susceptible to degraded quality due to analog signal noise, timing, and drift. When used, the image quality should be closely monitored. In general, the use of direct digital fluoroscopy panels or digital recording cameras with image intensifiers is strongly recommended.

III. EQUIPMENT SPECIFICATIONS

A. Acquisition or Digitization

4. General Requirements

1. At the time of patient imaging, the imaging modality must have capabilities for capturing imaging information such as accession number, patient name, identification number, date and time of examination, name of facility or institution, unique modality identifier (eg, station name), type of examination, patient or anatomic part orientation (eg, right, left, superior, inferior), and amount and method of data compression. The imaging modality should also have the ability to capture the patient demographic information such as date of birth and sex. It may be desirable to capture indications for the examination and a brief patient history. It is best practice to obtain the above examination and image information using DICOM modality worklist services that communicate the correct information electronically
2. To provide adequate information for ongoing quality monitoring and improvement, including radiation exposure and protocol monitoring, the modality should have the capability for capturing and communicating information about acquisition technique factors, dose indicators reconstruction, or image processing parameters (for all images acquired) as applicable to the imaging modality. Specifically, to support radiation exposure monitoring, a modality that uses ionization radiation should provide a DICOM Radiation Dose Structured Reporting (SR) as described in the IHE Radiation Exposure Monitoring Integration Profile [5].
3. The above information associated with the images or study should be contained in the appropriate DICOM object (eg, modality specific DICOM Radiation Dose SR), in accordance with the relevant DICOM information object definition (IOD).
4. Imaging modalities that use ionizing radiation should provide a means to capture and transmit information about “rejected” images (“rejected” images are acquired but not viewed or transmitted for diagnostic use). It is recommended that modalities provide reject rates (or information that can be used to calculate the reject rate) in addition to acquisition information and reject reasons. Whenever possible, the DICOM standard should be leveraged in capturing this information (eg, in DICOM Key Object Selection Modules, or DICOM RDSR).

III. EQUIPMENT SPECIFICATIONS

B. Compression

Compression may be defined as either mathematically reversible (lossless) or irreversible (lossy). Reversible compression may always be used, since by definition there is no impact on the image quality. Irreversible compression may be used to reduce transmission time or storage space only if the quality of the result is sufficient to reliably perform the clinical task. The type of body part, the modality, and the objective of the study will determine the amount of compression that can be tolerated.

The term "diagnostically acceptable irreversible compression” (DAIC) refers to mathematically irreversible compression that does not affect a particular diagnostic task [6]. DAIC may be used under the direction of a qualified physician with no reduction in clinical diagnostic performance by either the primary image interpreter or decision makers reviewing the images. From a practical perspective, this means that any artifacts generated by the compression scheme should not be perceptible by the human viewer or are at such a low level that they do not interfere with interpretation.

The ACR and this technical standard make no general statement on the type or amount of compression that is appropriate to any modality, disease, or clinical application to achieve the diagnostically acceptable goal. The scientific literature and other national guidelines may assist the responsible physician in choosing appropriate types and amounts of compression, weighing the risk of degraded performance against the benefits of reduced storage space or transmission time. The type and amount of compression applied to different imaging studies transmitted and stored by the system should be initially selected and periodically reviewed by the responsible physician to ensure appropriate clinical image quality, always considering that it may be difficult to evaluate the impact on observer performance objectively and reliably [7].

If reversible or irreversible compression is used, only algorithms defined by the DICOM standard such as Joint Photographic Experts Group (JPEG), JPEG-LS, JPEG-2000, or MPEG should be used, since images encoded with proprietary and nonstandard compression schemes reduce interoperability, and decompression followed by recompression with a different irreversible scheme (such as during migration of data) will result in significant image quality degradation [6]. The DICOM standard does not recommend or approve any particular compression scheme for any particular modality, image type, or clinical application. However, the use of proprietary compression algorithms or file formats may impede interoperability and usability of data, including data viewing, processing, and migration.

The U.S. Food and Drug Administration (FDA) requires that when an image is displayed it be labeled with a message stating if irreversible compression has been applied and with approximately what compression ratio (and/or quality factor) [8]. In addition, the name or type of compression scheme used (for standard schemes such as JPEG, JPEG 2000, etc) should also be displayed, since this affects the interpretation of the impact of the compression. The DICOM standard defines specific fields for the encoding of this information and requires its persistence even after the image has been decompressed.

The FDA does not allow irreversible compression of digital mammograms for retention, transmission, or final interpretation, although irreversibly compressed images from prior studies may be used for comparison purposes, if deemed of acceptable quality by the interpreting physician [9]. Retention of digital breast tomosynthesis (DBT) images using DICOM breast tomosynthesis object (BTO) is preferred to DICOM secondary capture object (SCO) to permit providers to view and exchange tomosynthesis images across sites and vendor platforms. For other modalities, the FDA does not restrict the use of compression, but it does require manufacturers of devices that use irreversible compression to submit data on the impact of the compression on quantitative metrics of image quality (such as peak signal-to-noise ratio (PSNR) [8]. The responsible physician, working with the Qualified Medical Physicist as appropriate, is responsible for ensuring that the image quality is sufficient to achieve a diagnostically acceptable goal.

III. EQUIPMENT SPECIFICATIONS

C. Transmission

The transmission infrastructure should have a bitrate and bandwidth commensurate with expected volumes to ensure images are delivered in a timely fashion. It is strongly recommended that infrastructure for transmission of images and image data be implemented in accordance with the relevant IHE Integration Profiles to best support interoperability and imaging workflows. Only the appropriate modality-specific DICOM service-object pair (SOP) classes should be used for transmission and storage. For further information on security, see the Consensus, Frameworks, and Best Practices in A Review of Cybersecurity and Privacy Standards in Medical Imaging [2]

III. EQUIPMENT SPECIFICATIONS

D. Display

The consistent presentation of images (CPI) on workstations is fundamental for electronic imaging operations. Images seen by technologists during acquisition, by radiologists during interpretation, and by physicians as a part of patient care should have similar appearance. The spatial and contrast resolution of images displayed for interpretation is particularly important. The presentation of images is influenced by workstation software, graphic controllers, display devices, and viewing environment.

With awareness that differences in display performance in the imaging chain may alter desired image appearance and/or limit what can be seen, it is often practical to differentiate between display use-cases in terms of requirements for performance and evaluation. Different display use-cases within a radiology practice include diagnostic interpretation, modality, or postprocessing displays. In some cases, modality or postprocessing displays that directly influence clinical decision making, procedural guidance, or diagnostic image capture should be considered as diagnostic displays (even though they are not used for primary interpretation).

III. EQUIPMENT SPECIFICATIONS

D. Display

1. Workstation characteristics

a. Graphic bit depth

A display device must accurately represent image information with a sufficient number of grayscale values to prevent the loss of image contrast and eliminate contour artifacts. The operating systems of most workstations manage images with red, green, and blue channels having 8 bits (256 values each). The number of available gray levels where the red, green, and blue values are equal (producing grayscale images) is thus 256. Systems with increased bit depth, such as 30-bit graphics with 10 bits per channel, require support from the operating system, workstation software, graphics card, and display. Although subtle differences between 8-bit and 10-bit systems can be demonstrated using test patterns, no evidence has been found to date that diagnostic interpretations are affected by the use of higher than 8-bit systems.

III. EQUIPMENT SPECIFICATIONS

D. Display

1. Workstation characteristics

b. Display technology

Displays for medical image viewing with few exceptions are liquid crystal displays (LCDs). There remain issues with organic light emitting diode (OLED) displays in terms of display calibration, artifacts, and QA that have limited their application as medical imaging displays. Other display types (eg, CRTs, plasma) should be avoided. Distinguishing characteristics of different LCDs include:

i. Front panel reflectivity:
- Spectral and diffuse reflection should be minimized. Diffuse reflectivity coefficients should be provided by the display vendor to properly calibrate a display in the presence of ambient illumination.

ii. Backlights that provide the light output of LCDs:
- LED backlights have shown greater stability and longevity than cold-cathode fluorescent lamp backlights. With either type, backlight stabilization provides for better retention of display calibration.
- Displays for medical imaging often have higher (luminance) output backlights than other displays. Higher (luminance) output backlights allow for achieving recommended luminance levels and maintaining that display calibration over a longer period of time before replacement is needed.

iii. Viewing angle:
- LCD panel type affects how perceived image contrast degrades at large viewing angles. Displays for radiology should use LCD panels, which have a viewing angle performance equivalent to or better than in-plane switching LCD panels which are widely available.

iv. Luminance uniformity:
- Displays for medical imaging may offer built-in uniformity correction, which reduces display nonuniformities.

v. Integrated photometers:
- These allow for remote quantitative testing and display calibration. This is helpful for limiting the amount of hands-on efforts needed for display testing and/or calibration, particularly with

teleradiology and geographically distributed radiology practices.

vi. Resolution:

- Different offerings in pixel pitch and display size are tailored for different viewing distances and resolution needs as described in section 2.b below.

III. EQUIPMENT SPECIFICATIONS

D. Display

1. Workstation characteristics

c. Graphic interface

LCD devices are inherently digital with an internal buffer storing the data for each pixel in the rows and columns of the device. The interface between the graphic controller and the LCD device should transfer the image data using a digital format such as HDMI, DVI-D (either single-link or dual-link), or DisplayPort. Due to the difference in video signals between the DVI and DisplayPort standards, adapters to convert between the two are discouraged because of the potential distortion or loss in signal. For optimal resolution, the graphic controller device driver should always be set to the native rows and columns of the LCD device. An analog video interface signal such as VGA or DVI-A is strongly discouraged since the digital-to-analog conversion in the graphic controller and the analog-to-digital conversion in the LCD device can introduce image degradation.

III. EQUIPMENT SPECIFICATIONS

D. Display

1. Workstation characteristics

d. Image presentation size

The rows and columns of the displayed image are typically different than the rows and columns of the acquired image. The application software working in conjunction with the graphic controller interpolates from the acquired image data to get the displayed image data.

For optimal image resolution, the interpolation of each displayed pixel, whether up-sampling or down-sampling, should consider more than just the closest 4 acquired pixel values. 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. When down-sampling noisy images, the extended neighborhood region considered in the interpolation also helps reduce noise in the presentation

III. EQUIPMENT SPECIFICATIONS

D. Display

1. Workstation characteristics

e. Presentation support features:

The application software used to select and present imaging studies should provide features to allow rapid and easy review or interpretation of a study.

1. Hanging protocols that address the selection of image series and display format should be flexible and tailored to user preferences with proper labeling and orientation of images.
2. Fast and easy navigation between new and old studies should be feasible.
3. Accurately associating the patient and study demographic information with the images of the study performed is essential.
4. Window (contrast) and level (brightness) adjustment tools must be available since the full dynamic range of most images cannot be displayed on most digital devices. Preset window/level settings (eg, bone or lung windows using set lookup table (LUT) transformations) are recommended to increase the speed of user interaction with the display device.

5. Zoom (magnification) and pan functions capable of meeting guidelines for display at the originally acquired spatial resolutions (ie, direct presentation of acquired pixels on the display pixels at one-to-one pixel mapping) are essential so that the display does not limit the intrinsic spatial resolution of the image. For some applications, the ability to present an image with anatomic structure having true size relative to the acquisition is important.
6. Rotating or flipping the images must preserve the correct patient orientation labels.
7. Calculating and displaying accurate linear measurements and pixel value determinations in values appropriate for the modality (eg, Hounsfield units for CT images) are necessary, if those data are available and can be calibrated to the acquisition device.
8. Prior application of irreversible compression ratio, processing, or cropping on the image and/or overlay should be indicated. Clinically relevant technical parameters should be accessible, with overlay information on the display or with capabilities to view the DICOM metadata content.

III. EQUIPMENT SPECIFICATIONS

D. Display

1. Workstation characteristics

f. Ergonomic factors

1. Adequate air flow, optimal temperature, and humidity control should be maintained in reading areas.
2. Viewing conditions should be optimized to minimize eye fatigue by controlling the reading room ambient lighting. The ambient lighting should be set to minimize specular and diffuse reflection on the workstation display, which can be accomplished by setting the ambient illuminance to 25 to 75 lux [10,11]. Modern displays with improved reflection characteristics may allow the use of brighter ambient lighting conditions, although conformance with current recommendations from the AAPM and ACR should always be considered (see section III.D.2.a.i-ii and AAPM Report 270) [12,13].
3. Noise from computer equipment and other devices should be minimized.
4. Proper chairs with lumbar support and adjustable height controls (including armrests) are recommended to avoid injuries and excessive fatigue.
5. The workstation table should be height adjustable, and the keyboard, mouse, and displays should be designed to maximize comfort and efficiency. The display devices should be placed to maintain the viewers at an arm's length from the display (ie, approximately two-thirds meter or 60 cm).
6. Dictation tools, internet access, and other reference tools should be readily accessible and easy to use during image interpretation.
7. Guidelines on the maximum number of acceptable pixel defects are specified by ISO 9241 as a function of display class [14]. Documentation of allowed pixel defects should be provided by the display manufacturer. Displays should be evaluated for significant pixel defects initially and periodically (at least annually is recommended). Pixel defects should be evaluated for clinical relevance by the interpreting physician in consultation with a Qualified Medical Physicist.

III. EQUIPMENT SPECIFICATIONS

D. Display

2. Display Characteristics

a. Luminance Response

Ambient Luminance (L_{amb}):

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When the power to the display device is off, the display surface will still show some brightness due to diffusely reflected room lighting. This is called the L_{amb}. The L_{amb} should be less than one-fourth of the luminance of the

darkest gray level. If the L_{amb} is above this level, the contrast in the darkest regions of the image may be affected by the L_{amb}. If the ambient lighting cannot be adjusted to meet this threshold, the luminance response described in III.D.2.a.iv should explicitly account for L_{amb}.

III. EQUIPMENT SPECIFICATIONS

D. Display

2. Display Characteristics

a. Luminance Response

Minimum luminance (L_{min}):

●

Because the contrast response of the adapted human visual system (HVS) is poor in very dark regions, the luminance of the lowest gray value, L_{min}, should not be extremely low. The L_{min} including a component from ambient lighting, $L'_{min} = L_{min} + L_{amb}$, should satisfy the $L_{amb} < L_{min} / 4$ and be at least 1.0 cd/m2. Below this level, changes in luminance are less perceptible and small luminance errors cause greater relative errors in the calibrated response.

III. EQUIPMENT SPECIFICATIONS

D. Display

2. Display Characteristics

a. Luminance Response

Maximum luminance (L_{max}):

●

For a given L'_{min}, the perceived contrast characteristics of an image on a display depends on L'_{max} (the luminance for the maximum gray value including the component for ambient lighting). The luminance ratio (LR), L'max/L'min, describes the overall visual contrast of a display. The LR must be large for good image contrast; however, an excessively large LR will exceed the range of the adapted HVS. An LR of 350, which is equivalent to a film OD range from 0.20 to 2.75, is effective for many clinical radiology environments. Brighter environments (eg, surgical suits) with much higher ambient lighting may benefit alternative settings. Consultation with a Qualified Medical Physicist or other qualified professional is recommended in such situations.

For an L'_{min} of 1.0 cd/m2 and LR of 350, the L'_{max} of diagnostic displays used for interpretation would be set to 350 cd/m2. Higher minimum and maximum luminances are acceptable, so long as the display calibration takes into account the nonlinear contrast response behavior of the HVS and does not exceed the capability of the HVS, which may degrade the calibration's assumptions of perceived contrast. For brighter displays (eg, surgical suites with large L'_{max}, L'_{min}), the display should be adjusted accordingly to maintain perceived contrast, which may require a review of clinical images, relevant test patterns, and/or consultation with a Qualified Medical Physicist or other qualified professional.

Based on this LR, the L'_{max} of diagnostic displays used for interpretation should be at least 350 cd/m2 with an L'_{min} of 1.0 cd/m2. For the interpretation of mammograms, L'_{max} should be at least 420 cd/m2 with an L'_{min} of 1.2 cd/m2. The displays used for other purposes should have an L'_{max} of at least 250 cd/m2 with an L'_{min} of 0.8 cd/m2. For brighter displays (ie, larger L'_{max}, L'_{min}), the LR should be adjusted accordingly to maintain perceived contrast at the display, which may require a review of clinical images and relevant test patterns.

III. EQUIPMENT SPECIFICATIONS

D. Display

2. Display Characteristics

a. Luminance Response

Luminance versus gray level:

-

The luminance of intermediate gray values between L'_{min} and L'_{max} should follow the same response function for all displays in a facility. It is strongly recommended that the DICOM grayscale standard display function (GSDF) be used to set the intermediate gray values. The perceived contrast visible to the user of the display may be held consistent across different displays by maintaining a consistent number of just-noticeable-difference (JND) between the calibrated minimum and maximum luminance values.

III. EQUIPMENT SPECIFICATIONS

D. Display

2. Display Characteristics

a. Luminance Response

Calibration:

-

The luminance response, including both the LR and contrast curve, of some medical and professional graphics displays can be selected using the display on screen display (OSD) controls. Other medical/professional devices require software from the display manufacturer to load look-up tables (LUTs) to the display that set the luminance of each gray level. For consumer-grade displays without either of these functionalities, the calibration may be achieved by loading a LUT to the driver of the graphic control card.

III. EQUIPMENT SPECIFICATIONS

D. Display

2. Display Characteristics

a. Luminance Response

Quality control:

-

Displays should be evaluated for acceptable performance initially and periodically (at least annually is recommended) and after major upgrades or repairs to the display workstations (eg, major software upgrade, graphics card replacement). Visual test patterns (eg, TG18 or TG 270 test patterns [15]) can be used for qualitative evaluation of display performance, although it is difficult to accurately characterize a display only by visual inspection. Advanced tests, done on an annual or quarterly basis, measure the luminance in relation to gray value and evaluate the contrast response curve. The contrast response of displays used for diagnostic interpretation should be within 10% of the DICOM GSDF over the full luminance response. For other displays, the contrast response should be within 20% of the DICOM GSDF over the full luminance response. Advanced tests to measure the luminance characteristics of a display may be performed periodically using automated software and internal photometers or backlight sensors. Care should be taken to ensure proper calibration of the internal/automated measurement devices and software as part of acceptance testing and periodically thereafter (eg, every 10,000 backlight hours from AAPM Report 270 [13]).

III. EQUIPMENT SPECIFICATIONS

D. Display

2. Display Characteristics

a. Luminance Response

White point:

-

The color characteristics of a display with respect to the presented color space are not considered in this technical standard. However, the white point associated with presentation of grayscale images is important for medical imaging systems. It is recommended that displays be set to a consistent white point to maintain consistent image appearance. In addition, it is recommended to set the white point to a standard illuminant, for example, CIE Standard Illuminant D65 (corresponding to daylight standard), rather than a correlated color temperature (CCT) (6500 K in the cases of D65). Standard illuminants are often cited with a CCT; however, it should be noted that not all displays with a CCT of 6500 K have a white point of D65 (with the same being true for other standard illuminants). If the display(s) does (do) not meet these specifications after corrective action is attempted, then the decision to continue using these displays should be determined by the lead interpreting physician in consultation with a Qualified Medical Physicist. Justification for the recommended course of action should be documented.

III. EQUIPMENT SPECIFICATIONS

D. Display

2. Display Characteristics

b. Pixel pitch and display size

The spacing of pixel structures, referred to as the pixel pitch, determines how much detail can be presented within a given display region. The size of the active display region in combination with pixel pitch determines the number of pixels in the display device. Although it has been common to classify displays based on the number of pixels (ie, 1 megapixel [MP], 2 MP, 3 MP, 5 MP, or 10 MP), it is recommended that the pixel pitch and display size be used when considering the capabilities of a particular device.

III. EQUIPMENT SPECIFICATIONS

D. Display

2. Display Characteristics

b. Pixel pitch and display size

Pixel pitch:

-

The pixel pitch of a display determines the maximum spatial frequency that can be presented. Note that the limiting spatial frequency of the image is based on the image acquisition system, not the display. Using the sampling theorem, the maximum spatial frequency that can be described by digital signals with a constant pitch, P in mm, is 1/(2P) cycles/mm. It is desirable to have the pixel pitch sufficiently small so as to present all of the spatial frequencies that the human visual system can perceive. At an arm's length viewing distance (2/3 meter, 60 cm), the typical human observer can perceive displayed spatial frequencies up to a maximum of 2.5 cycles/mm. For displays used in diagnostic interpretation, it is recommended that the pixel pitch be approximately 0.200 mm and not larger than 0.215 mm. At this pixel pitch, individual pixels and their substructure are not visible and images have continuous tone appearance. No advantage is derived from using a smaller pixel pitch since higher spatial frequencies are not perceived by a typical human observer at typical

viewing distances.

For the presentation of images requiring closer inspection, zoom and pan display features should be used rather than decreasing the viewing distance. Since the human visual system has maximum contrast sensitivity at approximately 0.5 cycles/mm, image zoom with interpolation can often reveal subtle detail not seen at true size.

Displays used by technologists and clinical care staff are often not viewed at a desk, and the viewing distance may be larger than for diagnostic interpretation. For these displays, a larger pixel pitch based on the typical viewing distance may be appropriate (0.250 mm at 75 cm, 0.300 mm at 90 cm).

III. EQUIPMENT SPECIFICATIONS

D. Display

2. Display Characteristics

b. Pixel pitch and display size

Display size:

-

When interpreting images, the attention of the viewer is not limited to the center of the display but extends to the edges as well via peripheral vision. Good visualization of the full scene is achieved when the diagonal display distance is approximately 80 percent of the viewing distance. At 2/3 meter, this corresponds to a diagonal size of 53 cm (21 inches), with a total viewing area of approximately 32 cm × 42 cm. Displays with a pixel array size of 1,500 × 2,000 (3 MP) and a pixel pitch of approximately 0.210 mm will have a diagonal size of 52.5 cm and satisfy both the size and pixel pitch recommendations for typical interpretation environments.

Displays developed specifically for mammography often have larger pixel arrays (eg, 2048 × 2560 [5 MP]). For a display of a given size, such an array will have a finer pixel pitch (eg, 0.165 mm). The finer pitch will not improve the spatial resolution of the underlying image data, which is determined by the imaging system, and the benefits over a pixel pitch of 0.200 mm are negligible at a viewing distance of 60 cm because of the limitations of the human visual system discussed earlier. However, the larger array size allows for viewing a larger region of the mammography image at the native, or full, resolution (ie, 100% zoom, no interpolation). The ability to view more of the image on the display improves the workflow of image interpretation by reducing the amount of panning required to review all parts of the image.

A number of manufacturers have developed 8, 10, or 12 MP widescreen displays or “dual displays.” These are generally suitable for the majority of radiologic images, including mammography, because they make it feasible to display 2 images (eg, right and left CC or MLO views of the breast) or large series of images (eg, multiple MR or CT series) simultaneously on the same display, rather than requiring two displays side-by-side. Such displays may be treated as a single display from a calibration and quality control (QC) standpoint, so long as they are controlled from a single video input.

An aspect ratio, width to height, of 3:4 or 4:5 is well suited for the presentation of diagnostic images. Such a portrait presentation requires image rotation from the graphic controller. However, some of the displays currently being manufactured have a wide format, 16:9 or 16:10. These can be used similarly to a dual display workstation if the application software can present images in two regions with 8:9 or 8:10 aspect ratio.

III. EQUIPMENT SPECIFICATIONS

E. Archiving, Retention, and Retrieval

1. Digital imaging data management systems must provide storage capacity capable of complying with all facility, state, and federal regulations regarding medical record retention. Images stored by either a transmitting or receiving site should meet the jurisdictional requirements of both the transmitting and

receiving site. Images interpreted off-site need not be stored at the receiving facility provided they are stored at the transmitting site or its designee. However, if the images are retained at the receiving site, the retention period of that jurisdiction must be met as well. The policy on record retention should be in writing.

2. Digital imaging data and their corresponding records may be stored either on-premises or remotely. In either case, the data archiving, retention, and retrieval policies and workflow should reflect the storage architecture.
3. Each examination data file must have an accurate corresponding patient and examination database record that includes patient name, patient identification number, accession number, examination date, type of examination (modality and study description), and facility at which the examination was performed. It is desirable that space be available for a brief clinical history.
4. Current and prior examinations must be retrievable in a time frame appropriate to the clinical needs of the facility and medical staff.
5. Quality patient care depends on the stability and reliability of the digital image data management system. Written policies and procedures must be in place to ensure continuity of care within a facility or institution. They should include internal redundancy systems, backup telecommunication links, disaster recovery, emergency downtime contingency plan, and business continuity plan.

III. EQUIPMENT SPECIFICATIONS

F. Image Sharing

1. Each facility should have a mechanism for image sharing on physical media, including CD, DVD, or removable media, and should be able to export and import data compliant with the IHE Portable Data for Imaging (PDI) profile [16,17]. The PDI profile requires that DICOM images be recorded in a standard manner and also permits additional "web content," such as in the form of prerendered (JPEG) images. Even if a facility has a means of sharing images over a network, standard physical media are required if a patient requests this. Physical media containing proprietary formatted images should not be used. Physical media may contain an executable viewer. If present, an embedded viewer should be capable of displaying the standard DICOM PDI images and not depend on the presence of proprietary formats [16]. Each facility should comply with the recommendation of the American Medical Association Expert Panel on Medical Imaging, which put forward the following statement that embodies the standard the medical imaging community must achieve: "All medical imaging data distributed should be a complete set of images of diagnostic quality in compliance with IHE-PDI." The panel further stated that "this standard will engender safe, timely, appropriate, effective, and efficient care; mitigate delayed care and confusion; enhance care coordination and communication across settings of care; decrease waste and costs; and, importantly, improve patient and physician satisfaction with the medical imaging process." The statement was signed by the American Medical Association, the American Association of Neurological Surgeons, the Congress of Neurological Surgeons, the American Academy of Neurology, the American College of Radiology, the American Academy of Orthopedic Surgeons, and the American College of Cardiology.

2. Each facility should have a mechanism for secure image sharing over the Internet. The network exchange of imaging information should be conducted in accordance with the IHE Cross Document Sharing (XDS.b) profile (and XDS-I.b for imaging objects) [17]. Depending on the needs of the recipient, the images exchanged may be of original diagnostic quality, in which case DICOM PS 3.10 images are required, or may be prewindowed and prerendered. Every facility should have a mechanism for providing both a full set of diagnostic quality DICOM images and a subset of prerendered images of the appropriate quality for this purpose, consistent with the AMA's recommendations for the analogous exchange on physical media.

3. Each facility should have a mechanism for importing images and associated information in standard DICOM form from physical media and from the Internet, with reconciliation of foreign identifiers, accession numbers, and procedure descriptions or codes such that they do not collide with local identifiers. Each facility should make it possible to display such foreign images with the same fidelity and side by side in the same user interface as locally acquired images. This allows for better patient care and fewer unnecessarily

repeated studies (hence avoiding the cost, inconvenience, and safety risk from contrast and radiation of repeating a study). The importation should be performed in accordance with the IHE Import Reconciliation Workflow (IRWF) profile.

III. EQUIPMENT SPECIFICATIONS

G. Security, Privacy, Reliability, and Redundancy

See the Consensus, Frameworks, and Best Practices in A Review of Cybersecurity and Privacy Standards in Medical Imaging [2]

III. EQUIPMENT SPECIFICATIONS

H. Informatics Infrastructures and Workflow Processes

Electronic practice of diagnostic radiology involves a number of processes that should be coordinated by systems using the DICOM, HL7v2 FHIR, IHE, and IHE-RO informatics standards to ensure that information associated with the imaging study and patient record is accurate, errors are minimized, and the processes are efficient. These include:

- Patient demographic data should be obtained on admission (registration) rather than repeatedly reentered at each step of the workflow.
- The appropriate modality and modality-specific imaging protocol should be selected [18-20].
- The demographic and scheduling information should be communicated electronically to the modality in a standard form using DICOM Modality Worklist.
- Complete and consistent demographic data should be transferred across all systems.
- Relevant data about the acquisition should be included in the electronic radiology record (preferably in an automated and structured manner).
- Relevant data about the acquisition should be made available for correct coding of the examination for billing, tracking, and quality control.
- Relevant observations by the technical staff and interpreting radiologist should be retained and distributed in a standard form including error corrections (eg, data mismatches).

The DICOM and HL7 [16,21] standards provide the building blocks for such an infrastructure, and the IHE Radiology Technical Framework [16] defines profiles for using those standards to implement the required processes.

Some of the processes associated with diagnostic radiology workflow and the standards that should be used are given below.

1. Ordering and scheduling of procedures, performance of the acquisition, and transfer of images and associated information to the PACS should be in compliance with the IHE Scheduled Workflow (SWF) profile. This profile establishes the continuity and integrity of basic departmental imaging data, specifies transactions that maintain the consistency of patient and ordering information, provides the scheduling and imaging acquisition procedure steps, and makes it possible to determine whether images and other evidence objects associated with a particular performed procedure step have been stored (archived) and are available to enable subsequent workflow steps, such as reporting. The SWF profile may also provide central coordination of the completion of processing and reporting steps as well as notification of appointments to the placer of the order.

2. Correction of incorrect identification used during acquisition should be performed in compliance with the IHE Patient Information Reconciliation (PIR) profile. PIR extends the SWF profile by providing the means to match with the patient's record, images, diagnostic reports, and other evidence objects acquired for a misidentified or unidentified patient (for example, during a trauma case).

3. In selecting a procedure, the ordering physician should be assisted by appropriateness use criteria, such as the ACR Appropriateness Criteria®, or a clinical decision support system.

4. Standard terminology and codes for ordering and reporting should be used, including:

    a. Systematized Nomenclature of Medicine – Clinical Terms (SNOMED-CT) (see https://snomed.org or https://browser.ihtsdotools.org/).
    b. RadLex – Lexicon for Uniform Indexing and Retrieval of Radiology Information Resources (see http://www.radlex.org).

5. Each facility should use a standard set of predefined image acquisition protocols. Many image acquisition systems (eg, CT, MRI, NM) have complex protocols that need to be defined by the radiologist in consultation with the Qualified Medical Physicist prior to the acquisition. The appropriate protocol needs to take into consideration the order information (eg, history, patient type), modality capabilities, and the technologist's knowledge of the equipment/protocol. By requiring the definition of the appropriate protocol prior to the acquisition, the examination can be optimized to use the appropriate radiation dose to achieve the necessary image quality and the parameters matched to the equipment and clinical needs of the patient. Written protocol documents should contain both technical parameters that are programmed into the modality unit and instructions to the technologist. The written documents should be easily accessible to the technologist performing an examination, either as printed documents or electronically. Software to retrieve, store, and compare protocols can make the process of protocol management more effective; this is especially true when comparing the written protocol documents with the protocols installed on the scanner.

    Using standard protocol codes, such as those defined by LOINC [22], the choice of protocol should be communicated to the acquisition modality using the IHE Assisted Acquisition Protocol Setting option to the SWF profile [16,23]. When available, facilities should use imaging protocol management, such as that described by the IHE-MAP profile [24], to simplify the oversight of protocol maintenance and improve the standardization of a modality's protocols across disparate machines by using a centralized repository of all protocols. In addition to standardized protocol naming, facilities are encouraged to use standard naming for series within a given protocol to allow for improved automation of image transfer, processing, and presentation.

6. Each facility should have a policy regarding storage of annotations on images in a standard form as defined by DICOM in presentation states, structured reports, structure sets, etc. The IHE Consistent Presentation of Images (CPI) profile specifies the use of DICOM presentation states. It also requires that displays be calibrated according to the DICOM grayscale standard display function (GSDF) for the purpose of consistent image presentation on different displays and in different viewing environments (see also section III.D.2, Display characteristics). The IHE CPI profile with DICOM GSPS can be used to standardize annotation object encodings to display simple visual overlays created on a PACS to be viewed on a DICOM enterprise viewer, for example, but these do not retain the semantics of the annotation in a machine-readable form and hence are not reusable for machine learning. Storing annotations in machine-readable formats (for use with Artificial Intelligence (AI) applications, clinical pathways, and clinical decision support) is valuable. This can be achieved using the IHE AI results (AIR) profile, which incorporates DICOM SR. The DICOM SR template TID 1500 enables storage of quantitative and qualitative observations, 2-D and 3-D regions-of-interest, DICOM segmentation objects, and DICOM parametric maps.

IV. DOCUMENTATION

Physicians officially interpreting examinations[4] using digital image data management systems should render reports in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [25].

If reports are incorporated into the data management system, they should be retrievable with the same conditions of timeliness and security as those for the imaging data.

[4] The ACR Medical Legal Committee defines official interpretation as that written report (and any supplements or amendments thereto) that attach to the patient's permanent record. In health care facilities with a privilege delineation system, such a written report is prepared only by a qualified physician who has been granted specific delineated clinical privileges for that purpose by the facility's governing body upon the recommendation of the

medical staff.

V. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, non-physician radiology providers**,** radiologic technologists, and all supervising physicians have a responsibility for safety in the workplace by keeping radiation exposure to staff, and to society as a whole, "as low as reasonably achievable" (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel who work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection, application of dose constraints and limits) and the principles of proper management of radiation dose to patients (justification, optimization including the use of dose reference levels). https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1775_web.pdf

Nationally developed guidelines, such as the ACR's Appropriateness Criteria®, should be used to help choose the most appropriate imaging procedures to prevent unnecessary radiation exposure.

Facilities should have and adhere to policies and procedures that require ionizing radiation examination protocols (radiography, fluoroscopy, interventional radiology, CT) to vary according to diagnostic requirements and patient body habitus to optimize the relationship between appropriate radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used, except when inappropriate for a specific exam. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available from the following websites – Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org). These advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, technologists, referring providers, medical physicists, and radiologists).

Radiation exposures or other dose indices should be periodically measured by a Qualified Medical Physicist in accordance with the applicable ACR Technical Standards. Monitoring or regular review of dose indices from patient imaging should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry and relevant publications relying on its data, applicable ACR Practice Parameters, NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States or the Conference of Radiation Control Program Director's National Evaluation of X-ray Trends; 2006, 2009, amended 2013, revised 2023 (Res. 2d).

Exposures to patients from digital X-ray equipment (including projection radiography, tomography, fluoroscopy, angiography, and CT) should be recorded digitally by the modality in a standard form (such as the DICOM Radiation Dose Structured Report (RDSR)) and transmitted and monitored following the IHE Radiation Exposure Monitoring (REM) Integration Profile. Facilities should also contribute de-identified digital records of patient radiation exposure to the appropriate dose index registry (such as the ACR's Dose Index Registry (DIR) component of the National Radiology Data Registry (NRDR)) for the purpose of establishing, maintaining, and comparing facility performance against national Diagnostic Reference Levels (DRLs). Facilities that have legacy technology not supporting standards such as DICOM RDSR should employ tools using techniques such as Optical Character Recognition (OCR) to extract the numeric exposure information from modality manufacturer's dose screens or other mechanisms, where possible.

VI. QUALITY ASSURANCE, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading ACR Quality Control and Improvement, Safety, Infection Control, and Patient Education Concerns on the ACR Policy Finder; 2018 (Res. 33-v).

Any facility using a digital image data management system must have documented policies and procedures for monitoring and evaluating the effective management, safety, and proper performance of acquisition, digitization, processing, compression, transmission, display, archiving, and retrieval functions of the system. QA programs should be designed to maximize the quality and accessibility of diagnostic information. Radiology practices should establish a QA committee that includes representative stakeholders to organize, review, and prioritize QA-related activity.

QA policies, procedures, and activities for the electronic practice of medical imaging should include but are not limited to:

1. Acceptance and Integration testing for new or modified components of the electronic practice.

Maintaining medical image and information fidelity in an electronic practice is a key aspect of guarding patient safety. Poor system interoperability can create errors in patient information, compromising patient safety and hindering practice efficiency. Whenever software is modified or introduced, testing should be done to assure data fidelity and interoperability. This includes new or modified PACS, RIS, clinical viewers, acquisition modality, postprocessing, and reporting systems. Details for user acceptance testing may be included in purchase contracts and should be tailored to the particular clinical use and workflow [26-28].

2. Ongoing QA [29]

a. Verification of examination archival and delivery for diagnostic interpretation
   - When this is done by the acquiring technologist or QC technologist as part of the examination QA, it helps prevent delays that might occur if left to exception handling processes. Exceptions can occur when images are not sent or stored because of information mismatches with an information system.

b. Verification of correctly labeled patient and examination information

c. Verification of correct presentation for diagnostic viewing, including:
   - Image ordering.
   - Appropriate window/level.
   - Image sizing, orientation, and orientation labels.

d. Repeat and reject analysis

e. Dose monitoring
   - Each imaging facility should have documented policies and procedures for monitoring and evaluating the effective management, safety, and operation of equipment involved in the use of ionizing radiation for therapy, diagnosis and imaging.

f. Reliability analysis
   - Includes identification of points of failure, needs for redundancy, and rehearsing downtime procedures.

g. Turnaround time monitoring
   - Timing measurement and analysis of delays between examination start and report delivery.

h. Image quality monitoring
   - QA features available with some PACS or software that can be integrated into the radiologists reading environment can be used by radiologists to provide feedback on image or examination quality. This type of tool especially provides benefit in an electronic practice where the radiologist may not have regular encounters with technologists in order to provide feedback.

i. Radiologist peer review
   - Conducted in a manner that complies with statutory and regulatory peer-review procedures to ensure the confidentiality of the peer-review process [30].

j. Acquisition modality quality control
   - Equipment performance should be monitored by a Qualified Medical Physicist as described in the appropriate ACR–AAPM equipment technical standard.

k. Display quality control
   - In the absence of adequate manufacturer procedures, guidelines, or standards, the recommendations for the performance evaluation of display devices testing methods and frequencies contained in AAPM Report 270: Display Quality Assurance [13] (or its successors) should be followed.

l. Comprehensive preventive maintenance activities to minimize downtime

The use of digital imaging and digital image data management systems does not reduce the responsibilities for managing and supervising radiologic examinations. Locations and physicians providing remote imaging services should participate in a documented ongoing QA program at least equivalent to that of the originating facility. Summaries of the quality control monitoring should be provided to the originating facility.

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*Practice parameters and technical standards are published annually with an effective date of October 1 in the year in which amended, revised or approved by the ACR Council. For practice parameters and technical standards published before 1999, the effective date was January 1 following the year in which the practice parameter or technical standard was amended, revised, or approved by the ACR Council.

<u>Development Chronology for this Technical Standard</u>
2007 (Resolution 13)
Amended 2009 (Resolution 11)
Revised 2012 (Resolution 35)
Amended 2014 (Resolution 39)
Revised 2017 (Resolution 41)
Amended 2020 (Resolution 8)
Revised 2022 (Resolution 48)
Amended 2023 (Resolution 2c, 2d)

APPENDIX A

Glossary

1. Analog signal – a form of information transmission in which the signal varies in a continuous manner and is not limited to discrete steps.
2. Archive – a repository for digital medical images in a picture archiving and communications system (PACS), typically with the specific purpose of providing either short-term or long-term (permanent) storage of images. Erasable or nonerasable media may be used in an archive.
3. Artificial Intelligence – a technique that enables machines to mimic human behavior.
4. Bit (binary digit) – the smallest unit of digital information that a computing device handles. It represents off or on (0 or 1). All data in computing devices are processed as bits or strings of bits in factors of 2^n.
5. Bit depth – the number of bits used to encode the signal intensity of each pixel of the image,
6. Cloud storage – a model of computer data storage in which the digital data is stored in logical pools, said to be in "the cloud"; physical storage spans multiple servers, and the physical environment is typically owned and managed by a hosting company. Cloud storage servers are typically located off site from the facility storing the data.
7. Compression ratio – the ratio of the number of bits in an original image to that in a compressed version of that image. For example, a compression ratio of 2:1 would correspond to a compressed image with one-half the number of bits of the original.
8. CPU – central processing unit is the main processor in a computer that retrieves and executes instructions.
9. CR (computed radiography) – a system used for projection radiography that uses a storage phosphor plate instead of film-screen in a cassette. A laser beam scans the exposed plate to produce the digital data that is then converted into an image.
10. CRT (cathode ray tube) – an older technology monitor or display device used for viewing digital softcopy images. A CRT uses a controlled beam of electrons incident on a phosphor to generate a luminous image.
11. CT (computed tomography) – A CT scan combines a series of X-ray images taken from different angles and uses computer processing to create cross-sectional images, or slices.
12. Deep learning – a subset of machine learning with multiple hidden layers.
13. Data communication – all forms of computer information exchange. Data communication may take place between 2 computers in the same building via a local area network (LAN), across the country via telephone, or elsewhere by a wide-area network (WAN).
14. Data compression – methods to reduce the data volume by encoding it in a more efficient manner, thus reducing the image processing and transmission times and storage space required. These methods may be reversible (lossless) or irreversible (lossy).
15. Diagnostic displays – displays used for the primary interpretation of medical images.
16. Digital imaging and communications in medicine (DICOM) – a standard for interconnection of medical digital imaging devices, developed and sponsored by the American College of Radiology and the National Electrical Manufacturers Association, consisting of a standard image format and a standard communications protocol.
17. Digital signal – a form of information transmission in which the signal varies in discrete steps, not in a continuous manner.
18. Digitize – the process by which analog (continuous value) information is converted into digital (discrete value) information.
19. Direct image capture – the capture or acquisition of digital image data that have been acquired in digital format by an imaging modality. The image produced from the data, regardless of the modality that produced it (CT, MRI, CR, US), should include the full spatial resolution and bit depth (contrast resolution) of the original.
20. DR (digital radiography) – also called direct DR is a projection radiography device in which the digitization occurs within the detector, typically consist of a Phosphor and Cesium Iodide scintillator photodiode read out by an amorphous Silicon thin film transistor.
21. Dynamic range – the difference in signal intensity, or frequency, between the largest and smallest signals a system can process or display. Increasing the number of bits per pixel in a digital image increases the dynamic range of the image.
22. File – a set of digital data that have a common purpose, such as an image, a program, or a database.

23. FHIR – Fast Healthcare Interoperability Resources; HL7v2 integration standard.
24. GPU – graphics processing unit is a specialized processor that can process many instructions simultaneously making them useful for machine learning and real-time graphics rendering.
25. Grayscale – the number of different shades of levels of gray that can be stored and displayed by a computer system. The number of gray levels is directly related to the number of bits used in each pixel: 6 bits = 64 gray levels (2^6), 7 bits = 128 gray levels, 8 bits = 256 gray levels, 10 bits = 1,024 gray levels, and 12 bits = 4,096 gray levels; most digital medical images are 10 or more bits.
26. GSDF (grayscale standard display function) – a standard luminance contrast response curve as defined in Part 14 of the DICOM standard that is perceptually linearized to the human visual system.
27. Hardware – a collective term used to describe the physical components that form a device such as a computer. The display, CPU, disk drives, memory, modem, and other components are all considered hardware.
28. Image matrix size – the size of an image described as the number of rows and the number of columns of pixels; file size is the image matrix size times the total number of bits expressed in 8-bit bytes (generally 2x).
29. HL7 – Health Level Seven is an international interoperability standard for textual medical data exchange used in most EMR, ordering and reporting systems.
30. Image sampling: Up-sampling – small matrix images are typically sampled more finely than the acquired pixel spacing in order to increase the number of rows and columns and increase the presented size on a display. Down- sampling - Large matrix images are typically sampled more coarsely than the acquired pixel spacing in order to decrease the number of rows and columns so that the full image area can be presented.
31. Irreversible compression – some permanent alteration of digital image data such that upon decompression the file does not return to the original full spatial resolution. This is sometimes referred to as lossy compression.
32. LCD (liquid crystal display) – a modern display or display device used for viewing digital softcopy images.
33. Lossless compression – see reversible compression
34. Lossy compression – see irreversible compression
35. Machine Learning – a subset of artificial intelligence techniques which use statistical methods to enable machined to improve/learn with experience/data.
36. Medical imaging workstation – the term "medical imaging workstation" describes a computer system that allows a user to search, retrieve, display and manipulate images that have been created from various imaging modalities, such as: digital X-ray computed radiography, direct digital radiography, computed tomography (CT) scanner, magnetic resonance imaging (MRI) scanner, ultrasound (US) or any of the other digital imaging modalities found in recent imaging departments. The workstations that are used for the primary interpretation of imaging examinations are often called diagnostic workstations, whereas those used for clinical viewing are often called Review Workstations (RWS). The workstations that are used during image acquisition for the specific imaging modality are often called acquisition workstations (AWS).
37. Modality displays – displays that typically are an integral component of the onsite imaging modality. They are used during the acquisition and modification of images prior to primary interpretation and prior to being sent to the PACS database and archive.
38. Monochrome display – a computer display in which an image is presented as different shades of gray from black to white (see also grayscale).
39. Mouse – an input device that allows the computer user to point to objects on the screen and click buttons to execute commands.
40. MRI (magnetic resonance imaging) – MRI is an imaging device that uses a magnetic field and radio waves to create detailed images of the organs and tissues representing hydrogen atoms within the body.
41. NM (nuclear medicine) – NM is the medical specialty that uses the tracer principle, most often with radiopharmaceuticals, to evaluate molecular, metabolic, physiologic and pathologic conditions of the body for the purposes of diagnosis, therapy and research.
42. OLED (organic light emitting diode) – a modern display device used for viewing digital softcopy images. Distinct from LCD as the pixels themselves emit light (rather than being transmissive to a backlight)
43. PACS – picture archiving and communication system
44. Phosphor – the coating on the inside of a CRT or monitor that emits light when it is struck by an electron beam.
45. Pixel (picture element) – the smallest individual element in a digital image and, therefore, the smallest

pixel of information that can be displayed on a CRT. It is represented by a numerical code within the computer and displayed on the display as a dot of a specific color or intensity. An image is composed of a large array of pixels of differing intensities or colors; a pixel has an x-, y- and sometimes z-location and an associated value for the pixel at the (x,y,z) location representing the gray level in the image.

46. Protocol – a set of guidelines by which 2 different computer devices communicate with each other, or a set of instructions or procedures
47. RAM (random access memory) – a type of temporary memory in a computer in which programs are run, images are processed, and information is stored. The amount of RAM that a computer requires varies widely depending on the specific application. Information stored in RAM is lost when the power is shut off.
48. Resolution – spatial resolution is the ability to distinguish small objects at high contrast. It is related to and in some cases limited by the pixel size and the matrix dimensions. Contrast (grayscale) resolution is the ability of a system to distinguish between objects of the same size having different signal intensity. It is related to and in some cases limited by the bit depth.
49. Reversible compression – no alteration of original image information upon reconstruction, such that upon decompression the file does return to the original full spatial resolution. This is sometimes referred to as lossless.
50. Secondary image capture – the capture in digital format of image data that originally existed in another primary format (eg, a digital image data file on a CT scanner, a screen-film radiographic film) through the process of video capture or film digitization
51. The Society of Motion Picture and Television Engineers (SMPTE): a SMPTE pattern is often used during QA processes to assess display performance.
52. Software – a name given to the programs or sets of programs that are executed on a computer
53. US (ultrasound) – diagnostic ultrasound, also called sonography or diagnostic medical sonography, is an imaging method that uses high-frequency sound waves to produce images of structures within the body.
54. VNA (vendor neutral archive) – is a medical imaging technology in which images and associated data are stored in a standard (non-proprietary) format (such as DICOM) such that they can be retrieved by other systems using standard (non-proprietary) protocols (such as DICOM, DICOM web and IHE XDS-1.b).