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ACR–AAPM–SIIM PRACTICE PARAMETER FOR DETERMINANTS OF IMAGE QUALITY IN DIGITAL MAMMOGRAPHY

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 care¹. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also 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 sole purpose of this document is to assist practitioners in achieving this objective.

¹ *Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing*, _ N.W.2d _ (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 practice parameter was developed collaboratively by individuals with recognized expertise in breast imaging, medical physics, and imaging informatics, representing the American College of Radiology (ACR), the American Association of Physicists in Medicine (AAPM), and the Society for Imaging Informatics in Medicine (SIIM), primarily for technical guidance. It is based on a review of the clinical and physics literature on digital mammography and the experience of experts and publications from the Image Quality Collaborative Workgroup [1-3]. Additionally, this practice parameter includes input from industry, radiologists, and other interested parties in an attempt to represent the consensus of the broader community. It received further input from another working group of the Integrating the Healthcare Enterprise (IHE) Initiative [4].

For the purposes of this practice parameter, digital mammography is defined as the radiographic examination of the breast utilizing dedicated electronic detectors to record the image (rather than screen-film) and having the capability for image display on computer monitors. This practice parameter in digital mammography does not pertain to computed tomography (CT) mammography.

In many parts of this practice parameter, the level of technical detail regarding the determinants of image quality for digital mammography is advanced and is intended to provide radiologists, Qualified Medical Physicists, mammography technologists, regulators, and other support personnel directly involved in clinical implementation and oversight an expanded knowledge of the issues pertinent to assessing and maintaining digital mammography image quality from the acquisition, display, and data storage aspects of the process. Where basic technical requirements for digital mammography overlap with those for digital radiography in general, users are directed to consult the referenced ACR practice parameters [5,6]. All interested individuals are encouraged to review the [ACR–AAPM–SIIM Practice Parameter for Digital Radiography](#) [7]. Furthermore, the ACR Subcommittee on Quality Assurance in Mammography has developed a Digital Mammography Quality Control (QC) Manual [8].

Analysis of image quality has meaning primarily in the context of a particular imaging task [9]. This practice parameter has been developed with reference to specific imaging tasks required by mammography, using the information available in the peer-reviewed medical literature regarding digital mammography acquisition, image processing and display, storage, transmission, and retrieval. Specifically, the imaging tasks unique to mammography that determine the essential characteristics of a high quality mammogram are its ability to visualize the following features of breast cancer:

1. The characteristic morphology of a mass
2. The shape and spatial configuration of calcifications
3. Distortion of the normal architecture of the breast tissue
4. Asymmetry between images of the left and right breast
5. The development of anatomically definable changes when compared to prior studies

The primary goal of mammography is to detect breast cancer by accurately visualizing these features. At the same time, it is important that these signs of breast cancer not be falsely identified if breast cancer is not present. Two aspects of digital image quality can be distinguished: technical and clinical. It is possible to make technical measurements describing the above attributes, and it may be possible to infer a connection between these technical measures and clinical image quality. The extent to which these features are rendered optimally with a digital mammography system using current technology depends on several factors and is the major focus of this practice parameter.

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

Interpreting physicians, Qualified Medical Physicists, and radiological technologists who work in mammography must meet the requirements of the Mammography Quality Standards Act (MQSA) final rule as published by the Food and Drug Administration (FDA) [10]. Under MQSA, personnel need to receive 8 hours of initial training prior to independently using any new mammographic modality, defined as a modality in which the person has not

previously been trained. See the [ACR Practice Parameter for the Performance of Screening and Diagnostic Mammography](#) [11]. This includes digital mammography and digital breast tomosynthesis (DBT).

Although the FDA's Division of Mammography Quality Standards (DMQS) considers each manufacturer's DBT system to be a new modality, they recognize that there are many features which are common to different DBT systems, while some features are unique to each specific system [12]. Consequently, the FDA specifies that training must include both the common features of DBT and the unique features of the particular manufacturer's DBT system. These two aspects of the training may be obtained either in a single training program or in separate settings. Also, once personnel have received training in the common features of DBT, they do not need to repeat this portion of the training when receiving training in the unique features of another DBT system. For further information see the FDA's [Frequently Asked Questions about DBT and MOSA Training Requirements](#) [12].

III. DIGITAL MAMMOGRAPHY IMAGE ACQUISITION

In digital mammography and DBT, the processes of image acquisition, display, and storage are performed by separate systems, each of which can be optimized. The digital detector is designed to efficiently absorb x-rays, produce an electronic signal, digitize the signal, and store the results in computer memory. The output image is saved as a 2-dimensional matrix, where each picture element (pixel) represents the x-ray transmission corresponding to a particular path through the breast. This image can be digitally processed such that when it is displayed in softcopy form on a high-resolution display device or printed on laser film, the key features required for mammographic interpretation can be visualized.

Technical descriptions of digital radiography image acquisition devices and specifications are available in [6]; and individual device specifications are available on request from the specific equipment manufacturers. Once a system has been purchased, calibrated, and acceptance tested, regularly scheduled quality control (QC) procedures performed by the technologist and annual testing (or as needed) by the Qualified Medical Physicist are required to maintain compliance with the FDA regulations of the FDA. Currently, the responsibility for the development and provision of QC testing procedures for the image acquisition system is the specific manufacturer of the image acquisition device. Manufacturers of mammography equipment are responsible for developing system-specific QC test procedures. However, the ACR Digital Mammography Quality Control Manual [8] has recently been approved by the FDA as an alternative standard to the manufacturer's recommended quality assurance program for full-field digital mammography (FFDM) systems.

For digital acquisition systems, accurate representation of anatomical detail and pathology requires adequate anatomic coverage and image quality. Image quality can be described in terms of spatial resolution, image contrast, latitude or dynamic range, noise, and artifacts.

- A. Tissue coverage depends on the chosen view (projection) and positioning of the breast. The goal is to project as much of the breast tissue as possible onto the image detector to maximize breast disease detection. The following factors affect tissue coverage:
1. The geometrical relationship of the x-ray source, collimation, compression device, patient, grid, and image detector requires the x-ray beam and image receptor to come as close to the chest wall edge of the breast support as possible for digital mammography, DBT, and stereoscopic digital mammography, just as for screen-film mammography.
 2. The image receptor should be large enough to image the entire breast of most women. Along the edge of the detector nearest the chest wall, inactive regions of the image receptor will result in missed breast tissue. Consequently, the gap between the chest wall edge of the image receptor and the breast support should be minimized and in no case should exceed 7 mm. Typical digital units have a gap of 4 mm to 7 mm [3,13]. On all other sides of the detector, there should be complete coverage of the breast tissue.

3. Clinical assessment of positioning in digital mammography matches that required for screen-film and evaluates the retromammary aspects of the breast between the craniocaudal (CC) and mediolateral oblique (MLO) views. On the CC view, the posterior nipple line of the breast (the distance between the nipple and the posterior edge of the image) should be no more than 1 cm less (approximately) than that on the MLO view (the distance between the nipple and the anterior edge of pectoralis muscle). The anterior edge of the pectoralis muscle on the MLO view should be convex, and it is desirable for the muscle to extend to the level of the nipple. The posterior nipple line should be drawn at an angle perpendicular to the muscle, usually at about 45 degrees on the MLO image.
 4. Large breasts may require imaging of the breast in sections, particularly for smaller field of view (FOV) detectors. The resulting multiple images in the same projection must be viewed together to form the complete mammogram. An increase in radiation dose occurs to regions of the breast that are exposed to x-rays in more than 1 image in the same projection. Standard tiling methods that minimize double exposure should be used. A larger FOV detector lowers the need for multiple-section imaging.
- B. Spatial resolution [6] of an imaging system refers to its ability to depict 2 adjacent structures as being separate, or the distinctness of an edge in the image (ie, sharpness). Measurement is performed by qualitative or quantitative methods [6]. Spatial resolution losses occur because of blurring caused by geometric factors such as the size of the x-ray tube focal spot and the magnification of a given structure of interest. Other factors include unsharpness due to detector material, detector element effective aperture and pitch, and relative motion of the x-ray source, the breast, or the image detector during the exposure. The effects of spatial resolution on clinical image quality are most easily observed when imaging fine detail in the breast such as spiculations radiating from a mass or microcalcifications. Shape and margins help differentiate a benign from a malignant process. However, one may not isolate spatial resolution effects on clinical image quality from effects due to quantum mottle and electronic noise under typical digital image acquisition conditions.

It should be noted that although image processing has a number of beneficial aspects, the user must also be aware of the potential deleterious consequences of using certain image processing tools with digital mammography. For example, un-sharp masking can enhance the sharpness of mass lesion borders, but it can make indistinct masses appear more circumscribed. Histogram-based intensity windowing can improve the conspicuity of edges, but at the potential cost of losing detail outside of the denser parts of the image. Contrast-limited adaptive histogram equalization also brings out edge information of lesions but, at the same time, enhances the visibility of distracting nonlesion features, potentially leading to false positive reports. Peripheral equalization brings out lesion detail while preserving peripheral information in the surrounding breast, but the downside is possible flattening of image contrast in nonperipheral areas

Motion blurring can have a particularly strong impact on limiting spatial resolution and image sharpness. In digital mammography, motion blurring is caused by movement of the breast during exposure and is minimized by using a short exposure time and appropriate breast compression.

1. Applied kilovoltage (kV) may be increased for thick, dense breasts to allow reduction of exposure time. Image processing may compensate for contrast losses to the extent allowed by the background noise and the image signal-to-noise ratio (SNR).
2. Magnification techniques with small focal spots and lower tube current (mA) require longer exposure times. The amount of blurring depends on object motion speed, exposure duration, and degree of magnification.
3. For scanned slot systems, motion causes misregistration artifacts between the anatomy imaged both before and after motion occurs.

4. Spatial resolution may be diminished when using DBT because of x-ray tube motion during acquisition and the increased angle of incident x-rays in wider projections. Geometric optimization techniques are vendor-specific, resulting in variability in image quality of DBT systems [14].

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C. Contrast resolution (radiographic contrast) refers to the magnitude of the signal difference between the structure of interest and its surroundings in the displayed image and is influenced by subject contrast and display (image) contrast [6]. High radiographic contrast needed to visualize the subtle differences in soft-tissue densities of normal and pathologic structures, including structural characteristics of the margins of masses and the detection and characterization of minute microcalcifications.

1. Subject contrast is the relative difference between the x-ray transmissions at the entrance plane of the image receptor through different parts of the breast. Attenuation, and therefore subject contrast, depend strongly on the x-ray energy spectrum, which is determined by the target material, kV, and filtration (either inherent in the tube or added).
 - a. Molybdenum (Mo) target x-ray units generate characteristic radiation at 17.4 and 19.5 keV. A Mo filter 0.025 to 0.03 mm thick strongly suppresses photon energies less than 15 keV and those greater than 20 keV, yielding high subject contrast and avoiding excess radiation dose for 2 to 5 cm breasts imaged at typical voltages of 25 to 28 kV.
 - b. For thicker and/or denser breasts, a higher-energy x-ray beam is needed to achieve adequate tissue penetration. To image thicker breasts (5 cm to 7 cm), a mammography system with a Mo target material uses a Mo filter (0.030 mm thickness) or a rhodium (Rh) filter (0.025 mm thickness) and a tube voltage higher than 28 kV. For denser breasts, a Rh filter is used, preferentially transmitting photon energies between 15 to 23 keV.
 - c. For very dense or difficult-to-penetrate breasts, a tube voltage of 28 kV is used with a Rh target and Rh filter (0.025 mm), producing characteristic x-rays at 20.2 and 22.7 keV. This preserves subject contrast without a substantial increase in dose.
 - d. Anode targets made with tungsten (W) produce a beam with higher effective energy and, in some cases, lower patient dose compared with Mo or Rh systems. W targets can withstand a higher tube heat load, allowing for longer exposure times. Since the characteristic x-rays produced by W are above the energies used in mammography, the energy spectrum by using Mo, Rh, and silver (Ag) filters with a typical thickness of at least 0.05 mm. Greater filter thickness is necessary to attenuate higher energy L-shell characteristic x-rays. Careful choice of kV and filter material can yield excellent image contrast with a radiation dose similar to that of a system with a Mo or Rh target.
 - e. There are specific artifacts associated with DBT imaging that can enhance or impede object visibility. Adjacent high-contrast objects can cause out-of-plane ghosting or result in shadowing that appears as dark, “embossed” regions in the direction of the tube movement. Both are due to incomplete sampling that results from the limited angular range and the reduced number of acquisition angles [15,16]. These artifacts can be minimized via image post processing, either by reconstructing thicker slices or by viewing multiple slabs or stacked thin slices. Each vendor has reconstruction algorithms for artifact reduction and enhancement. Training is imperative for understanding individual vendor reconstruction characteristics.

2. The properties of digital detectors and adjustment of display contrast through image processing allow the use of higher energy x-rays (25 to 35 kV and above) for digital systems compared to screen-film systems (where 22 to 32 kV is more typical). Dose is reduced while maintaining image SNR by using higher energy x-rays, especially for large or dense breasts.
 3. Grids [6] designed for mammography reduce scattered radiation and improve subject contrast at the cost of higher breast dose [17,18]. Grids are used for contact (non-magnification) imaging to reduce noise contributed by scatter. With geometric magnification views, the increased air gap between the breast and detector eliminates the need for a grid. Mammography systems may use image processing instead of a grid to reduce the effects of scattered radiation on contrast. Some DBT systems do not use a grid because of the low exposure available per projection and the moving x-ray source position during acquisition.
 4. Breast compression is as important for digital mammography as it is for screen-film mammography. It contributes to digital image quality by immobilizing the breast and shortening exposure times, reducing the likelihood of motion unsharpness. In addition, compression produces thinner, more uniform tissue, which results in less scattered radiation, more even penetration of x-rays, less magnification or geometric blurring, less anatomical super-position, and lower breast radiation dose.
 5. Any technique adjustments should be performed in consultation with and verified by the radiologist in charge of the digital mammography program and the Qualified Medical Physicist.
- D. In digital mammography, it is important to discuss noise as well as contrast [6]. Radiographic image noise is the unwanted random (uncorrelated), nonrandom (correlated), or static (eg, detector defect) variation in signal in an image acquired from a uniform x-ray exposure [19-21]. Using fewer x-rays (quanta) increases random noise or quantum mottle (for a fixed signal), decreases SNR, and reduces the ability to discern subtle differences in contrast. Fine calcifications or subtle masses that can be the first signs of cancer may not be visible in a noisy (underexposed) image. The exposure required to achieve a desired SNR is inversely related to the detective quantum efficiency (DQE). Consequently, as DQE increases, so does the dose efficiency. “Appropriate” x-ray exposure depends on the system’s DQE, and requisite SNR can be achieved with a calibrated automatic exposure control (AEC) system.

IV. DIGITAL MAMMOGRAPHIC IMAGE DISPLAY

Although it is possible to display digital images in a hardcopy format, the advantages of digital mammography may not be fully realized without softcopy display [22]. The quality of the display used to view mammographic images has a direct effect on radiologic interpretation. A faulty, inadequately calibrated, or improperly set-up display device can compromise the overall quality of the mammography examination [15,22,23]. Since DBT provides the radiologist with a series of images through the breast that are scrolled through, rather than viewed as single images as with FFDM digital mammography, there are added display requirements (eg, temporal resolution or frame rate). Many display manufacturers have DBT specific displays to counteract motion blur during scrolling.

Many aspects of display technologies and uniform practice have been addressed by standards-setting groups [24-29]. The Medical Imaging and Technology Alliance (MITA) has published 2 standards that include templates and describe a minimum set of QC tests that should be included as part of the quality assurance plan for displays and workstations [30] as well as hardcopy printing devices [31] for FFDM. As new display technologies emerge (eg, workstations for viewing DBT images), it is important to ensure verify that the technical specifications of the device are reviewed and compared to the image specifications to ensure adequate presentation of image details on the display for display provides adequate image quality to ensure efficient and accurate diagnoses. For example, hand-held displays are currently available with software applications approved for viewing certain types of radiographic images under certain explicit conditions (eg, ambient light requirements). At this time, these devices do not have the spatial resolution required for viewing mammograms and thus should not be used.

A. Hardcopy Printing

Despite the adoption of digital mammography, some images are still printed to hardcopy for display and interpretation. MQSA gives the decision of maintaining a printer and/or the ability to print hardcopy images to each individual facility. MQSA states, “If a facility chooses to maintain a printer, it must follow all the quality control requirements that are prescribed by the manufacturer of the printer and mammographic unit. The manufacturer’s quality control program benefits the facility that wants to provide the best possible quality in any hardcopy mammography images it prints. Although the FDA’s MQSA inspection program has removed printer QC questions from its inspection procedures, if a facility decides to maintain a printer, medical physicists must continue to include that printer QC in the mammography equipment evaluation upon installation, after a major repair, and annually, if required by the printer’s or image receptor’s manufacture quality control program” [32].

Lightbox considerations

1. Luminance: A minimum of 3,000 candelas per square meter (cd/m^2) is the standard for screen-film mammography [33]. The same guidelines should be used for display of digital images printed on film. A “hot light” (focal or lightbox) will be of limited value for digital mammograms printed to film.
2. Uniformity: No specific standards address spatial uniformity of lightbox luminance or of intralightbox luminance uniformity. Luminance variations should be minimized.
3. Shutters and masking: The FDA requires that masking materials be available for interpreting physicians [10,34]. Viewscopes are allowed as long as the illuminated area can be limited to a region equal to or smaller than the exposed portion of the film. The average ambient light conditions should be adjusted relative to the average luminance of the displayed images (properly masked). Care should be taken to avoid any direct reflections on image surfaces. Darker images require a darker environment to interpret properly.

MQSA requires facilities to have the ability to print images. Thus, hardcopy mammographic image quality remains an important issue and must be included in any effort to address digital image quality in mammography. Although the FDA recommends that only printers specifically cleared for FFDM use by the FDA be used, the use of other printers is also legal under MQSA [34]. The ACR also strongly recommends that only FDA-cleared printers be used for digital mammography. Quality assurance issues for hardcopy display have been set forth in a number of publications [31,33,35]. While there are no recommendations regarding the use of hardcopy versus softcopy display for interpretation, the FDA requires the ability to print FFDM images of final interpretation quality to film if so requested by patients or their health care providers [34]. When FFDM images are printed to film, the manufacturer’s guidelines should be followed.

B. Softcopy Display Devices

Many factors contribute to image quality in softcopy radiographic and mammographic display [36-39]. Although the FDA recommends that monitors used for interpretation be specifically cleared for FFDM/DBT use by the FDA, the use of other monitors is permitted under MQSA [34]. Softcopy displays for mammography should meet minimum quality specifications for acquisition, interpretation, and review workstations [5]. Displays for DBT should incorporate technology to compensate for image blur during scrolling via optimized frame rates. The AAPM Task Group 18 documentation on assessment of display performance for medical imaging systems provides test images [37], an executive summary of tests [40], and a complete overview [41], which are very useful for specifying and verifying adequate performance for displays used in medical images. Descriptions of most of the display performance metrics can be found in Krupinski et al [5]. Individual device specifications and expected performance criteria can be requested from display manufacturers. Once a display has been purchased and calibrated, it should be tested regularly by a Qualified Medical Physicist, a biomedical engineer, or a qualified technologist to ensure compliance. MQSA requires that a Qualified Medical Physicist test the review workstation prior to its clinical use. Facilities should refer to their FFDM system quality control manuals or the ACR Digital Mammography Quality Control Manual [8] for details and requirements pertaining to ongoing and annual testing for their image displays [42].

1. Minimum and maximum luminance
 - a. Monitor luminance, L , is characterized by minimum (L_{\min}) and maximum (L_{\max}) values. Ideally, the maximum luminance of monitors used for primary interpretation should be at least 400 cd/m^2 , whereas greater than 450 cd/m^2 is recommended for optimized contrast.
2. Luminance response

The brightness and contrast of grayscale medical images result from the luminance in relation to the image gray level values [40].

 - a. Ambient luminance (L_{amb}): 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 ambient luminance and should be less than one-fourth of the luminance of the darkest gray level.
 - b. Minimum luminance (L_{\min}): Since the contrast response of the adapted human visual system is poor in very dark regions, the luminance of the lowest gray value, L_{\min} , should not be extremely low. The minimum luminance including a component from ambient lighting, $L'_{\min} = L_{\min} + L_{\text{amb}}$, should be at least 1.2 cd/m^2 for interpretation of mammograms.
 - c. Maximum luminance (L_{\max}): The perceived contrast characteristics of an image on a display depend on the ratio of L'_{\max} (the luminance for the maximum gray value) to L'_{\min} . This is the luminance ratio (LR), which is not the same as the contrast ratio often reported by monitor manufacturers. Ideally, all display devices in a facility should have the same LR so that the presentation is consistent for all viewers of a study. To achieve a suitable LR, for a system with an L'_{\min} of 1.2 cd/m^2 , L_{\max} should be at least 420 cd/m^2 for displays used to interpret mammograms.
3. Contrast

Within the applicable luminance range of the mammographic display, the device should render the image details with a consistent grayscale that should be measured and maintained over time. The contrast (luminance) response of mammographic displays should comply with the AAPM Task Group 18 recommendations and be within 10% of the Digital Imaging and Communication in Medicine (DICOM) grayscale display function (GSDF) over the full luminance response [40,41].
4. Bit depth
 - a. A display device must accurately represent mammography image information with a sufficient number of grayscale values to prevent the loss of image contrast and eliminate contour artifacts.
 - b. The bit depth of mammographic images should be at least 8, corresponding to 256 grayscale values. At the time of publication, relatively few studies have been reported in the literature that address possible advantages of higher bit-depth display devices. However, 9-bit or higher is recommended if the “for processing” image data are greater than 8 bits.
 - c. Several manufacturers provide FDA FFDM approved monitors with 5 megapixel displays and bit depths of 10 to 12 bits (1024 grayscale capabilities). Their use is recommended particularly for DBT image viewing.
5. Digital image matrix size and display size
 - a. A 5 megapixel monitor ($2,048 \times 2,560$) requires less zoom/pan for image interpretation when the mammography radiologist desires to view the full resolution image dataset compared to a lower resolution display [43]. Display device specifications should match the acquisition matrix size as closely as possible. A number of manufacturers have developed 8 and 10 megapixel widescreen displays for mammography (and other applications) and these are generally suitable for FFDM and DBT viewing as they make it feasible to display 2 images (eg, right and left CC or MLO) on the same display.

For a standard viewing distance of approximately 67 cm, the diagonal dimension of a standard display should be 21 inches (53 cm), with a total viewing field approximately $32 \times 42 \text{ cm}$. Widescreen displays typically require a slightly farther viewing distance.

- b. Mammographic displays should render images with a pixel density sufficient to enable viewing of a full or partial (50% or greater area of the breast image) mammogram with sufficient spatial detail at a normal viewing distance of approximately 67 cm. Panning through a reduced subset of the entire image at full spatial resolution without excessive magnification should be easily available to the reader. Zoom/pan functions should be used rather than moving closer to the display or using a magnifying glass to view details. A magnifying glass is generally inappropriate, as it simply magnifies the pixels rather than increasing the magnification of the image details.
 - c. During image interpretation, all images should be viewed at 1:1 or 100% size. Routine viewing at 2:1 (or 200% size increase) with zoom/pan function to examine the entire image is feasible [43]. When using a “fit to view” feature, images are often displayed at a size that is less than 100%, although the amount of size reduction will vary. For example, some displays scale the fit to viewport to maximize the scale of the mammogram. Hanging protocols and viewing modes for evaluation and comparison of longitudinal studies are important to maintain consistent viewing conditions, particularly for mammograms from different acquisition devices. The IHE Mammography Image profile [36] should be consulted for recommendations and implementation of digital mammography image display for interpretation.
 - d. Monochrome versus color
 - i. No clinical application requires color rather than monochrome displays for mammography.
 - ii. With technological advances, newer LCD or OLED monitors may meet the performance criteria for the display of mammographic images and may be appropriate for mammography applications.
6. Other softcopy display characteristics
- a. Image displays must be able to display mammography computer-aided detection (CAD) marks (when CAD is implemented) and to apply marks on the displayed image corresponding to all findings encoded in the DICOM mammography CAD structured reporting (SR) objects.
 - b. Image displays must be able to display images at the same size as the imaged object [36]. This is critical since the sizes of objects in the image are generally judged visually and limitations in the size of the displayed image could distort the appearance of anatomy and negatively affect the interpretation of mammograms.
 - c. Displays must be able to show images at the “same” physical size on the display (eg, 18 × 24 cm) even though they might be from different acquisition stations with different pixel sizes and detector dimensions.
 - d. Displays must be capable of showing image information, including patient identification, image information, and acquisition technique [34].
 - e. Image displays must be capable of displaying a set of current and prior conventional 4-view screening mammograms (left and right CC and MLO views) simultaneously.
 - f. Image displays should be able to display a ruler on the screen as a visual clue to indicate physical size.
 - g. Image displays should ensure that the luminance of the image background (outside the breast) is maintained at L_{min} as window width and level are adjusted during interpretation.
 - h. Additional guidelines for viewing images can be found in the [ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging](#) [44].

C. Digital Image Presentation Issues

The IHE initiative has defined a presentation of image integration profile that provides a standard method for storing grayscale images and information about their presentation state, including user annotations, shutters, flip/rotate, display area, and zoom [36].

1. It should not take more than 3 seconds to retrieve an image from online local storage and display it on a workstation. Times for image retrieval from storage archives and from remote sites will vary

significantly depending on prefetching rules, management of image routing, and network speeds, among other issues.

2. Mammographic displays should allow fast and easy navigation between old and new studies. This is especially critical when there is a mix of FFDM and DBT images.
3. Hanging protocols should be specific to mammography, have proper labeling and orientation of the images, and be flexible and tailored to user preferences.
4. Workstation software tools must include window/level and zoom/pan. Use of image display tools can aid in image interpretation but increases reading time. There are no specific recommendations regarding which tools should be used with softcopy mammography displays and how they can be used effectively. Further research on the ergonomics of using image display tools is encouraged.
5. Multimodality datasets and interoperability:
 - a. To ensure that a workstation is capable of displaying digital mammograms correctly, it should conform to the IHE MAMMO profile. If it does not, then it is possible that the workstation will fail to show all digital mammograms as they are intended to be displayed by the acquisition system manufacturer.
 - b. Mammography workstations should accommodate and display images from several modalities.
 - c. Vendor-specific workstations form part of the “vertical industrial stack,” making image sharing among different workstations difficult. For those who seek best-of-breed solutions tailored to imaging needs, current capabilities are limited.
 - d. New workstations should also be capable of displaying DBT examinations correctly (eg, proper frame rates) and should conform to the IHE DBT profile as well as the IHE MAMMO profile. If it does not, then it is possible that the workstation will fail to show all DBT examinations as they are intended to be displayed by the acquisition system manufacturer.
6. An interpreting physician’s or “primary interpretation” workstation is one that is used to render an “official” or “final” interpretation of a study.
7. A “technologist’s workstation” is one used by the technologist during the acquisition and QC process of an examination. It should also comply with and be calibrated to the DICOM GSDF standard [27]. Since technologists will perform QC on mammographic images at the acquisition or QC workstation to ensure that the radiologist has images of adequate quality, these displays must be of high quality.
 - a. When checking for positioning, contrast, and patient motion, the technologist should use a monitor having the same maximum luminance (eg, 400 cd/m²) as the one used by the interpreting physician.
 - b. A high-resolution monitor similar to the one at the primary interpretation workstation is desirable.
8. An “acquisition workstation” is one used to review images as an adjunct to the official interpretation by a radiologist and may not require the high-resolution displays necessary for final interpretation.
9. Monitors used to display images acquired in the process of needle localization must provide sufficient spatial resolution compared to final image interpretation monitors, so there should be the means to provide zoom and pan features allowing the user to view images at full spatial resolution in the acquisition room.

D. Computer-aided detection (CAD)

1. The purpose of CAD is to help radiologists find cancers they may have overlooked otherwise. Studies of mammography CAD alone (without a human observer) suggest that mammography CAD detects some types of lesions well (especially calcifications, although possibly less well with amorphous forms). Mammography CAD is used to supplement routine image evaluation, and a human reader

would not be expected to recall all or even most of mammography CAD marked lesions for further workup.

2. CAD may potentially play a role with DBT [45]. The increased number of images along with the subsequent time needed for review can have a significant impact on workflow. Because DBT is still fairly new, more research needs to be done before recommendations can be made for the particular properties associated with the various CAD programs designed for DBT. The current research suggests that DBT CAD software is comparable in sensitivity and false-positive rates when compared with other commercial CAD systems used with standard digital mammography [45].

E. Image Processing Considerations

Image processing has great potential to improve image quality and secondarily diagnostic accuracy and even to reduce the radiation dose necessary to achieve an image of acceptable quality [50-52]. Digital mammograms typically have a wide dynamic range, and the ability to process the image data provides an opportunity to display the data more effectively. Storage of “for processing” image data provides greater flexibility for subsequent postprocessing using different algorithms. Systematic variations in intensity can be equalized, local contrast can be enhanced, and the sharpness of calcifications can be restored. Enhanced visualization of subtle structures is suggested as a possible contributor to the improved performance of digital mammography in patients with dense breast tissue [53].

1. Segmentation of the breast from the region of the direct beam is the first step for defining the areas to be processed, using edge detection algorithms and grayscale adjustment to equalize apparent tissue thickness. Artifacts near the skin line can occur in the equalized image, and the potential for this improper segmentation requires the ability to turn off the algorithm.
2. Image processing steps (spatial frequency restoration and deblurring) are then carried out to render microcalcifications with greater detail and higher conspicuity.
3. Selective (adaptive) noise reduction attempts to reduce noise only in regions where tissue contrast does not have noticeable fine detail. Difficulty arises in reducing noise and preserving high spatial resolution with the same process. In some cases, noise reduction might not improve detection performance if the reduced noise texture is similar to that of target objects.
4. Unsharp masking and global latitude reduction increase the relative signal in underpenetrated areas and reduce the signal in highly transmissive regions. Fourier filters or spatial convolution kernels of large spatial extent create a low frequency blurred image that is then subtracted from the nonblurred image.
5. Adaptive local contrast enhancement and multiscale processing are other methods that have been used. When applying global latitude equalization or adaptive contrast enhancement, there is always some risk that subtle tissue characteristics of potential diagnostic significance may be diminished in relation to the detail that is enhanced.
6. Differently processed versions of the same digital mammogram are preferred depending on the task and lesion type, suggesting that workstations might implement multiple processing options for use during interpretation [53].
7. Desired processing parameters may vary with radiographic factors such as tube target, kV, and tube filter type and thickness. One must be careful to ensure that the processing being used is appropriately matched to the techniques used to obtain the mammogram.
8. Comparison of images from prior mammography examinations is essential in the interpretation of a new study. However, variations in the processing of prior and current images may make such

comparisons difficult. See the discussion below under section V. C. “[Archive](#)” for further information on this subject.

9. Application of image processing at the reading station (or by a processing box located separately from the primary interpretation workstation) requires image processing software that is applicable to the images from any digital mammography system. This requires an understanding of the characteristics of the image data from the digital mammography system or other input devices (eg, film digitizers) as well as storage of image data in the DICOM format intended “for processing.”

F. Reading Environment

Factors as diverse as ambient light, temperature, noise, posture fatigue, and poor ergonomics may have significant effects not only on radiologist comfort but also on the quality, accuracy, and consistency of image interpretation [5,54,55]. Some of the more critical considerations include the following:

1. Impact of ambient light
 - a. Ambient light should be low and consistent, particularly in a hybrid viewing environment where stray light from bright lightboxes can be detrimental when displaying softcopy images. The amount of ambient light (illuminance) should be approximately equal to the level of the average luminance of a clinical image being displayed [55], generally in the 20 to 45 lux range; total darkness is not recommended.
 - b. Distracting glare and reflections occur from the display surface, even when antiglare coatings are applied. Thus overhead or direct lighting is not recommended; rather, indirect lighting is preferred.
 - c. Variations in the adaptation of the human eye to ambient light levels affect the contrast sensitivity and hence the ability to detect low-contrast targets. Thus it is recommended that radiologists take at least 5 minutes to “dark adapt” to reading room light levels before viewing images when transitioning from daylight or other higher ambient light conditions.
 - d. Fatigue levels and eyestrain increase and interpretation accuracy decreases with higher levels of ambient light [55].
2. Other environment factors [55]
 - a. Adequate air flow, optimal temperature, and humidity control should be maintained in reading areas.
 - b. 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 50 lux [56,57]. 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.
 - c. Noise from computer equipment and other devices should be minimized.
 - d. Proper chairs with lumbar support and adjustable height controls (including armrests) are recommended to avoid injuries and excessive fatigue.
 - e. The workstation table should be height adjustable, and the keyboard, mouse, and monitors 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, about 2/3 meter or 60 cm).
 - f. Dictation tools, internet access, and other reference tools should be readily accessible and easy to use during image interpretation.
 - g. Guidelines on the maximum number of acceptable pixel defects are specified by ISO 9241 as a function of display class [58]. 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.

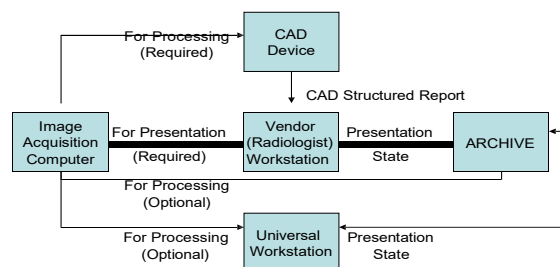
V. TRANSMISSION, STORAGE, AND RETRIEVAL

The development of tools for image storage and retrieval has emphasized the isolated silo concept, with each manufacturer optimizing its own system, at the expense of the PACS interoperability common for other imaging technologies, such as computed tomography (CT) and magnetic resonance imaging (MRI). The goal of DICOM is to provide a standard for storage and transmission, whereas the IHE mammography profile [36] provides a recommendation for best practice implementation and work flow. Relevant standards are the DICOM DX Image Information Object, the DICOM Digital Mammography X-Ray Image Information Object (MG), the DICOM Mammography CAD Structured Report (SR), the DICOM Accumulated Mammography X-Ray Radiation Dose SR, and the DICOM Breast Tomosynthesis Image Storage SOP Class. Any of these information objects can be stored for later retrieval.

A. Digital Mammography Image and Data Types

1. The MG information object descriptor includes a specification for 2 types of image information. “For processing” represents image data that are corrected for detector acquisition but not processed for interpretation. “For presentation” image information has been processed by vendor-specific algorithms and is ready to be displayed on a workstation.
 - a. “For processing” image data require mammography-specific algorithms to produce a high quality image for interpretation. Mammography CAD devices most commonly use “for processing” image data.
 - b. “For presentation” image data are processed for display on any DICOM-compliant and calibrated monitor acceptable for mammography viewing. DICOM presentation state information enables the reproduction of the appearance of the image on different display devices or media.
2. Mammography CAD devices produce a DICOM mammography structured report and presentation state that may be used by other mammography workstations to display the results of the mammography CAD process.
3. Digital mammography acquisition devices may transmit all types of image data to other storage devices, display devices, or postprocessing devices such as mammography CAD systems (see Figure 1).
4. Since many mammography CAD systems require “for processing” images, vendors of digital mammography acquisition devices should ensure that the devices support DICOM transmission of both “for presentation” and “for processing” MG images.
5. Telemammography demands high speed networks and/or compression (see below). Reasonable transmission speeds may make the difference between an efficient, successful service and failure.
6. Other considerations regarding image datasets
 - a. File sizes of stereotactic biopsy unit images are typically 0.5 to 2 MB per image.
 - b. Breast MRI, breast ultrasound, breast CT, and DBT are modalities that typically produce a large number of images and, for breast CT and DBT, very large datasets.

Figure 1. Flowchart of image data distribution



B. Workstation

1. The mammography display workstation must support receipt of DICOM-compatible MG images, DBT datasets, and mammography CAD structured reports “for presentation.”
2. Display of new data “for processing” should be optional and configurable for digital mammography workstations.
3. The display system should support DICOM query and retrieve digital mammograms from a DICOM archive.
4. Support for DICOM presentation states for displaying images with the ability to save and retrieve various presentation states as specified by the user is required.
5. Mammography workstations should support the IHE Consistent Presentation of Images Integration Profile and the IHE Mammography Image Profile (see the IHE Radiology Technical Framework, Supplement 2006-2007 [36]).
6. A universal workstation should:
 - a. Properly display “for processing” and “for presentation” MG data, with mammography-specific hanging protocols and support for the IHE Mammography Image Profile
 - b. Provide user-defined processing algorithms for digital mammograms as well as display acquisition-defined “for presentation” algorithms and Look up Tables (LUTs).
 - c. Allow multimodality image viewing of associated breast imaging studies (eg, ultrasound, MRI, CT, PET/CT, biopsy specimens, stereotactic images, surgical specimens, and other pertinent studies).

C. Archive

1. The archive device for digital mammography should support DICOM receipt of MG images and DBT data sets.
2. Storage of “for presentation” images is required to ensure the ability of radiologists to reproduce the original images used for interpretation. The “for presentation” image set must be archived to PACS and be viewable with comparable quality on different but suitable workstations.
3. Storage of images “for processing” is encouraged but is not required. The “for processing” image data storage is optional, with the possible exception of mammography CAD, which might require storage of the “for processing” data. Each facility should carefully consider the ramifications of archive space necessary for additional storage of the “for processing” images as well as the potential downstream benefit and legal implications of reprocessing these data to create new “for presentation” image sets for future comparisons. Storage of these datasets should not be required for technical reasons but may be required for local medical-legal ones.

4. Storage of mammography CAD structured reports (SR) is recommended but should be optional. However, those who choose to discard the mammography CAD information on which they based their interpretations should understand that the only way to reproduce the original mammography CAD data is to retain the original report. Reprocessing may yield different results. If CAD SR is not stored, the CAD version used at the time of the original interpretation should be documented.
5. The archive device should be able to query and retrieve digital mammograms and DBT data sets.
6. Prior examinations
 - a. If possible, comparison of current studies to prior examinations is strongly recommended (see the [ACR Practice Parameter for the Performance of Screening and Diagnostic Mammography](#) [11]). Storage requirement estimates should therefore take into account the need to store and access current and prior images.
 - b. Prior examinations may be imported from portable media. Prior examinations may have been obtained using a screen-film system, and these can be digitized for softcopy display. Currently, a digital practice of about 150,000 examinations per year would produce 25 GB of data per day, assuming non-storage of the “for processing” images. If the “for processing” images are stored, the data storage requirements will be considerably higher.
 - c. Although the FDA does allow the digitization of prior film examinations for comparison purposes, its current guidelines [34] do not allow digitized film images to be the sole source for archival purposes. The original film images must be maintained.

D. Image and Data Compression

Digital mammogram image compression can provide more efficient transmission and storage. The digital image is an exact representation of an inexact noisy signal, with finite limits to the amount of compression that can be applied. Mammography images are suitable for compression (lossless or not) because of large black areas outside the breast that do not contain diagnostically relevant information.

Compression may be defined as mathematically reversible (lossless) or irreversible (lossy). Reversible compression may always be used, since by definition there is no impact on the image. 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 image, modality, and the objective of the study will determine the amount of compression that can be tolerated. The term “diagnostically acceptable irreversible compression” (DAIC) is mathematically irreversible compression that does not affect a particular diagnostic task [59]. DAIC may be used under the direction of a qualified physician or practitioner with no reduction in clinical diagnostic performance by either the primary image interpreter or the decision makers reviewing the images.

The ACR and this practice parameter make no general statement on the type or amount of compression that is appropriate to any particular modality, disease, or clinical application to achieve the diagnostically acceptable goal. The scientific literature and other national guidelines may serve to 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 [60]. Lossy compression is not justified solely by the small cost savings to be realized. The benefits and costs of using lossy compression need to be carefully considered, and compression schemes that preserve the high frequency content of microcalcifications should be used.

If reversible or irreversible compression is used, only algorithms defined by the DICOM standard, such as 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 [59]. DICOM does not recommend or approve any particular compression scheme for any particular modality, image type or clinical application. 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 [61]. In addition, this technical standard recommends that the type of compression scheme (JPEG, JPEG 2000, etc) 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 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 may be used as priors for comparison [62]. 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]) [61]. Since it is known that such simple metrics do not correlate well with human assessment of quality or performance for diagnostic tasks [56], the claim of the manufacturer that irreversible compression is satisfactory may not be sufficient, and the burden remains on the responsible physician to assure that the image quality is sufficient to achieve a diagnostically acceptable goal.

E. Legal Challenges

The legal requirements for digital mammography are established by the FDA Final Rule [10] and by the state that has appropriate jurisdiction.

1. For acquisition and interpretation, the legal requirements are the same as those for film mammography.
2. Current FDA regulations require that facilities maintain mammography films and reports in a permanent medical record of the patient for a period of not less than 5 years or not less than 10 years if no additional mammograms of the patient are performed at the facility, or a longer period if mandated by state or local law. The record retention requirements may differ from state to state.
3. Security requirements for disaster recovery of digital imaging are greater than those for film-based imaging. A physically separated redundant archive increases safety of the data and may actually be required in some jurisdictions.
4. Circumstances become more complex for the patient who is seen in more than 1 state as well as for the practice that receives images from more than 1 state. Clearly, the requirements of each jurisdiction must be analyzed carefully.
5. Use of lossy compression for data storage, transmission, and retrieval is not allowed by the FDA.

VI. QUALITY CONTROL RECOMMENDATIONS

A. Acquisition

1. Manufacturer-specific QC procedures are required under the current FDA rules for digital mammography and must be followed. Documents provided by the manufacturer of the digital mammography system define the procedures and limits for corrective action for periodic tests (daily, weekly, monthly, quarterly, and semiannually) performed by a designated QC technologist and for annual tests by a Qualified Medical Physicist. These documents are periodically updated, so the technologist and Qualified Medical Physicist need to stay abreast of updated versions of the documents.

2. The ACR Digital Mammography Quality Control Manual [8] for FFDM digital mammography systems has been approved by the FDA as an alternative standard to the manufacturer's recommended quality assurance program. See the Mammography Quality Standards Act and Program [63].
3. Other requirements regarding the overall QA program mandated by the FDA must be carefully followed. QC for hardcopy devices used for printing of digital mammograms should include implementation of the DICOM GSDF standards for printers [27]. Specific manufacturer **or** ACR QC test procedures, frequencies, and corrective action limits must be followed for digital mammography displays, workstations, hardcopy devices, and verification of proper grayscale rendition of printed images compared to displayed images is necessary. MITA standards and document templates are available to assist in the recording of these processes [30,31].

B. Image Display and Processing

1. QC guidelines for display monitors include implementation of the DICOM GSDF standard [27] and the mammography-specific recommendations of AAPM Task Group 18 [40]. Recommendations are also provided in the ACR Digital Mammography Quality Control Manual [8].
2. QC for image processing of digital mammograms should include interaction with radiologists and verification of reproducible image processing characteristics and proper rendition of images and correct functioning of task-dependent processing.

C. Storage and Archiving

Optimal components of digital storage and archiving include the following:

1. Verification of DICOM metadata in header and accuracy of information
2. Security and privacy protection
3. Backup and disaster recovery testing

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- 2007 (Resolution 35)
- Revised 2012 (Resolution 36)
- Amended 2014 (Resolution 39)
- Revised 2017 (Resolution 42)