Breast Imaging Basics

Module 10 Transcript
Breast Imaging Basics: Module 10 – Digital Mammography

1. Breast Imaging Basics – Digital Mammography
   Welcome to Module 10 of Breast Imaging Basics – Digital Mammography. This module was written by Patricia M. Dycus, BS, RRA, R.T.(R)(M), RDMS.

2. License Agreement and Disclaimer

3. Module Objectives
   After completing this module, you will be able to:
   • Explain the theory behind producing, acquiring and displaying digital mammograms.
   • Discuss the benefits of full-field digital mammography for both the patient and breast imaging staff.
   • List quality assurance tests that are specific to digital mammography.
   • Describe the quality assurance testing done by the medical physicist.

4. Breast Cancer
   The National Cancer Institute reports that the mortality rate from breast cancer has been steadily declining since 1986. Although many factors account for this decrease in the mortality rate, screening mammography certainly has played a significant part in this positive trend.

5. Film-screen Mammography
   With advances in film emulsion and screen crystal technologies it became more advantageous to perform mammography using dedicated analog film and screens specifically designed for mammographic use. Mammographic equipment now consists of dedicated upright units that make the examination far easier for the patient to tolerate and for the technologist to perform. Because the equipment used for mammography is dedicated solely for that use, the tube target material can be designed specifically to create the type of x-ray beam needed to reduce radiation exposure and improve image quality.

6. Film-screen Mammography
   Some advantages gained in the transition from xeromammography to film-screen mammography are: faster examination times, more consistent quality control (QC), decreased radiation exposure and improved contrast resolution. Over the past several decades film-screen mammography has continuously improved within the confines of analog technology.

   Improvements came about largely by adding automatic exposure control (AEC) to the mammographic unit. AEC allowed exposure factors to be adjusted based on patient breast density, resulting in better image contrast and reduced radiation exposure. Improvements within the film-screen system, such as faster film-screen combinations, dedicated mammography film processors and improved viewing conditions also improved mammography’s effectiveness as film-screen combinations evolved.

7. Mammography Advancements
   Over the years mammography has continually evolved, keeping in step with current technological advancements. In the 1970s, breast imaging was performed using
xeromammographic imaging technique. This imaging method used a selenium coated plate encased in a cassette that, when exposed to x-ray energy, formed a latent image made of charged electrons. The plate was then developed in a process-specific machine manufactured by Xerox.

The permanent image was recorded on paper as a blue image on a white background, as shown on the right. One disadvantage of this imaging modality was frequent processing machine malfunctions. Because of the difficulty with recumbent positioning of the patient and pressure-sensitive selenium plates, there were many repeat images, which resulted in more radiation exposure to the patient. Xeromammography was extremely labor intensive to perform; most facilities performed the studies with a general purpose x-ray unit and used a diagnostic radiography positioning table for the mediolateral images.

8. **Digital Mammography**
   Digital technology is the next step in the evolution of mammographic imaging and is now a well-established technique for mammographic image acquisition, processing, viewing and storage. The most significant change that digital imaging has brought is that the film-screen cassette has been replaced with a type of detector that uses x-ray energy to produce an electronic signal that is digitized and stored. Producing a digital mammogram can be divided into 3 functions: acquisition, conversion and display. In analog imaging, all 3 of these functions were dependent on the selected film-screen combination, but in digital Imaging each of these functions remains independent of one another. This allows the manufacturer to modify the imaging chain at each step to maximize the attributes of each function.

9. **Detector**
   The detector is responsible for acquiring the image and is described according to the process used to obtain the image. There are currently 2 methods used to acquire information in digital mammography: direct capture and indirect capture. Direct capture detectors capture the x-ray energy and convert the information to a digital signal in 1 step. Indirect capture requires 2 steps. Most vendors use the indirect capture method, which adds the second step in the conversion process and subsequently reduces efficiency or resolution. The indirect capture process uses a secondary medium such as phosphors to trap and store the image temporarily before creating the digital image.

10. **Direct Capture**
    Look at this illustration. In direct capture the remnant x-ray beam strikes the x-ray conductor (such as amorphous selenium), which directly converts the x-ray photons into an electrical charge.

11. **Indirect Capture**
    This illustration shows the steps in the indirect capture process. Indirect capture uses a 2-step process that involves a scintillator. The x-rays strike the scintillator and are converted into visible light. Photodetectors such as thin-film transistors (TFTs) convert the light to an electrical charge.

12. **Knowledge Check**
    Answer the following question.

13. **Knowledge Check**
Answer the following question.

14. **Knowledge Check**
Answer the following question.

15. **Knowledge Check**
Answer the following question.

16. **Capturing Acquired Information**
Although there are only 2 methods to acquire the image, there are several different techniques used by detectors, with multiple mechanical approaches to capturing this acquired information. This next section describes various technological and mechanical methods involved in acquiring digital information that are used to produce a mammogram.

17. **Computed Radiography (CR)**
The first type of indirect imaging system is computed radiography, often abbreviated as CR. Most CR systems use a detector made of photostimulable storage phosphors. This type of detector feels familiar to mammographers who are used to performing film-screen mammography because the detector is housed within a device that looks and feels very similar to a film-screen cassette. Once the detector is struck with x-radiation, the phosphors become excited and trap the radiographic image. The excited electrons trapped in the phosphor crystalline structure remain stable for up to 24 hours and retain the information that makes the image.

18. **Processing**
When the base containing the excited electrons is loaded into a reading device, a laser beam is used to re-energize the phosphor material, which emits light proportional to the amount of radiation exposure the material received during the mammographic exam. The emitted light is converted into an electrical signal and amplified using a photomultipier tube before digital conversion. This process is indirect capture because the x-ray energy is transferred to the photostimulable storage phosphors, then converted to light by the laser, and finally converted into an electrical signal using a photomultiplier tube.

19. **Phosphor Charge-coupled Device (CCD)**
The second type of indirect capture detector is called a charge-coupled device, or a CCD. This detector uses cesium-iodide phosphors with thallium doping as a medium for converting x-ray energy to light. Play this animation. The light emitted from the phosphors is trapped by millions of optical fibers that conduct the light to the CCD array where it is converted to an electrical signal that is subsequently digitized.

20. **Slot-scanning System**
In CCD systems, the detector does not generally cover the entire image area but is designed as a strip of detectors approximately 1 inch by 24 inches that is matched to an x-ray beam collimated to the same size. The slot-scanning approach used by the CCD system generally results in a lower amount of radiation exposure because of the thin area of exposure through the slot. With the use of the slot technology there is also very little scatter radiation, and antiscatter grids are unnecessary. Because slot-scanning digital equipment is constructed with fewer detectors than some other types of imaging equipment, it generally is less expensive.
The beam and the detector move simultaneously across the image field during image acquisition. This scanning method is called a “slot-scanning system” because of the shape of the image acquisition field. In this process the x-ray energy is converted to light by the phosphors, trapped and carried by the optical fibers, and then converted to an electrical signal.

21. Flat-panel Detector
A third type of indirect capture system consists of a flat-panel detector coated with a layer of cesium iodide. Cesium iodide is an ideal material for indirect image capture because of its inherent property of producing light when exposed to x-ray energy. This process of emitting light is termed scintillation. The layer of cesium iodide that absorbs the x-ray energy and converts it to light is attached to a thin flat panel of photodiodes coated with amorphous silicon. The amorphous silicon converts the light emitted from the cesium iodide into electrical charges that are converted to digital information. TFTs convert the electrical charges into digital information.

22. Flat-panel Detector
Unlike the previous systems, the nonphosphorous flat-panel detector system uses a direct capture method, which means that this system does not use light energy or scintillation emitted from excited phosphors. It is composed of a flat-panel amorphous selenium detector attached to a thin flat panel of photodiodes. The x-ray energy interacts with the amorphous selenium directly and is converted directly to electrical charges. The electrical charges are immediately recognized by the TFTs and converted to digital information. Because this system does not use scintillation and the electrical charges come directly from the interaction of the x-ray energy with the amorphous selenium, this system is called a direct capture flat-panel detector.

23. Performance Factors
Understanding the various digital mammography acquisition systems on the market is important when weighing the advantages and disadvantages of each system. To evaluate the merits of a particular digital acquisition unit, it is important to understand all of the factors that affect the detector’s ability to perform. Let’s examine these factors in the next section.

24. Detector Elements
There are a finite number of cells in a digital detector that capture information. These cells, which are the smallest resolvable area in certain types of detectors, are called detector elements. The detector elements' number and spacing are determined by the detector design. Many people think of detector elements in the same manner as pixels, but there is a difference. Detector elements are involved in the detector’s ability of to acquire images, whereas pixels refer to the display capabilities.

25. Detector Elements
Look at this illustration. Digital information recorded from the detector is sent to an image matrix, or array of small picture elements called pixels. In a CR system the laser reading device limits the amount of information available by the size of the laser spot. In the CCD slot scanning system the system resolution is limited by the number and size of detector elements in the CCD array. The resolution in both the phosphor and the selenium flat-panel detectors is determined by the number and spacing of the detector elements within the TFT. Ultimately, the number and
size of the detector elements and the efficiency with which the detector sends information to the capturing device determine the equipment's sensitivity.

26. **Benefits of Full-field Digital Mammography**
The benefits of full-field digital mammography (FFDM) continue to be recognized as more facilities make the transition from film-screen mammography to FFDM. According to results from the Digital Mammographic Imaging Screening Trial conducted by the American College of Radiology Imaging Network in 2005, the improved diagnostic capabilities of FFDM are most apparent in patients who have dense breast tissue, those who are less than 50 years old, and women who are premenopausal or perimenopausal.

One benefit of digital mammography most often mentioned is the reduction in radiation dose to the patient. There are many reasons why dose can be reduced in digital mammography. One reason is the increased efficiency in digital image acquisition. Another reason is the wider latitude in digital imaging display that makes it possible to reduce the number of repeated images. The narrow latitude inherent in radiographic film and the integration of acquisition and display made repeat imaging more common in film-screen mammography than in FFDM.

27. **Magnification**
When FFDM was first implemented, it was hoped that the use of postprocessing techniques for image evaluation would reduce the number of additional images required, especially when evaluating microcalcifications using electronic magnification. The intent was to replace additional magnification views with postprocessing zoom functions to evaluate microcalcifications. However, experience proved that electronically magnified images contained less, rather than more, information compared with evaluating calcifications on film-screen mammograms using a magnification technique and a magnifying glass. In these 2 images you can see the difference between a digital image on the left and a film-screen magnified view on the right.

28. **Benefits of Full-field Digital Mammography**
One of the benefits to using FFDM most appreciated by patients is the increased speed with which the examination can be completed. The following factors contribute to faster examinations. The image is acquired and displayed within seconds compared with several minutes in analog imaging, which means that the mammographer can evaluate the need for additional imaging more quickly. If additional images are needed, the mammographer can acquire them within seconds and the patient does not have to leave the examination room. Finally, mammographers can consistently obtain technically good images because the inconsistencies that occur during wet processing are eliminated. This reduces the delays and need for additional images caused by processing errors.

A common misconception is that breast compression is not necessary in digital mammography. Because compression affects the geometric factors related to imaging, breast compression is every bit as important in FFDM as in film-screen mammography.

29. **Benefits of Full-field Digital Mammography**
Another benefit that results from the transition to digital mammography is improved department workflow. Digital detectors replace cumbersome film cassettes, and use of FFDM
30. **Benefits of Full-field Digital Mammography**
In addition to patient benefits, FFDM has many advantages for clinical staff. Reduced procedure times can increase technologists' productivity; mammographers can perform more studies on the same piece of equipment. This increase in productivity is necessary for mammography centers to survive the current economic demands of increased costs and reduced reimbursements.

The radiologist’s time is extremely valuable and must be considered when evaluating workflow processes. Within seconds of digital image acquisition and recording, the mammogram can be displayed and reviewed by the radiologist, who can manipulate the image using a variety of software tools. These tools include, but are not limited to, annotation features, hanging protocols, pan and zoom features, magnification, window/level function and image inversion techniques. As with any new process, there is a learning curve associated with these tools and their use may increase interpretation times in the short term. However, with improved familiarity, interpretation times decrease and productivity and accuracy increase.

31. **Computer-aided Detection**
Computer-aided detection, or CAD, is a tool that is compatible with FFDM and is helpful in detecting breast abnormalities. The x-ray energy from the FFDM image is transformed into electronic signals that can be transmitted very quickly. When the electronic data is sent to the CAD device, various software algorithms designed to recognize breast abnormalities such as calcifications and masses are applied. The CAD system marks the image according to the type of abnormality detected. The system marks areas of potential suspicion for further interpretation by a radiologist. Many studies have indicated an increase in the cancer detection rate among interpreting physicians who use CAD. The increases were greatest among radiologists who interpret low volumes of mammograms.

32. **Computer-aided Detection**
Look at this image. The small asterisk is an example of how CAD marks an area of suspicion on a mammogram.

33. **Computer-aided Detection**
Although CAD evaluation can be applied to film-based systems, it is more difficult because the hard-copy mammogram must be converted to electronic information by a digitizer and displayed on a monitor that can display CAD markings to the interpreting physician. This process is cumbersome and time consuming and is used most often during the transition from analog to digital imaging.

34. **Picture Archiving and Communication Systems**
   To store digital information an imaging department must have some type of picture archiving and communication system, commonly known as a PACS. As its name implies, PACS is an electronic method used to store and retrieve electronic data. PACS takes the place of file folders stored in a file room. Every PACS should be capable of performing the following 5 functions:
   - **Image acquisition** – Interface with the digital equipment performing the image acquisition and recognize the digital data.
   - **Image storage** – Store a large amount of image data securely.
   - **Image transfer** – Quickly transfer large amounts of image information over an electronic network.
   - **Image display** – Send image data to monitors and workstations so that the images display on the appropriate workstations in the proper format.
   - **Image management** – Finally, the PACS must be able to attach information to the images that identify and index the data correctly.

35. **Knowledge Check**
   We just discussed the five functions of PACS. To review, match each function with the appropriate task.

36. **Storage Considerations**
   The images acquired in digital mammography occupy a great deal of space in electronic form. A database usually provides for both short-term and long-term storage. Short-term storage holds the most recent images acquired and retrieval of these images usually is faster than it is for those held in long-term storage. Retrieval from long-term storage and archival systems may take longer. The size of a digital mammogram data file is often underestimated by PACS administrators who are not familiar with the resolution requirements in mammography. A 4-projection FFDM exam with CAD markings requires from 3 to 10 times the storage space of an average computed tomography (CT) examination.

37. **Image Acquisition**
   The process of acquiring a digital mammogram doesn't start with the detectors. The detector system is the part of the acquisition process that makes FFDM different from film-screen mammography. The following factors contribute to FFDM image acquisition and, with the exception of detectors, are very much the same whether digital or film-screen techniques are used to acquire the image.
   - Generator
   - Tube target material
   - Filter material
   - Focal spot size
   - Collimation
   - Compression paddle
In the following sections we will look at each of these factors in more detail.

38. Generators
In this age of evolving technology, x-ray generators have become much more sophisticated and complicated than they once were, but also smaller and less expensive. Generators provide the voltage and the amperage needed to produce ionizing radiation. Mammography relies on high-frequency generators, which can produce waveforms that are near constant potential voltage. This is accomplished with capacitor banks, rectifiers and inverter circuits.

A single-phase alternating current (AC) supply is rectified first, which becomes direct current, or DC. When the DC current passes through a capacitor bank, it is made smoother, and then goes through an inverter circuit, which changes the current to high frequency (5 to 10 kHz). A step-up transformer makes the current high voltage as well. From there, the current is again rectified and passes through another capacitor bank for smoothing before passing to the x-ray tube.

The result of this relatively smooth and constant waveform is that mammographers can precisely control kilovolt peak (kVp) and miliamperage (mA), and ultimately patients receive lower radiation doses. The generator is evaluated for quality and efficiency at the time of equipment installation.

39. Target and Filter
Both the tube target material and filtration selection influence the quality of the x-ray beam and the quality of the x-ray beam has a direct relationship to patient radiation dose and image quality. The technical factors chosen for an exposure are based primarily on the structure being imaged. Optimum breast imaging requires a beam capable of producing high contrast and low radiation dose. This is accomplished by selecting the proper technical factors of low kVp and the proper tube target material and filtration.

Various FFDM units use multiple combinations of target and filter materials depending on the manufacturer. Some units allow a mammographer to choose between 2 different target materials and then further choose filtration materials. The common target materials are molybdenum, rhodium and tungsten. The types of internal filtration material most often seen are molybdenum, rhodium, aluminum and silver.

40. Knowledge Check
Answer the following question.

41. Knowledge Check
Answer the following question.

42. Focal Spot
Focal spot size selection affects spatial resolution in the acquired image. Manufacturers usually have 2 different size focal spots, the larger one for general imaging and the smaller one for high-
resolution imaging, as in the case of magnification views. Play this animation to see how small and large focal spots differ.

43. **Collimation**
Collimation is also important to the image because it restricts the amount of scatter radiation that reaches the image receptor. Unlike collimation in diagnostic radiology, collimators in mammography can't be independently adjusted by the mammographer. Instead, the collimators automatically adjust to the size of the image receptor to ensure that x-rays do not interact with any tissue outside of the imaging area. This helps to reduce patient dose and to decrease the production of scattered radiation that would otherwise be emitted from the tissue outside of the imaging area.

44. **Compression**
Compression can produce anxiety for patients, and therefore is a concern for mammographers as well. Perhaps the biggest myth about FFDM is that compression is unnecessary. Unfortunately, the advances in digital technology have not yet eliminated the need to separate breast structures and minimize breast thickness to reduce geometric blurring. The compression paddles are made of a rigid plastic that should not bend under pressure and should apply uniform pressure.

Compression paddles should be matched to the patient’s breast size for 2 reasons: first, for the ease of patient positioning, and second, because some mammography units recognize the paddle size and automatically select the appropriate pixel matrix. Using the wrong paddle size can affect how the image is displayed workstation monitor.

45. **Patient Motion**
The patient also can influence image acquisition in FFDM. Patient motion plays a major role in how effective the FFDM imaging process is in detecting potential breast abnormalities. Mammographers can help reduce patient motion with good patient communication, adequate compression and the correct selection of technical factors.

Patient breast composition is a factor that cannot be changed, and often cannot be predicted without first imaging. With FFDM, the mammographer can make a small test exposure that measures breast density and then automatically selects the appropriate technical factors. This helps reduce the need for repeat exams caused by overexposure or underexposure.

46. **Antiscatter Grids**
Antiscatter grids attenuate the scattered photons that are either too low in energy or are not correctly aligned with the detector to provide valuable information for image acquisition. In turn this hardens the beam and improves quality.

47. **Standard Linear Grid**
There are multiple types of grid systems, but standard linear grids are the type used in general radiography. Standard linear grids are reciprocating and consist of multiple long, thin, radiopaque stripes separated by radiolucent spacers. These grids are usually described by size and the number of stripes per inch. Linear grids effectively reduce scatter in 1 direction, but they also attenuate some of the primary beam.
48. **High-transmission Cellular Grid**

Another type of grid is the high-transmission cellular grid that has a crosshatched design. This grid absorbs scatter in 2 directions and attenuates less of the primary beam because the radiolucent spacer is air.

49. **Automatic Exposure Control**

AEC could be considered the brains behind the mammography unit. Most manufacturers include some type of exposure optimization such as AEC on their equipment. Mammographers can think of AEC as an advanced, internal technique chart. The manufacturer builds a technique chart called a “look-up table” created from vendor-specific algorithms. There are various look-up tables in each unit that can be chosen based on selecting any 1 fixed setting: breast density, breast thickness, tube target material, filtration, KVP or time. In addition, the unit can automatically select each of the settings.

Vendors use technique choices to create algorithms that either decrease the radiation dose to the patient or improve image contrast. Usually these choices result in a tradeoff in either dose or contrast. When using the AEC function, a short test exposure is made to assess the breast density. The equipment easily records the breast thickness, then chooses the proper look-up table and selects the appropriate technical factors. The technologist can choose to self-select any single factor or combination of technical factors, overriding the AEC function.

50. **Display System**

The final step in the digital acquisition process involves the detector system. It is this phase of the process that separates FFDM from film-screen mammography. Using any of the digital detector systems already discussed, image information is acquired during an exposure and must now be evaluated and displayed as an image that can be interpreted.

In film-screen imaging, display simply involves placing the film on a viewbox for radiologist interpretation. With digital imaging, the process is more complex, but also provides increased viewing options for the radiologist. An adequate image display system must provide appropriate luminance, contrast, resolution, sharpness and uniformity across the display medium. All of these factors are evaluated when determining whether the image displayed includes enough information to make a clinical interpretation.

51. **Image Acquisition Recording**

With film-screen mammography, image acquisition and image recording are incorporated into one process. For this reason, the image information submitted for interpretation is limited based on the lowest resolution capability of any factor used throughout the entire imaging process. This limitation can be from a technique used to acquire the image, film-screen combination, wet or dry processing or viewing conditions. In digital mammography, separating image acquisition from the display process creates opportunities and obstacles. Opportunities include improving image optimization and information storage and portability. Obstacles include limited monitor technology, high cost of equipment and acceptance by the interpreting physician.

52. **Digital Display – Hard Copy**

There are 2 ways to display a digitally acquired mammographic image: hard copy on film or soft copy on a display monitor. Hard-copy display with digital imaging is accomplished by printing the
image as a film-based black-and-white negative image printed on a dry laser printer or developed in a wet processor. Dry laser-printed film can display higher spatial resolution with higher optical density and fewer artifacts than film produced using wet processing, but the laser-printed film has a reduced dynamic range that limits image contrast resolution.

53. **Hard-copy Display**
A disadvantage of hard-copy display is that it can't be integrated with CAD if you delete the digital files. Other disadvantages include increased labor demands to hang and remove films for interpretation and matching hanging protocols to those of each interpreting physician. Long-term storage of film can be much more problematic in terms of space and time than can electronic storage of digital files.

Hard-copy film can display an image obtained from an original film-screen acquisition, or from digitally acquired electronic files that are printed. A significant limitation to film-screen mammography is the inability to replace the information should the original become lost or damaged. The original electronic information from a digitally acquired film remains safe from loss or damage even after a patient receives a printed copy.

54. **Display – Soft-copy Viewing**
Radiologists interpret soft-copies of digital images using electronic monitors. In the early years of digital mammography, soft-copy viewing was extremely limited because of the spatial resolution limitations of the monitors.

For soft-copy display to be a success in FFDM, it must have a spatial resolution as least as good as the spatial resolution at acquisition. Cathode ray tube monitors are limited in both pixel size and depth, however many improvements in monitor technology have helped FFDM become more viable and widespread in use.

55. **Liquid Crystal Display Monitors**
Flat-panel liquid crystal display (LCD) monitors have improved both the contrast and spatial resolution capabilities of soft-copy display. One limitation that should be noted about LCD monitors is that they are angle dependent. When viewed at an angle, the displayed levels of gray are altered. One study found that the effect, most prominent at 45° off center, has a substantial effect on radiologist performance. Therefore, mammographers also must understand that if they are standing off center from the display, some abnormalities may not be visible.

56. **Soft-copy Viewing Tools**
The success of soft-copy review is contingent upon accomplishing 2 main goals: First, the images must be viewed at the size at which they are acquired, and second, the radiologist must be able to use the tools available to maximize diagnostic information within reasonable interpretation times. Viewing the image at 100% allows matching of acquisition pixel to display pixel. This is how film-screen mammograms have always been viewed. If the monitor has a smaller pixel matrix than the digital detector system, less information can be included on the monitor at any one time. This results in an image that is too large to be seen in its entirety. If the monitor has a larger pixel matrix than the digital detector system, the image appears smaller than actual size.
The image displayed can be manipulated with multiple software tools, including pan and zoom, magnification, window/leveling and inverted display. These tools don’t add information to the display; they simply provide a different perspective or otherwise isolate the area being viewed. The information available is limited by the detector and display systems.

57. **Telemammography**
One of the benefits of digital mammography is the portability of the information captured; digital images can be sent to any number of locations quickly. Sending information to distant reading sites is referred to as telemammography, which is a system of one or more digital mammography units linked by a network or communications line to a remote workstation. Telemammography can be very beneficial to both the patient and the medical community because mammography screening services can be provided in remote, medically underserved areas, with the captured images sent to qualified interpreting physicians located in larger communities. This allows more efficient use of the limited number of highly trained interpreting physicians.

58. **Telemammography**
For a telemammography system to be effective, it must be able to handle large amounts of data quickly. In addition, several factors must be considered and addressed before highly confidential information is sent electronically to remote locations. Foremost is the issue of privacy, followed by a method of verifying the authenticity and integrity of the information received. Electronic security usually consists of using a virtual private network, or VPN, and firewalls on both ends of the information transfer. Verifying the authenticity and integrity of the information received is completed using a variety of proprietary encryption and decryption routines. Currently there are no government regulations specific to telemammography.

59. **CD-ROM File**
The CD-ROM is a form of media used to provide examination information to a patient or medical provider. Advantages include the minimal material and labor costs involved. In addition, the CD is a copy and does not jeopardize the original information. A disadvantage is incompatibility of software vendors in supporting the various PACS systems used by mammography facilities. These issues could make it difficult for the referring provider to access the information from the disc. However, most PACS systems now include an executable viewer when the CD is burned. This viewer, which is automatically launched when the CD is viewed, ensures that neither the referring physician nor the patient needs the proprietary software to view the images.

60. **Digital Imaging and Communications in Medicine (DICOM)**
Digital imaging and communications in medicine (DICOM) is a standard developed by the National Electrical Manufacturers Association, or NEMA, in collaboration with the American College of Radiology. The new standard allows for efficient transfer of electronic medical information in binary form. Medical professionals, through the ACR, and later the American College of Cardiology and manufacturers represented by NEMA, have worked together to create this standard for the transmission, storage and display of medical imaging information.

61. **DICOM Images**
DICOM images are labeled with a specific code indicating the imaging modality used to acquire the image; the code is designated by the DICOM standards. Digitally acquired mammograms are labeled under the modality code of mammography images, which is MG, and further
characterized by an object code of DX, which stands for digital x-ray. The reason for standardizing these modality and object codes is so that any DICOM-compatible software can recognize the information and display it correctly. For example, any image acquired as a DX object requires accompanying information that indicates laterality, projection, geometry, position angles and compression thickness.

In addition to DICOM standards for data transmission, there are standards designated by modality code that require minimum storage and display capabilities. This detailed information is beyond the scope of this module. The outcome is that manufacturers can create systems that can speak to one another with minimal difficulty. This allows facilities to choose different vendors based on personal preferences, add new equipment to existing equipment and transfer information within the facility efficiently.

This standard has many benefits for everyone involved in breast imaging. Facilities benefit from the ease of transferring data in and out of the facility, at the same time remaining confident that the information is retrievable. The patient benefits because imaging results can be easily and quickly evaluated by experts distant from the physical location where the initial imaging took place.

The only negative aspect of DICOM is that storage of DICOM information can be space intensive; the image files already are large, and must contain the additional image labeling data, along with potentially storing CAD annotations.

62. **Image Quality**

Image quality guidelines for digital mammography have been established by the ACR with input from the AAPM and the Society for Imaging Informatics in Medicine. These guidelines address maintaining quality throughout the imaging process starting with image acquisition, display, storage and printing of digital mammographic images. A subcommittee of the ACR developed a quality control manual for digital mammography that was released in 2011. Much like film-screen mammography, QC in digital mammography is designed to ensure that patients receive a quality mammogram at acceptable radiation exposure levels. This can only be accomplished by including and evaluating all equipment and personnel involved in providing a mammographic examination.

63. **Rules and Regulations**

The Mammography Quality Standards Act (MQSA) enacted by Congress in 1992 mandated that mammography centers in the United States adhere to specific rules and regulations to provide mammography services. Unlike accreditations for other modalities, the MQSA requirements are mandatory for facilities that want to perform mammography, and are enforced by the Food and Drug Administration. They were based largely on the ACR’s voluntary program that had been in place since 1987. Any mammography facility, with the exception of the Veteran’s Administration, must receive accreditation from one of the FDA-approved organizations listed here. The ACR and the appropriate departments in the states of Iowa, Illinois, South Carolina and Texas may accredit mammography facilities.

In this next section we will examine several MQSA requirements and see how they are implemented with FFDM.
64. **Labeling**

The MQSA requires that specific information be included on each mammogram at a minimum. The following is a list of the information that must be included on each image:

- Name of the patient and a second identifier.
- Date of the examination.
- View and laterality using the standard codes specified by the FDA.
- Facility name and location.
- Technologist identification.
- Mammography unit identification.

Universal labeling of sorts was recommended even before ACR's voluntary accreditation of mammography facilities. Images are labeled with the projection and side indicators on the lateral edge of the breast in the craniocaudal or CC projection and the superior level adjacent to the axillary area on both the mediolateral oblique (MLO) projection and the 90° lateral projection.

The MQSA's mandate that mammography facilities must communicate examination results in lay terms directly to the patient was a first for any aspect of medical imaging services. The requirement was made in response to the number one cause of litigation in mammography: delays in reporting of diagnosis. Standardization of the medical report includes both the content and terminology of the report and the method of communicating results.

65. **Content and Terminology**

Content and terminology refer to the mammographic examination report that is communicated to the referring physician and must include the following information:

- The name of the patient and an additional patient identifier.
- The date of the examination.
- The name of the physician who interpreted the mammogram.
- A final assessment of findings that can be classified into one of the Breast Imaging Reporting and Data System (BI-RADS) levels.
- Recommendations should be made to the health care provider about additional actions, if any, that should be taken.

66. **Mammographic Examination Results**

Mammographic examination results must be communicated to the patient in lay terms and to the health care provider. A report that includes the proper content and terminology, as previously discussed, must be sent to the health care provider as soon as possible; but no later than 30 days from the date of the examination. If the result is labeled as “suspicious” or “highly suspicious,” reasonable attempts must be made to communicate with the health care provider and patient as soon as possible. In addition, a report communicating the results in lay terms in place of medical terminology must be provided directly to the patient within 30 days of the examination.

Reporting and recording standardization in mammography services through the MQSA has improved the quality of care patients receive. The MQSA has accomplished this through better communication between the patients and their health care providers by ensuring patients receive a copy of their report that uses clear and precise language. The MQSA requirements for reporting and recording are identical for film-screen and digital imaging.
67. **MQSA Requirements**

Film-screen mammography, FFDM and mobile mammography all are included in the mandatory requirements of the MQSA. Accreditation of mammographic breast interventional equipment still is voluntary. QC tests must be performed for the mammographic equipment, along with the display and printer equipment.

Manufacturers of mammographic equipment work closely with the FDA following specific equipment specifications mandated through the MQSA regulations. These specifications refer to the following equipment features:

- Motion of tube-image receptor assembly.
- Image receptor size.
- Light fields.
- Magnification.
- Focal spot selection.
- Compression.
- Technique factor selection and display.
- AEC.
- Film, for film-screen only.
- Lighting.
- Film masking devices.

When the manufacturers develop mammographic equipment adhering to these well-established equipment standards, the quality of mammography services provided nationally is more easily ensured. In addition, the continuing QC tests are standardized, which means the FDA receives more uniform reports.

68. **Quality Assurance**

Quality assurance (QA) is a continuous program comprising various tests designed to ensure the safety, reliability, clarity and accuracy of mammography services. The FDA, through the MQSA, requires documentation of continuous QA efforts from all facilities. Equipment QA records include documentation of the following: frequency of monitoring, recording of the data, problems detected by analysis of that data, corrective actions taken and the effectiveness of the corrective actions. Each facility must maintain personnel records documenting initial qualifications and continuous qualifications to perform patient examinations, interpret examinations or to evaluate and maintain the mammography equipment.

QA records are properly updated and maintained by the facility for annual inspection by the FDA. The records should be kept until the next annual inspection has been completed and the FDA has determined that the facility is in compliance with QA requirements or until the test has been performed 2 additional times at the required frequency, whichever is longer.

69. **Testing**

Testing for digital mammography is recommended daily, weekly, quarterly, semi-annually or annually, depending on the test. These frequencies were selected based on the need to recognize degradation in quality of performance counterbalanced with the increased labor costs to perform the testing. With the various types of digital detectors available from different manufacturers, MQSA standards recommend that facilities follow the vendor-specific QC
manufacturers. Manufacturers have patterned their QC manuals after the MQSA recommendations and have adhered to the established requirements. Absolute uniformity does not exist between vendors in QC testing procedures.

70. **Testing**
Because digital mammography separates the functions of acquisition and display, but analog mammography functions are integrated, differences in QC testing exist between system types. The following section includes descriptions of specific QC tests required for each type of equipment used in the digital mammography process. These descriptions include the frequency of testing and the people responsible for performing the specific test. Even manufacturers of monitors, printers and FFDM equipment may vary in their recommendations for QA. For this reason it is imperative that mammographers precisely follow the department’s current QC manual for each unit.

71. **Monitor Check**
Monitor cleaning is recommended daily by most monitor manufacturers. Mammographers should follow the specific recommended method for cleaning each monitor, including acquisitions and review workstation monitors. The mammographer who performs the cleaning should record the date the action was performed on the appropriate forms required by the facility. A test pattern should be viewed on the display monitor to ensure that there is no distortion of the image and that proper contrast and brightness can be seen.

72. **Printer QC Test**
A laser imager or DICOM printer QC test should be performed weekly or after preventive maintenance, service or a software change occurs for the printer or the digital mammography equipment. This test replaces the processor QC tests in film-screen mammography. Performance of this test measures the optical density of the printed laser film and is used to track visual stability over time. Much like film sensitometry, a densitometer is used to measure the densities on a test strip. In the case of digital mammography, a Society of Motion Picture and Television Engineers (SMPTE) pattern is generally used. Optical measurements are taken at 3 different locations on the SMPTE pattern and are used to calculate a mid-density point, a low-density point and a density difference. The information is then recorded on the proper vendor-provided data collection worksheet. The control limits are plus or minus 0.15 on all 3 values.

If the results of the pattern test fall outside the control limits the printer should be recalibrated and the test repeated. If results remain outside control limits a DICOM-qualified repair engineer must identify and correct the problem. The test must be repeated to document the effectiveness of the repair before any images can be printed. Most importantly, the facility must follow manufacturer-specific recommendations for QC and corrective actions.

73. **Detector Flat-Field Calibration**
Detector flat-field calibration helps ensure that the detector system is calibrated properly. This calibration corrects for nonuniformities in the detector elements. The calibration process sends x-ray energy through a known uniform attenuation block of vendor-supplied acrylic and measures each detector element’s response. It then makes a correction mask that adjusts each detector element to produce an even response across the entire image matrix. If the test fails, the mammographer should first ensure that a proper technique has been followed and then
repeat the test. If the test continues to fail, the unit cannot be used for patient imaging and a qualified service engineer should be contacted.

74. **Flat-field Artifact Evaluation**

Flat-field artifact evaluation should be completed before the weekly phantom image evaluation. This test evaluates the image field on the workstation and DICOM printer for any unwanted artifacts that could degrade image quality. It is performed using a vendor-supplied uniform attenuation block acrylic phantom with a fixed exposure technique and uses various target/filter combinations. The various steps involved, which are specified by the vendor, produce exposures using each target and filter and provide multiple uniform gray images to be evaluated for artifacts.

75. **Flat-field Artifact Evaluation**

At the acquisition workstation, the mammographer evaluates the images for artifacts. If there are no artifacts, the tester should document the date of the test and the absence of artifacts. If artifacts are displayed, the tester should rotate the acrylic phantom 180° and repeat the test using the same exposure used on the image containing the artifact. If the artifacts change location, they are located within the phantom and do not indicate system performance problems. If the artifacts remain visible, they most likely are the result of a problem in the x-ray system or detector system.

The mammographer should first perform a detector calibration test and then repeat the artifact evaluation test. If the artifacts are not resolved, staff should contact the department's medical physicist for an artifact evaluation analysis. If a radiologist determines that the artifacts do not affect clinical quality the unit can continue to be used and a qualified service engineer must correct the problem within 30 days. Persistent phantom artifacts can affect the detector flat-field calibration test, therefore the phantom should be considered for replacement.

76. **System Resolution Tests**

System resolution tests are designed to help ensure that adjacent structures are displayed as being separate, or that they have distinct edges. In FFDM, the modulation transfer function (MTF) is a test that can be used to determine spatial resolution. The MTF describes quantitatively how well a system can transfer the fine detail needed to maintain distinctions between adjacent structures. Testing of MTF is not required by all manufacturers, and there are multiple methods and phantoms used to evaluate MTF. Use of the MTF may help detect problems with the focal spot or synchronization errors. The higher a system's MTF, the better an image's sharpness and resolution.

77. **System Noise Ratio Tests**

Signal-to-noise ratio and contrast-to-noise ratio measurements are additional resolution parameters that should be tested weekly to document detector consistency. The QC tests used to measure results for these 2 properties are performed simultaneously using the same phantom image. Most vendors use the ACR Mammographic Accreditation Phantom. It is important to follow vendor-specific instructions, but for the test example we will use the ACR phantom.

The mammographer acquires an image using a standard phantom technique and places regions of interest on the image. Density measurements are taken in 3 different areas within the
phantom and are used to calculate the signal-to-noise and contrast-to-noise ratios. The signal-to-noise ratio calculation must be equal to or greater than 40. If the signal-to-noise ratio is lower than 40, the department must take corrective action. The first corrective step is to repeat the process and recalculate to ensure the mammographer receives the same results.

The baseline contrast-to-noise ratio is determined at equipment installation and must be readjusted after any of the following occurrences: detector replacement, detector modification, AEC dose adjustment, ACR phantom replacement or alteration, or any other reason the medical physicist believes may affect the contrast-to-noise ratio. Corrective action must be taken and recorded if the contrast-to-noise ratio deviates from the baseline by 15% or more. If both tests do not pass the requirements listed above the unit may not be used for patient imaging, and a qualified service engineer must be called.

78. **Monitor Calibration QC**
Monitor calibration QC and SMPTE pattern evaluation are important tests that ensure the high-quality images acquired by the FFDM equipment are displayed at the same level of quality. Mammographers should test monitors at least weekly to be sure that viewing conditions are appropriate for the specific workstations.

Most vendors supply the necessary equipment for monitor testing. The vendors calibrate the monitors and set operating levels at installation. Subsequent testing is compared by internal software to those installation levels to ensure consistent brightness and contrast capabilities. The SMPTE pattern is used to measure the range of contrast and spatial resolution the monitor is capable of recognizing over a wide dynamic range. It is very important to follow vendor-specific guidelines for QC and corrective actions.

79. **Knowledge Check**
Answer the following question.

80. **Medical Physicist Responsibilities**
The medical physicist's responsibilities begin when a digital mammography unit is first installed and are repeated annually, or when the machine is moved or modified. These responsibilities include, but are not limited to, setting and communicating operating levels and control limits for the QC technologist, personally performing QC tests at least annually and evaluating technologist QC results quarterly.

81. **Medical Physicist Tests**
The medical physicist evaluates FFDM equipment for proper patient radiation dose levels and ensures the unit is operating at optimum levels for both safety and efficiency. The tests listed on this page are the annual tests that a medical physicist is required to complete. Although a mammographer or QC technologist never performs these annual tests independent of a medical physicist, they are the same or similar to the daily, weekly, monthly and quarterly tests completed by the QC technologist or mammographer. A thorough understanding of these tests allows a mammographer to provide assistance to identify changes in equipment that occur over time.

82. **Future of Mammography**
Xeromammography, film-screen mammography and FFDM are precursors to a new and evolving breast imaging modality called digital breast tomosynthesis. The value of any screening breast imaging technique lies in its ability to detect breast abnormalities, or sensitivity, and its ability to recognize differences between benign and malignant disease, which is referred to as specificity.

It is believed that increased use of digital breast tomosynthesis will increase breast cancer detection rates, reduce callback rates, reduce the number of unnecessary biopsies, provide faster review time and reduce the amount of breast compression currently required in mammography. Digital breast tomosynthesis combines the principles of CT with new digital detector technology to create multiple 3-D breast images.

83. Digital Breast Tomosynthesis
Tomography is a technique in which the x-ray tube and the image receptor move in opposite directions simultaneously. One 2-D image is obtained from each exposure. A fulcrum, or center of rotation, is set before the movement begins and any structure above or below the center of rotation is eliminated, leaving the structure at the level of the center of rotation visible.

The concept of tomosynthesis is similar in that the tube moves within a defined arc and takes a specified number of images; however, the digital detector remains stationary. A tomosynthesis image can provide a 3-D breast image that is created from the reconstruction of the multiple digitally acquired images. The mammographer sets a center of rotation before image acquisition, although postprocessing allows additional selection of levels within the breast without acquiring additional images. Unlike CT and magnetic resonance, images cannot be reconstructed in an alternate imaging plane.

84. Advantages and Disadvantages
Advantages of digital breast tomosynthesis include the ability to evaluate dense breast tissue and reduce callbacks by recognizing tissue superimpositions as artifacts rather than abnormalities. This is expected to increase the sensitivity, specificity and breast cancer detection rate potentially decreasing recall rates, and therefore radiation dose. The technology also could increase patient tolerance for mammography.

There are some trade-offs to this new technology, however. For instance, if the degree of arc is increased, the slice separation also increases and some breast tissue could be missed. In addition, the larger the arc the longer the exposure time, which can be as long as 7 seconds. This increases the risk of patient motion.

Additional disadvantages of digital breast tomosynthesis are the high load on the x-ray tubes from increased exposure times and slightly higher radiation dose to the patient for typical examinations compared with typical FFDM examinations.

One manufacturer of digital breast tomosynthesis equipment has already received approval for use by the FDA and it is expected we will see DBT being performed in many mammography facilities in the near future. Unlike the transition from film-screen mammography to FFDM, the integration of digital breast tomosynthesis into mammography facilities should be smoother for those facilities that currently provide digital mammography services.

85. Conclusion
Full-field digital mammography brought detector technology and improved display capabilities, both of which paved the way for digital breast tomosynthesis technology. Although digital mammography is an exciting and quickly evolving aspect of breast imaging, the single most important component to any mammographic examination is the mammographer, who works closely with the patient to ensure a high-quality and safe examination.

86. Conclusion
This concludes Module 10 of Breast Imaging Basics – Digital Mammography. You should now be able to:
- Explain the theory behind producing, acquiring, and displaying digital mammograms.
- Discuss the benefits of full field digital mammography (FFDM) for both the patient and breast imaging staff.
- List quality assurance tests that are specific to digital mammography.
- Describe the quality assurance testing done by the medical physicist.

87. Bibliography
88. Bibliography
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