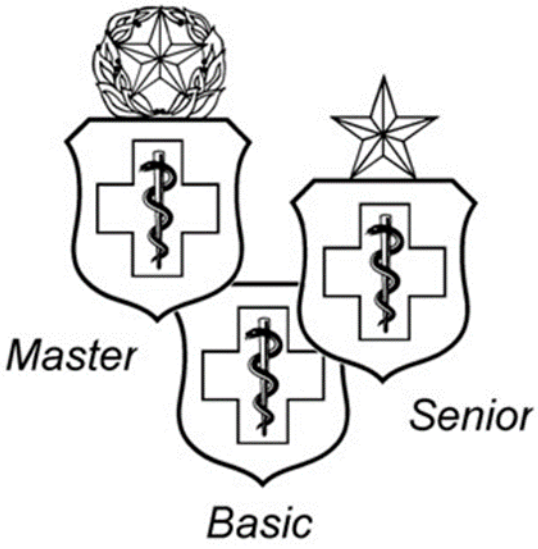
Diagnostic Imaging Testing For SSgt/TSgt



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Material in this volume is reviewed annually for technical accuracy, adequacy, and currency. For SKT purposes the examinee should check the *Enlisted Promotions References and Requirements Catalog* located at https://www.studyguides.af.mil to determine the correct references to study. The information in this study guide has been certified by the office of Diagnostic Imaging Career Field Manager.

This study guide—*Diagnostic Imaging Testing for SSgt and TSgt*, is devoted to digital radiography concepts and specialty imaging within Diagnostic Imaging (DI). The guide begins with the Promotion to SSgt/TSgt section and includes lessons on picture archiving and communication system (PACS), fluoroscopy, mobile radiography, and bone densitometry, computed tomography (CT), quality management, principles of image quality, and ionizing radiation protection. While not everyone agrees on which procedures are "special" and which are "routine," the procedures covered in these volumes are not performed at every USAF DI facility. A detailed explanation of the step-by-step procedures involved in each of the examinations covered is not possible due to the wide variety of personal preference amongst radiologists. Therefore, learning concentration is on their general principles and function.

Though your duty station may not include fluoroscopy, mobile imaging, mammography, bone densitometry, or CT, understanding these aspects of DI is important for your progression as a technologist and your career as a future leader. It is also likely that at some point in your USAF DI career, you will be stationed at a facility with these imaging services.

The next section, Promotion to TSgt, concentrates on the knowledge, skills, and behaviors necessary for the NCOIC or Flight Chief position in the Diagnostic Imaging career field. This section includes professionalism, legal, and ethical aspects of radiology, joint review committee on education in radiologic technology, diagnostic imaging regulating authorities, nuclear medicine, diagnostic medical sonography, and magnetic resonance imaging (MRI).

Again, though your duty station may not include all the above modalities, knowledge of these aspects of DI are important for progression to the grade of Technical Sergeant and assignment to the flight chief position. It is not in the scope of this guide to include all technical aspects of DI modalities, but rather provide the knowledge necessary to make managerial decisions. It will still be crucial to rely on modality NCOICs and subject matter experts to augment the information provided in this study guide to make the most informed decision.

A glossary is included for your use.

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Date	**American Registry of Radiologic Technologists Document Title**	**American Registry of Radiologic Technologists Standards Location**	**CDC Location**
2014	ARRT Standards of Ethics	Page 1, Standard 7	Unit 3

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section.

Testing for SSgt/TSgt

Page

Unit 1. Digital Radiography and Picture Archiving and Communication System.....1
1A Digital Radiography Concepts.....1
1B Picture Archiving and Communication System.....18
Unit 2. Fluoroscopy, Mobile Radiography and Bone Densitometry.....31
2A Fluoroscopy.....31
2B Mobile Radiography.....38
2C Bone Densitometry.....46
Unit 3. Computed Tomography.....57
3A Fundamentals of Computed Tomography.....57
3B Computed Tomography System Components.....74
3C Patient Preparation and Radiation Safety.....84
Unit 4. Quality Management.....93
4A Quality Assurance.....93
4B Quality Control.....102
Unit 5. Principles of Image Quality.....112
5A Radiographic Density.....112
5B Radiographic Contrast.....114
5C Controlling the Useful Beam.....118
5D The Effect of Geometric Factors on the Image.....130
Unit 6. Ionizing Radiation Protection.....136
6A Roles and Responsibilities.....137
6B Radiation Protection….....140

Promotion to TSgt Contents.....145

Unit 7. Professionalism, Legal, and Ethical Aspects of Radiology.....147
7A Professional Interaction Considerations.....147
7B Patient Information and Privacy.....155
Unit 8. Joint Review Committee on Education in Radiologic Technology.....163
8A Standards for an Accredited Educational Program in Radiography.....163
Unit 9. Diagnostic Imaging Regulating Authorities.....167
9A U.S. Nuclear Regulatory Commission.....166
9B Food and Drug Administration.....168
Unit 10. Nuclear Medicine.....170
10A Federal Regulations and Radiation Protection.....170
10B Generators and Radiopharmaceutical Shielding.....172
10C Patient Examinations.....173
Unit 11. Diagnostic Medical Sonography.....178
11A Patient Examinations.....178
11B Cidex/Trophon.....182
Unit 12. Magnetic Resonance Imaging (MRI).....183

12A Equipment Safety Zones....183
12B Patient Examinations....187
Unit 13. Mammography....190
13A Mammography....190

Glossary....G–1

Unit 1. Digital Radiography and Picture Archiving and Communication System

1A Digital Radiography Concepts.....1
1.1 Computed radiography 1
1.2 Direct radiography 5
1.3 Acquiring digital images.....9
1.4 Digital image processing 13
1B Picture Archiving and Communication System..... 18
1.5 Picture archiving and communication system overview.....18
1.6 Composite Health Care System 23
1.7 System downtime functions..... 25

Technology is ever-changing. As you are reading this unit, new X-radiation (X-ray) equipment is being installed somewhere at a medical facility. Computed radiography (CR) and direct radiography (DR), in conjunction with a picture archiving and communication system (PACS), are the latest and greatest technological advances to improve the field of Diagnostic Imaging (DI). Some professionals consider digital imaging to be the most notable breakthrough in DI since computed tomography (CT). Using advanced technologies, digital radiography provides many imaging options that conventional X-ray systems do not afford us.

Since the discovery of X-rays in 1895, digital radiography has provided some of the most technical advancements in how X-ray images are produced, viewed, and stored. In the early 1970s, researchers began to develop a system allowing the manipulation and storage of digital X-ray images. Back then, technology of the time hampered digital radiography advancements. Computers didn't have enough memory or processing capabilities to crunch the large amounts of data produced with digital imaging. It wasn't until the early 1980s that microprocessor technology and memory advancements in computers allowed digital radiography and PACS to become a reality.

This unit of instruction is dedicated to a thorough discussion of basic digital radiography concepts and PACS. We begin with digital radiography!

1A Digital Radiography Concepts

Digital radiography is a filmless concept for acquiring radiographic images using X-ray. Digital radiography systems, in the form of CR and DR, eliminate chemical processing while producing digital images. CR replaces film-screen combinations with a photostimulable phosphor screen inside a cassette housing, while DR replaces film-screen combinations and CR entirely with a fixed flat-panel electronic detector or charge-coupled device (CCD). In this section, we will discuss CR, DR, acquiring digital images, and digital image processing.

1.1 Computed radiography

CR uses the same type of X-ray tube, exposure control systems, and cassette holders as in conventional radiography. CR cassette sizes match those available in traditional film-screen cassettes. This lesson compares CR to conventional radiography, discusses digital signal conversion, CR imaging plates, and digitizing the image. Most of you reading this material have never used film-screen combinations; therefore, it is relevant to begin by comparing film-screen combinations to CR.

Computed radiography versus conventional radiography

When compared to CR, conventional radiography has several disadvantages: length of processing time, no image manipulation once film is processed, and large amounts of physical space needed to store all the hard-copy X-ray images. In conventional radiography, intensifying screens convert X-ray photons into light, and then the light exposes film to create an image (fig. 1–1).

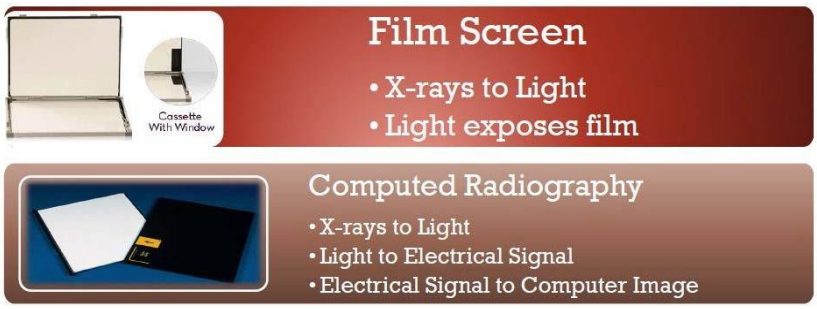


Figure 1–1. Film-screen and CR comparison.

With CR, remnant radiation from the primary X-ray beam interacts with a photostimulable phosphor screen inside a rugged cassette housing to record a latent image. The cassette with the exposed photostimulable phosphor screen is placed in a digital processing unit that reads the screen by scanning it with a helium-neon laser, which causes the photostimulable phosphor screen to emit light that is captured by a photomultiplier tube. A computer then processes the light information, in the form of electronic signals, into a digital X-ray image. The photostimulable phosphor screen is then erased only to be used again. The digital image is transferred electronically via a computer network to a PACS. The PACS stores and transmits the digital images via a computer network to radiologists and health care providers, allowing them to view and interpret the images for patient diagnosis and treatment.

CR reduces image-processing time from 90 seconds to approximately 30 seconds per image. It eliminates processor chemicals, which reduces operational costs and the danger of hazardous material exposure. You can only view hard-copy images from wherever the piece of film is located. With CR and PACS, images can be viewed in multiple locations, simultaneously via computer monitors.

Since CR images are digital, postprocessing manipulation of an image is now possible with a computer mouse and software included with the PACS. This allows minor adjustments to be made to the image scale of contrast during postprocessing versus having to repeat an image because of improper technique selection. Scale of contrast adjustments are made possible because CR photostimulable phosphor screens have extremely high exposure latitude, which allows for thousands of gray levels to be visualized.

Having such high-exposure (wide) latitude is definitely a benefit of CR, which allows diagnostic images to be acquired, even in the case of slightly under or overexposed radiographs. The broad, dynamic range of CR also allows the visualization of both bone and soft tissue structures on a single radiograph. This benefit affords the option of using one image for several different reasons. For example, someone’s hand getting stuck in an industrial machine and smashing several hand bones.

When an emergency room doctor orders X-rays, he or she also wants to see if there are any metal shavings or free air in the hand. Because of CR’s flexibility, a single image can be manipulated to change contrast, density, and to magnify a specific area of the image. The entire study can be completed with one examination instead of three. Being able to manipulate the processed image reduces repeated exams, patient exam times, and patient exposure dose rates.

CR also solves massive storage issues inherent to any film-screen department. A film library (file room) holding hundreds of thousands (or millions) of hard-copy films is now reduced to a mere fraction of the space since only a small room is needed to house the vertical computer server towers

(Fig. 1–2), which essentially becomes the film library. In addition the days of lost films due to misfiling, or films not being returned to the department, are now a thing of the past.

As with any technology, advances come at a price. Though the initial investment is quite substantial, small and large facilities are able to reap the benefits of digital imaging systems. Manpower requirements are reduced, film and chemical processing costs are eliminated, and facilities are become more efficient, which equates to an increase in patient load and, subsequently, income. Another aspect of reduced manpower requirements is from the radiologist's point of view. With CR, smaller facilities no longer need a radiologist on site to read images. CR images can be sent electronically to larger facilities for images to be remotely read and interpreted. So how do all these digital images get from one place to the next?

Digital signal conversion

At the time of inception, the basic accepted CR mode was to place a computer between the camera and the television monitor of a conventional fluoroscopic unit. The signal information was intercepted and manipulated by the computer before it reached the television monitor. The CR signal was acquired in an analog format, converted to a digital format, and manipulated and stored, then converted back to analog to be displayed on a monitor. The purpose of an analog-to-digital converter (ADC) is to change the analog image information into a binary code (a digital signal) so the computer can read it. Once in a digital form, the data can be manipulated by computers and then stored. After data manipulation, the resultant digital information is converted back to an analog state to visualize on a monitor. For this task, a digital-to-analog converter (DAC) is used.

Analog-to-digital conversion

The light signal that is emitted by the photostimulable phosphor screen is captured and converted to an electrical signal (a voltage). At this point, the electrical voltage signal is in analog form. For the computer to be able to use the information, the input signal must be converted to a digital format. Specifically, the computer assigns a number to each signal based upon the strength of the signal. This process is achieved with an ADC. The actual component where the signal is converted is an integrated circuit, similar to the ones found in personal computers.

Digital-to-analog conversion

The digital signal must then be converted back from a series of pulses to an analog voltage, so the information can be displayed on a monitor. Though newer monitors have the capability to receive and display a digital signal, many radiology monitors still require the digital signal to be converted to an analog signal because of the type of cable transferring the image signal. If the monitor receives the signal in an analog format, then a DAC in the receiver changes the signal before it is sent to the

monitor. The DAC in the digital-processing unit is responsible for this function in CR. The actual conversion is achieved using the same integrated circuit technology found in ADC.

Computed radiography imaging plates

As stated previously, CR uses the same type of X-ray tube, exposure control systems, and cassette holders as in conventional radiography. The cassettes used in CR look similar to the ones used for conventional radiography and are used exactly the same way in fixed or mobile CR. The term *imaging plate* (IP), as used in CR, actually refers to the combination of the cassette housing and the photostimulable phosphor screen located inside. The cassette provides a sturdy, protective housing for the photostimulable phosphor screen. CR *photostimulable phosphor* screens are made of barium fluorohalide coated with a trace amount of europium.

Europium is the most reactive, rare earth element, and it is responsible for the storage characteristics of the phenomenon known as photostimulable luminescence. *Photostimulable luminescence* is a process that allows stored light, following X-ray exposure, to be emitted later when exposed to a different type of light source. In digital radiography, the other light source is normally infrared light from a laser.

The photostimulable phosphor screen is constructed in much the same manner as a radiographic intensifying screen. Again, though, the intensifying screen and photostimulable phosphor screen have different functions. While intensifying screens emit light in response to X-ray interaction, photostimulable phosphor screens store the response to X-ray interaction by capturing the latent image as trapped electrons within photostimulable phosphors.

After an exposure is made, the cassette, with its photostimulable phosphor screen inside, must be processed to read the latent image. The photostimulable phosphor screen is capable of retaining the stored information for up to six hours, with little image quality degradation. Photostimulable phosphor screens, used in CR, are two to four times more efficient than the fastest, rare earth film-screen combination. The life expectancy of a photostimulable phosphor screen is about 10,000 exposures, depending on the individual workload and maintenance of each IP.

Using photostimulable phosphor screens drastically cuts repeat rates while also decreasing patient exposure doses. There is much greater exposure latitude when using photostimulable phosphor screens versus conventional X-ray film. The increased exposure latitude of photostimulable phosphor screens allow for a greater margin of error in technique selection for the technologist.

Digitizing the signal

In CR, the IP is exposed to the remnant radiation from the useful X-ray beam. When the IP reader processes the photostimulable phosphor screen, a laser is used to scan the screen and lift the latent image in the form of light. The scanning process results in converting light from the photostimulable phosphor to an electrical signal. For each light photon, an assigned numerical value represents the intensity of the light for that individual pixel or picture element. Imagine a pixel as a single square on the photostimulable phosphor screen.

Now imagine the entire surface of an entire screen as a matrix of many squares, each correlating to a specific area on the screen. Each square (pixel) also correlates to a specific area of the exposed body part. When all the pixels are scanned, and numerical values are assigned, they are eventually all combined (to piece together) and form the digital data for that particular image. Typical matrix displays in radiography are around 2500 x 2500. In other words, imagine 2,500 squares traversing the photostimulable phosphor screen from top to bottom and another 2,500 squares traversing the screen from side to side for 6,250,000 total squares (pixels).

As the laser in the reader scans each pixel in the matrix, it releases bits of information according to each pixel's bit depth. Bit depth refers to the number of gray shades available for each pixel. For example, if a pixel's assigned bit depth is eight (8), then that means the pixel can create two gray

tones to the power of eight, which equals 256 shades of grays that are available for that particular pixel.

$$2^8 = 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 256$$

The gray tones determine the quality of a digital image, and each pixel is capable of having a gray tone from one to 4,096, depending upon the bit depth for each pixel.

Computed radiography workload process

With CR, patient throughput increases due to a reduction in processing time and the elimination of the darkroom environment. Figure 1–3 demonstrates the CR process from start to finish.

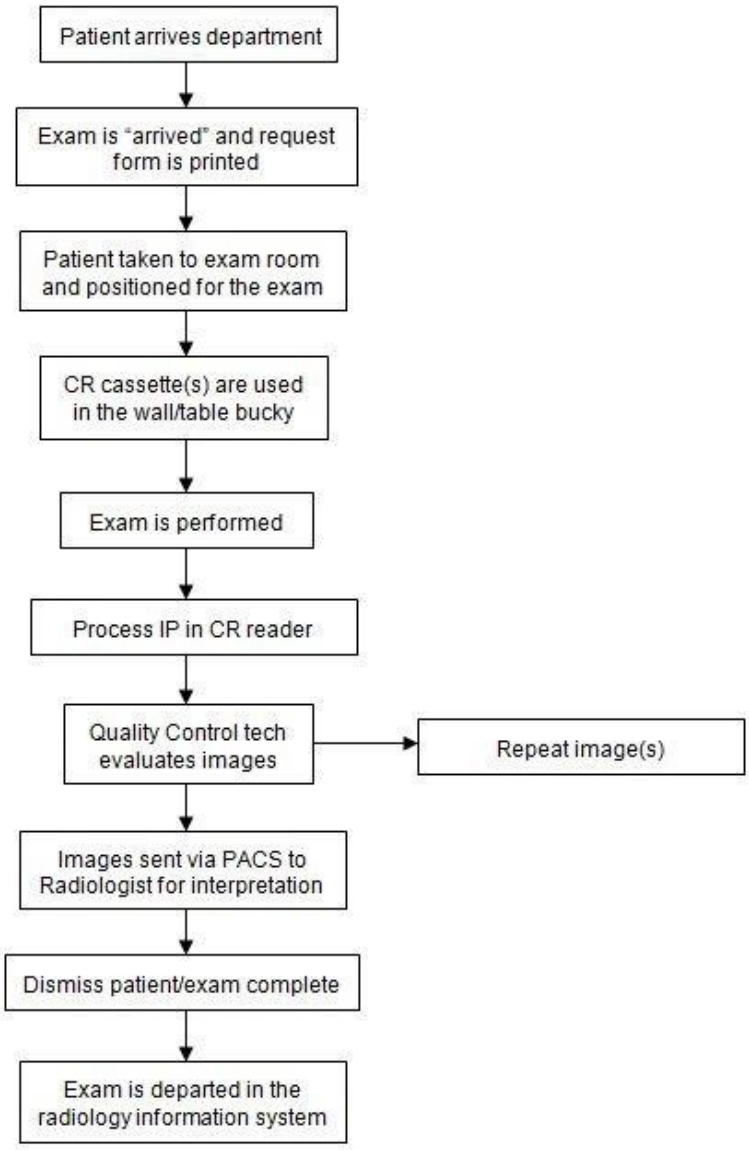


Figure 1–3. CR workflow process.

1.2 Direct radiography

After introducing third-generation CT imaging systems, scanned projection radiography was introduced to improve CT patient positioning. Scanned projection radiography basically allowed for a digital image (a scout or localizer) to be obtained by moving the CT patient couch through the gantry while the X-ray tube is energized without rotating the tube and detector array. The scout CT image

was a precursor to direct imaging, which allowed for many technological advances in the years that followed. DR removes the need for cassettes and IP processors, taking the advancements of CR another step. In this lesson, we will discuss the fundamental concepts of DR, flat-panel image receptors, and improvements in DI workflow.

Fundamental concepts behind direct radiography

DR, born of third-generation CT systems, eliminates the need for cassettes and photostimulable phosphor screens. In DR, a solid-state–flat-panel receptor, or CCD, is used to receive and measure the remnant radiation and, in turn, form the data into a digital image. No longer is a darkroom or IP reader needed to process images into a viewable form because DR image receptors are built into the X-ray table or vertical receptor apparatus (wall bucky). In addition, high-speed computers process the remnant radiation, transmit the data in the form of electronic signals, and display the image on a monitor for viewing immediately.

The CR capture element is the photostimulable phosphor; in DR, the **capture** element is a flat-panel receptor made up of cesium iodide (CsI) tiled to a CCD array, CsI and an amorphous silicon thin-film transistor, gadolinium oxysulfide and an amorphous silicon thin-film transistor, or amorphous selenium active matrix array, depending on the type of system installed. After the remnant radiation is captured, the electronic signals generated by the X-ray must be sent to the collection component. This is accomplished by using a **coupling** element via a fiber optic assembly or a contact layer. The last part of the DR image receptor is the specific **collection** element; this can be a photodiode, a CCD, or a thin-film transistor.

Photodiodes are semiconducting devices that convert light into current. A *CCD* is a device that allows the movement of an electrical charge. Photodiodes and CCDs are light-sensitive devices used to gather light photons. A *thin-film transistor* is a special kind of field-effect transistor that is made of a semiconducting layer (commonly amorphous silicon) sandwiched between (or painted on the surface of) supporting, non-conducting layers (commonly glass). Thin-film transistors are sensitive to *charges*; therefore, they gather electrons.

Scintillation is the process of emitting light. In typical screen-film radiography, the scintillator is the intensifying screen within the cassette. In CR, the scintillator is the photostimulable phosphors within the screen. In DR, the most common scintillator is CsI because it focuses light into a very narrow (or needle-like) area that reduces the lateral light spreading. CsI also allows thicker scintillators to be used without a large amount of degraded spatial resolution.

Flat-panel image receptors

Flat-panel image receptors incorporate the use of an X-ray absorbent material, which is then coupled to a CCD, or thin-film transistor, to create an image you can immediately visualize on a monitor at the control console. Flat-panel image receptors are categorized as either indirect or direct capture devices.

Indirect capture receptors

Indirect capture receptors change remnant radiation into light (fig. 1–4). A CCD, or thin-film transistor (scintillator), then collects the light and changes it to an electrical signal that is sent to a computer for processing and visualization in the form of an image on a monitor. A cesium iodide

Figure 1–4. Indirect capture digital radiography.

CCD array is an example of an indirect capture device. In this type of image receptor, CCDs (fig. 1–5) are tiled (connected together) to accept light from an X-ray beam as they interact with cesium iodide. The captured light is then transmitted, via fiber-optic bundles, to the CCD array, resulting in good image spatial resolution.

NOTE: Notice the acronym CsI, on figure 1–5. It refers to cesium iodide.

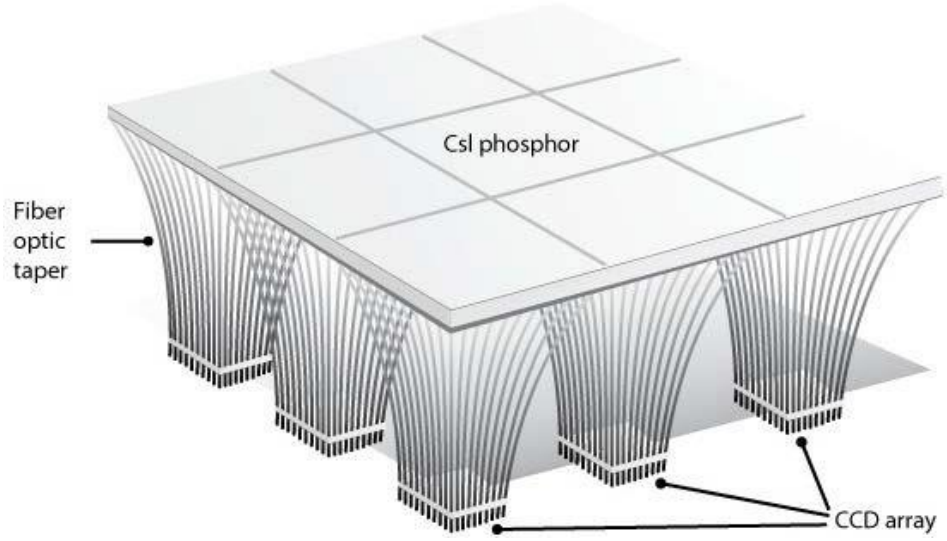


Figure 1–5. CCD array with fiber-optic bundles illustration.

NOTE: *CR* and *indirect* radiography convert X-rays to light, light to electrical charges, electric charges to a number (binary) code, and create an image to be displayed that corresponds to the number code via a matrix.

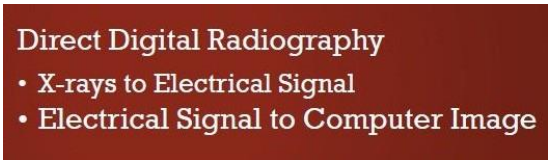


Figure 1–6. Direct capture digital radiography.

Direct capture receptors

Direct capture receptors change remnant radiation directly into electrical signals, which are sent to a thin-film transistor (fig. 1–6). From the thin-film transistor, an ADC sends the electrical signal to a computer for processing and for visualizing in the form of an image on a monitor. Amorphous selenium is referred to as direct capture DR because no phosphor-emitting light is involved in creating an image. With amorphous selenium flat-panel image receptors, the X-ray beam's interaction with the amorphous selenium element creates charged ion pairs (an electric signal) that acts as both the capture and coupling element. This type of flat-panel array is commonly referred to as an active matrix array of thin-film transistors (fig. 1–7).

Direct radiography workload process

As we previously discussed, CR increases patient throughput due to decreased IP processing time and the elimination of the darkroom. However, in DR, more steps in the workload process are eliminated, like loading the cassette into the bucky, placing the cassette in the reader to be processed, and having to wait for the phosphor screen to be reloaded into the cassette. Eliminating these additional steps makes DR even more efficient at processing patients in and out of the DI department. Figure 1–8 demonstrates the DR process from start to finish.

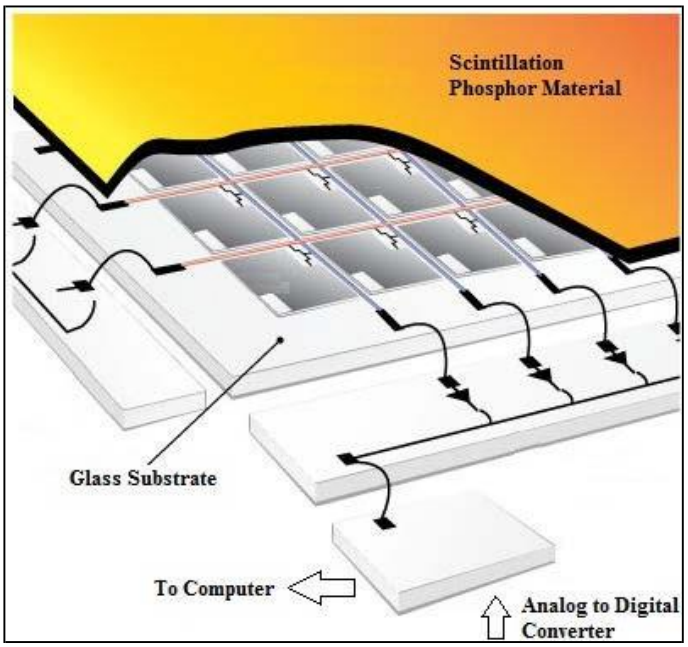


Figure 1–7. Active matrix array of thin-film transistors illustration.

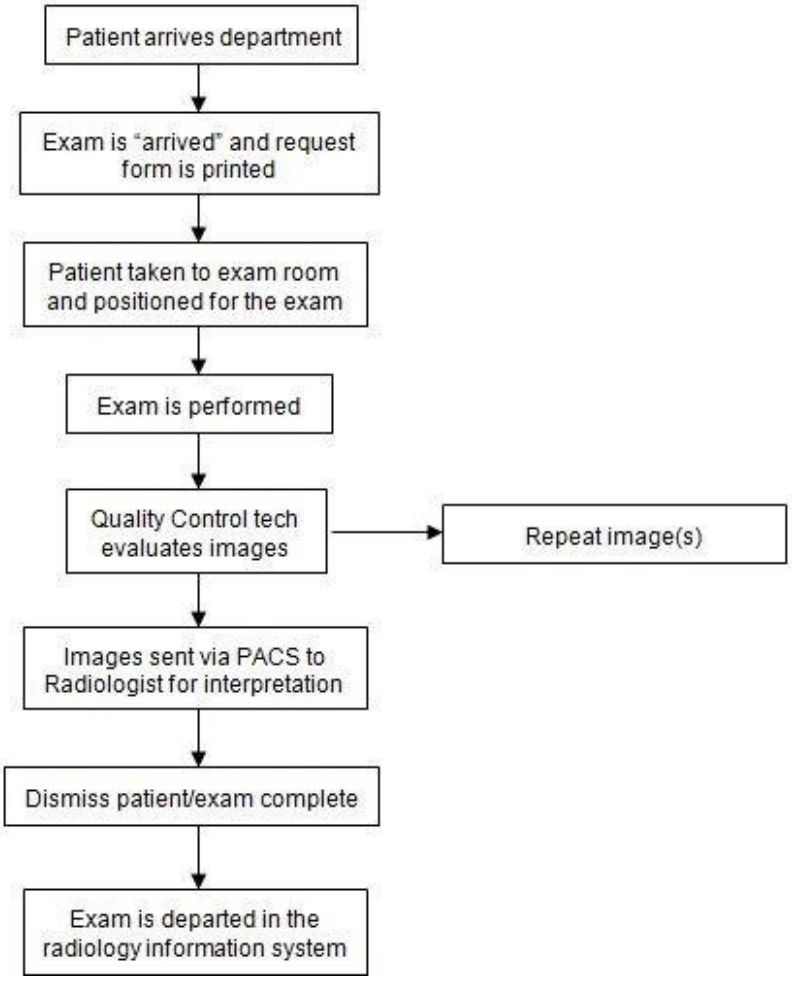


Figure 1–8. DR workflow process.

1.3 Acquiring digital images

Acquiring a digital radiograph is not that different from conventional film-screen radiography. By this point in your imaging career, you have done countless fixed and mobile exposures. Each time you acquired an image in a logical fashion, you represented proper training by your instructors and preceptors. This lesson lays out certain aspects you should already consider when acquiring a digital (CR or DR) image. We begin with acquiring a CR image.

How to acquire computed radiography images

During the acquisition of digital images, certain things should be considered: IP size selection, type of grid to use, appropriate lead marker use, how much to collimate, and kinds of technique to use. These steps have likely become second nature, due to the countless times they have been performed in the past, you perform these steps without much thought because they have become second nature.

Select an imaging plate

Since cassettes are still used with CR image acquisition, you must select the type and size of the IP that is appropriate for the body part you are imaging. Depending upon what your department has available, you may have to choose from one of two kinds of IP types: standard or high resolution.
High-resolution cassettes contain a photostimulable phosphor screen with a thinner phosphor layer, which results in better image sharpness due to a lower amount of lateral light leak. Lateral light leak causes the finished image to appear more blurry. As you know from previous material, CR images are displayed as a matrix containing up to 6,250,000 pixels. Field size directly affects spatial resolution of a digital image.

For example, as the field size decreases, the image's spatial resolution increases. Therefore, after choosing the type of cassette, it is important to choose the smallest cassette (field size) that will cover the body part. This will make sure the spatial resolution will be at its greatest for that particular image.

Select a grid

Understanding that the reader scans digital CR images row by row means images are displayed as very small pixel lines from one side to the other. For this reason, stationary grids can project grid lines onto the digital image and reduce image quality in the form of an artifact known as the *moiré pattern*. The moiré pattern artifact is displayed when the photostimulable phosphor screen is scanned parallel to stationary grid lines. The use of moving grids in a bucky system eliminates the moiré artifact and, therefore, is preferred.

When selecting a grid, always consider the frequency, ratio, and focus. For digital imaging, it is best to choose a higher grid frequency (more lines per square inch). Next, choose a high grid ratio (12:1) for fixed radiographic imaging and a low grid ratio (6:1) for mobile imaging to effectively reduce the amount of scatter radiation reaching the receptor. Lastly, note whether the grid choice is focused or unfocused. While unfocused (parallel) grids are less sensitive to lateral decentering, they should not be used at less than a 48-inch source-to-image distance (SID). Likewise, make sure to pay attention to the focal point of a focused grid.

Collimate

Always collimate (reduce the field size) the useful beam to only what is needed to properly expose the body part. Excessively large collimation only increases the volume of tissue being irradiated and the amount of scatter radiation produced. Selecting an appropriate collimation size increases image contrast resolution and reduces scatter radiation.

Lead marker use

Always use the correct right or left permanent lead marker while acquiring your radiographic image.

Using the computer to mark the right or left side during postprocessing is not acceptable if your images are ever used in a court of law. Make a habit of selecting and placing the appropriate marker on the cassette within the collimated field every time.

Select a technique

Technique selection with digital imaging is, for the most part, the same as with conventional film-screen radiography. Penetrability of the useful beam is still determined by the energy of the beam or in other words, your selected kilovoltage peak (kVp) setting. In CR, the optimal kVp range is typically between 60 and 110. Though kVp settings are used above and below this range, it is possible to cause too much or too little phosphor excitation; however, in digital radiography kVp does not necessarily correlate to the scale of contrast as in conventional radiography. Remember, contrast in CR is determined by the bit level of each pixel in the photostimulable phosphor screen and computer processing algorithms selected during processing.

Milliamperage and seconds (mAs) is still the factor used to make sure the correct numbers of photons are available for imaging a particular body part. If your mAs selection is insufficient, the image will likely turn out grainy, causing a quantum mottling effect to appear on the finished image. Quantum mottle appears as a salt-and-pepper pattern on the image. It is considered an image-noise artifact that is a result of insufficient X-ray transmission data caused by selecting the wrong mAs setting for the body part being imaged. Figure 1–9 illustrates various noise levels graphically, and figure 1–10 demonstrates it visually with a knee exposure. In figure 1–10, the image exposed with the technique of 60 kVp @ 4 mAs displays more quantum mottle effect (noise) than the knee exposed with the 60 kVp @ 8 mAs technique.

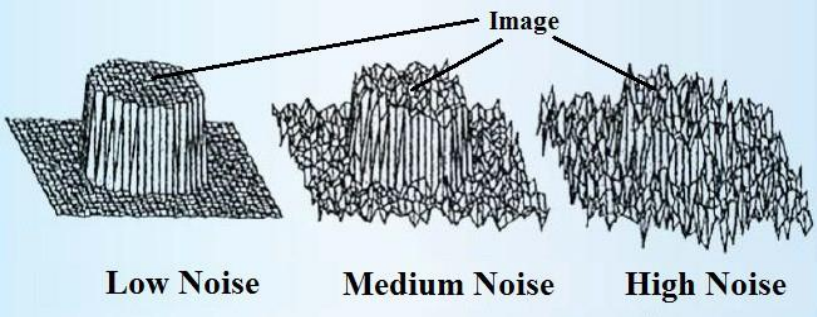


Figure 1–9. Quantum noise levels.

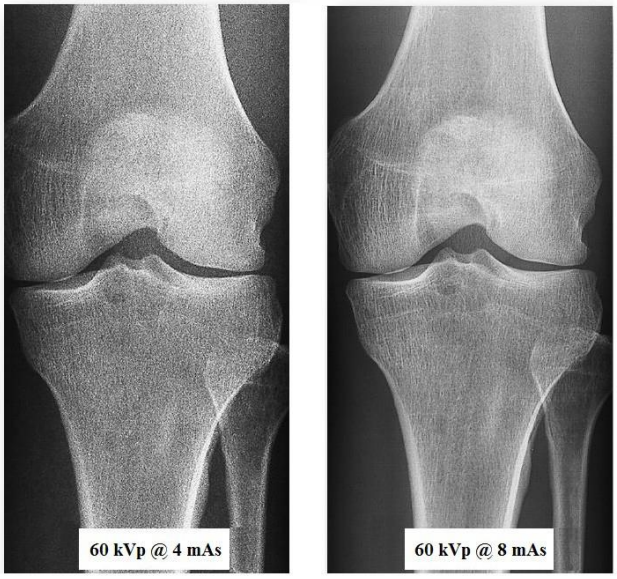


Figure 1–10. Quantum noise in a knee radiograph.

How to acquire direct radiography images

With DR, no cassette is used and images appear on a monitor next to the control panel already in a digital (electronic) format (fig. 1–11). Since the mental steps to acquire DR images are essentially the same as with CR (minus the IP), here we will discuss a few factors that affect the acquisition of a DR image beginning with detective quantum efficiency.

Figure 1–11. Illustration of technician imaging a patient with DR.

Detective quantum efficiency

Detective quantum efficiency (DQE) is one of the basic physical variables related to image quality in digital radiography, and it refers to the efficiency of a detector in converting incident X-ray energy into an image signal. DQE is dependent on radiation exposure, spatial frequency, modulation transfer function, and detector material. The quality of the radiation beam used to expose the body part is another factor that influences DQE.

Use DQE to evaluate the quality of a digital image in relationship to noise and contrast. Noise is inherent with an electronic signal and is expressed as a signal-to-noise ratio. For example, a 1000 to 1 signal-to-noise ratio is recommended for computer-assisted image enhancement. The signal portion of the ratio (1000) represents the usable aspect of the signal, while the noise portion (1) represents the negative image effects. In general, a high signal-to-noise ratio (or low system-noise factor) allows more useful information to be captured, which results in a better quality image.

Achieving high DQE allows smaller, low-contrast objects to be imaged. DQE is better with DR versus CR, and DQE is better with direct capture DR versus indirect capture DR because there is no light-conversion step in direct capture DR. With the light-conversion step removed, direct capture DR eliminates the light-spread effect and produces higher quality images.

Detector size

The most important aspect of flat panel image receptor (detector) size is that they must be big enough to acquire data over the entire exposure area. However, the size must also be practical. For example, most vertical image receptors (formerly a wall bucky apparatus) are 17 x 17 inches in length and width to accommodate both lengthwise and crosswise chest imaging. Long-leg and scoliosis examinations will likely require specially made, dedicated image receptors (detectors).

Pixel size and spatial resolution

As pixel size decreases, the amount of signal also decreases to allow a finer (larger) matrix to have a lower signal-to-noise ratio within each individual pixel. There are limits to this factor; in fact, film-screen radiography is still able to produce better spatial resolution than DR or CR (though DR produces better spatial resolution than CR). Concerning spatial resolution, it is important to note that with image post-processing, image sharpness in digital images definitely can be altered; however, excessively editing the sharpness of an image can result in increased image noise.

Pixel and matrix size relationships

You can probably figure out from the previous material that the size of the pixels determines the amount of image resolution. You must also consider the spacing between the pixels. The spacing in between the pixels is referred to as pixel pitch. As the quantity of pixels increase and the size of the pixels decrease, spatial resolution increases.

So would a large matrix consisting of several very small pixels be best for producing digital images? Not necessarily, because producing digital images with a large matrix of several small pixels would need lots of space on the PACS for storage, and larger files would take longer to transmit over the network.

The lack of storage could cause departments to incur increased costs to purchase additional PACS storage servers, and it could bog down networks when transferring increased amounts of data. Therefore, it is important for DI departments to predetermine what pixel and matrix sizes are practical for their units and networks to perform the task efficiently; that is, to provide the utmost in patient care while producing the highest quality digital images possible.

Technique selection

Essentially, there is no difference in technique selection for DR as compared to CR; however, it is best to always follow the guidance provided to you by technique charts. Since one exposure suite in your department may be CR and another DR, it is likely that your technique in one room may need to be slightly adjusted for the other room. Always reference your department's operating instructions and individual exposure-room technique charts.

Beam-part-receptor alignment

As you know by this point in your imaging career, beam-part–receptor alignment, also referred to as tube-part–film alignment, is necessary. Aligning the beam (tube) with the image receptor is a simple process, but when in a hurry, you may forget to line everything up properly. Some newer imaging systems actually automatically align the beam and the receptor for you; you then only have to center the beam to the body part properly. For discussion purposes, we will have to assume that the automatic alignment feature is not present.

For fixed-table radiography work, position your patient on the radiographic table as needed for the exam. If your unit is CR in nature, insert an IP in the table bucky. With the bucky still open, turn on the collimator light, align the transverse reference line to the center of the IP, and close the table bucky. Next, use only the table to move the patient (and body part) into the correct position. The central ray of the beam (identified by the intersection of the longitudinal and transverse reference lines projected onto the patient by the collimator light) should be centered according to which body part is imaged.

Most errors in misaligned beam-part–image-receptor alignment happen at the point in which the patient is being positioned. Once the beam (tube and collimator) is centered to the table bucky, do not move or adjust the collimator assembly when trying to center the body part to the beam. Instead, always move the patient table to center the body part to the beam. If you move the tube independently once it is aligned to the IP and bucky, you will have to redo these beam-part–image-receptor steps.

With DR, no IP or table bucky is used; simply align the beam to the image receptor if they are not automatically centered to each other. This concept of aligning the beam to the part and image receptor is also applied to the vertical (wall bucky) receptor in a similar fashion. Mobile radiography sometimes presents a bit more of a challenge; however, with patience and your ability to pay attention to details, use the same procedures to make sure the central ray of the beam is correctly aligned to the center of the image receptor while also correctly directed to the centering point of the body part. In mobile radiography, it is normal to adjust patients to the image receptor since they are not on a table as in the previous scenario.

1.4 Digital image processing

Digital images, in general, are defined as any imaging acquisition process that produces an electronic image that can be viewed and manipulated via a computer. Once the digital image has been acquired, the image must be brought to life via processing. This lesson discusses basic digital radiography preprocessing and post-processing concepts.

Preprocessing concepts

Film-screen radiography processing involves a darkroom, chemical solutions, and typically, an automatic processor. Digital radiography eliminates all three of these items and decreases the amount of time needed to display an acquired image. Once developed, film-screen images cannot be manipulated after processing. The ability to manipulate the radiographic image before and after processing is the main advantage of using digital imaging technology versus film-screen. Both cassette-based digital imaging (CR) and cassette-less digital imaging (DR) preprocessing involve selecting an algorithm to tell the computer how to process the histogram for a particular digital latent image while post-processing is performed by you (the technologist) using a variety of user-interface functions.

A *histogram* is a **graphic** representation of the exposure values (densities) collected from the CR phosphor screen during the photostimulable luminescence process. As the user, you select a body part (algorithm) from the *look-up table* on the computer connected to the CR reader. Look-up tables are actually **tables** (not graphs). Since each bone in our body attenuates the X-ray beam in its own particular way, there is a look-up table for every body part that can be imaged radiographically. The purpose of a look-up table is to provide a method for mapping various values recorded for every pixel along every point of the horizontal and vertical axes of the image receptor.

Each look-up table is a set of rules outlining how the computer should process the electronic signals (for similar body parts) repeatedly. To save the computer time, rather than repeat thousands of calculations each time an image receptor is processed, the computer matches key points in the acquired image data to the look-up table that you select during preprocessing. For this reason, it is important to always select a look-up table (algorithm) that is as close as possible to the body part you imaged. The final displayed digital image on the viewing monitor represents the appropriate appearance for each pixel in terms of brightness (density) and contrast (gray tones) as it correlates to the look-up table.

Digital processing units

During CR image acquisition, the phosphor-coated screen inside the cassette housing interacts with X-rays transmitted through the patient. Once the IP is placed within a digital processing unit, the following takes place to digitize an image:

1. The processing unit uses a helium-neon laser to scan the phosphor screen.
2. The laser causes the phosphor screen to emit light.
3. The photomultiplier tube captures the emitted light and converts it to an electronic signal.
4. The ADC assigns a numerical value to each pixel (picture elements) corresponding to the electronic signals.

5. The pixel numerical values are organized (mapped) into a matrix.
6. The DAC converts the numerical values within the matrix back to an analog signal to display the image on a monitor.

NOTE: Figure 1–12 illustrates the process of digitizing an image.

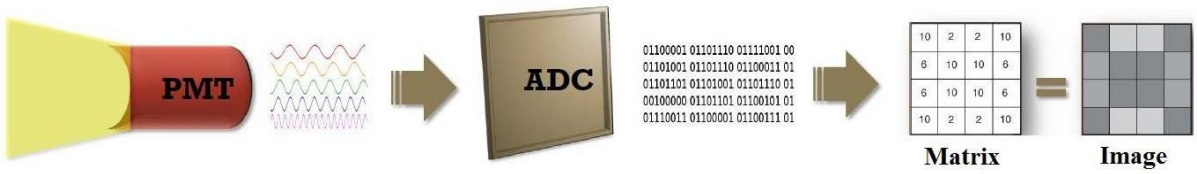


Figure 1–12. Digitizing an image.

As stated previously you use CR IP in the same way as a conventional film-screen cassette. Processing the latent image is where you can note the major difference between the two. There are single and multi-cassette CR IP–processing units in use today. Normally you'll find single CR IP readers located in an emergency room, surgical unit, or possibly an intensive care unit (ICU) X-ray area. Multi-cassette CR IP readers are usually found in the main DI department to help process multiple IPs at a given time and to keep the patients efficiently moving in and out of the exposure rooms.

With DR, patient demographics have to be identified and assigned prior to image acquisition. With CR, images can be acquired on an IP before or after patient demographic information is assigned to the IP. Whether you acquire the images on a CR IP before or after, the following steps are applicable:

1. Assign patient demographic information to a CR cassette:
    a) Use the computer attached to the CR IP reader, known as the acquisition station, to access the patient workload list (worklist) for the day. The patient list is populated when physicians input (order) radiographic exams into your radiology information system (RIS).
    b) Select the patient's name; *always* verify his or her full name, date of birth, and Social Security number (or Department of Defense [DOD] identification number) to see that you are assigning the correct demographic information to the CR IP. After selecting your patient, a list of exams will likely appear that are applicable to the patient.
2. Select the exam order and assign algorithms for the procedure you are performing:
    a) Select the correct exam order on the worklist under the patient's information.
    b) Select the individual IP algorithms for all IPs. Most radiographic exams will require anywhere from 2–5 exposures. Because multiple IPs are being used to acquire images, each IP must be assigned a preprocessing algorithm to tell the processor what specific image-processing formulas need to be assigned to that examination. The algorithm tells the processor how much density and contrast is needed.

    NOTE: This step requires you to demonstrate a higher level of attention to detail. Mistakes often happen at this step, which causes the digital image to be displayed incorrectly. Common mistakes are: (1) acquiring an image on a CR IP and then assigning the wrong body part algorithm to the IP; (2) assigning a specific algorithm to an IP prior to acquisition and then exposing the wrong body part to the particular IP, and (3) making an exposure on patient A but assigning the demographics for patient B. You must take extreme care while processing CR IPs. Though most are fixable, these errors increase patient exam times, increase the workload for your PACS administrator, and in some cases, cause misdiagnosis of a patient's condition if the errors are not caught prior to the radiologist interpreting the images.

3. Scan the IP barcodes:
    a) Each IP cassette has a window displaying the phosphor-screen's barcode.
    b) Select and assign the preprocessing algorithm for each IP. The algorithm you select and assign must match the type of position and body part you are exposing for the CR reader computer to assign gray values to the millions of pixels correctly. Choosing a lateral hand algorithm for a lateral lumbar spine will cause your image to not display correctly.
    c) Manually scan each IP with a bar code reader. This scanning action is the same action a cashier performs when scanning grocery or department store items. In CR the bar code reader is connected to an acquisition computer terminal that interfaces the RIS and the digital-processing unit. Scanning the IP barcode pairs all the patient demographic information, exam order information, and preprocessing algorithm information to the IP.
4. Place the CR IP in the processing unit:
    a) The digital-processing unit is where the rubber meets the road, so to speak. The processor automatically opens the cassette and removes the IP. The IP is fed by a series of transport rollers to a scanning area. As the IP continues along this path, it is scanned, line by line, with a stationary laser. The laser releases the stored analog X-ray energy in the form of light from the photostimulable phosphor screen, which is then picked up by a photomultiplier.
    b) The photomultiplier assigns a corresponding voltage to the energy and sends it to an ADC. The analog-to-digital circuit converts the analog voltage to a digital signal recognized by the processor. The processor then assigns the information that was previously paired to that IP from the barcode system. As a result, the image is sent through a DAC in digital form, allowing visualization on a computer monitor.
    c) After the photostimulable phosphor screen is scanned, the screen is erased with an intense light and fed back into the IP cassette housing. Once the screen is back in the cassette housing, the digital processing unit releases the IP, so you can use it again.

Now that the image is displayed on the monitor, post-processing can begin.

NOTE: The computer has made all the image corrections to this point.

Postprocessing digital images

Whereas preprocessing of digital images is almost entirely automatic, post-processing is where you, the physician, or the radiologist gets to manipulate the digital image personally. Anything you do to the digital image after its acquisition to optimize the appearance of the image for improved pathological viewing is considered post-processing. The following are some of the most common software-driven–post-processing functions of CR and DR imaging systems.

Stitching

With scoliosis or long-leg exams, the anatomy's area of interest is too large to fit on one cassette. In this case, multiple IPs can be *stitched* (combined) together using advanced software programs to be displayed as one image.

Annotation

This is simple; it is how you can add text (e.g., upright or decubitus) or possibly arrows (i.e., pointing to where the patient hurts on an extremity exam) to the finished image to help draw the radiologist's attention to a certain area. The annotation function should not be used to identify the patient's right or left anatomical side; instead use lead anatomical markers during the image acquisition.

Window and level adjustments

A major advantage of digital radiography is being able to adjust an image's gray scale and brightness, after it is acquired. The typical human eye can distinguish between approximately 30 or so shades of gray; however, normal digital images have the dynamic range to display up to 65,536 shades of gray. Adjusting the window and level of an image is the most often used post-processing feature. The *window* setting sets the number of gray shades to be displayed on a particular image, while the *level* setting determines the density (or brightness) of the structures shown on the digital image. Select this option to adjust window and level settings, and then slide the computer mouse up, down, and side to side. This feature will be discussed in more detail during the CT unit of this course.

Magnification

Magnification is often used to better visualize smaller areas of anatomy or pathology. This feature is like using a magnifying glass to read small letters on a document.

Image flip or inversion

Occasionally, you may need to flip an image horizontally (side to side) or vertically (top to bottom). The *image flip* feature allows you to do just that. At other times, *inverting* the appearance of an image sometimes can assist in viewing anatomy and pathology. Image inversion simply makes any structures that appear light now appear dark and vice-versa.

Edge enhancement

Edge enhancement is a feature that sharpens your digital image, making it appear more crisp and detailed. This feature is often used to evaluate images for fractures and small, high-contrast areas of tissue.

Panning, scrolling, and zoom

Panning an image refers to using the computer mouse to grab and move the digital image side to side on the display monitor. *Scrolling* refers to moving the digital image up or down on the display monitor. The *zoom* feature, not to be confused with the magnification feature, allows you to adjust an area of the image to appear closer to, or further away, from you, so you can examine anatomy or pathology more closely.

Digital imaging processing problems

Most digital imaging–processing units in use today automatically correct for pixel defects, image lag, and line-noise problems. As already pointed out, IPs have millions of pixels. It is normal for some of these pixels to, on occasion, not respond correctly to the remnant radiation and produce a usable electronic signal. When this problem occurs, the principle referred to as *signal interpolation* is applied to correct the situation. Signal interpolation takes into account signal values from the pixels surrounding the defective pixel to come up with an average value. Once this process is completed, the averaged value is assigned to the defective pixel so no data is missing from the finished digital radiographic image. *Image lag* is a condition created when an image receptor fails to release its entire electronic latent image completely.

Image lag most often appears when using an image receptor in secession (or flip-flopped back and forth) with high- and low-dose exposure techniques. To correct this situation, an offset voltage is applied to the image receptor via the CR reader that performs a thorough erasure procedure. *Line noise* is another defect that most systems correct automatically. Line noise refers to a problem with a horizontal or vertical line of pixels on an image receptor. Voltage inconsistencies within the circuits that communicate with pixels, and appear as line (linear) artifacts on the finished image, cause line noise. As a corrective measure, the system applies a voltage value from an unirradiated area of the image receptor to reset the voltage for the defective line.

Interpreting the exposure quality of a digital image

With film-screen, you could determine if your image was over or underexposed simply by looking at the film. If the film's anatomy was too dark, the exposure was overexposed. If the film was too light, then you can determine if the film was underexposed. Unfortunately, digital images cannot be viewed as too dark or too light to determine over or underexposure because of the ability to adjust the algorithm that was applied to the exposure and the ability to play with the window and level settings.

Over recent years, digital systems have used numerical values to help you determine whether your image is of optimum exposure, either over or underexposed. The premise of the numerical value was to demonstrate the *sensitivity* of a digital-imaging system to the amount of radiation the photostimulable phosphor screen received. Currently, the numerical value (sensitivity) method is being phased-out to use a more reliable exposure index (EI) metric.

Dose creep has also become a major issue with the advent of digital radiography technology (to include CR and DR). Dose creep is the result of technologists using more exposure technique (kVp and mAs) than what necessarily might be needed to make certain they use enough technique to produce a radiographic image for interpretation. Higher exposure techniques result in increased patient-exposure doses (the dose-creep affect).

While underexposures result in noisy images, image processing allows overexposures to provide excellent image quality; therefore, technologists use higher levels of exposure techniques, resulting in fewer complaints from the radiologists. The EI metric was conceived as a standard to help combat the dose-creep phenomenon. The EI metric is designed to be a feedback mechanism for radiologists and technologists to identify possible over or underexposures.

The International Electro-technical Commission (IEC) and the American Association of Physicists in medicine both identified the need for digital radiographic systems to have a standard exposure metric that would be consistent from manufacturer to manufacturer and model to model. The IEC developed the EI metric as an international standard for all manufacturers of digital radiography systems to use. The EI standard provides a method to monitor exposure differences between digital radiography systems within a facility, compare techniques between facilities, and estimate the image quality for a given system.

The detector exposure level may vary with a body part, view, speed class, or X-ray system; therefore, you must determine a target exposure index (TEI) for each digital radiography system and for each anatomical protocol and view.

The deviation index describes the difference between the TEI and the measured EI. The deviation index helps to show the adequacy of your exposure technique for each digital radiographic image. A passing deviation index range is +/-2 for photo-timed techniques, while a range of +/-3 is acceptable for fixed techniques. Using the deviation index, you will be presented with a *visual dashboard indicator* at the digital radiography–acquisition console that informs you whether your exposure is within the acceptable range (green), outside the acceptable range (yellow), or far outside of the acceptable range (red).

1B Picture Archiving and Communication System

The necessity of a PACS should be evident to any military member who, over the course of his or her career, has traveled to several different medical treatment facilities (MTF), both in garrison and in the deployed setting. In fact, the US military initially developed the PACS systems as a means to transmit images between various Veterans Administration (VA) hospitals and from the battlefield to longer-term treatment facilities. The basic concept of a PACS is to transmit images either across a network, within a facility, or across the country.

1.5 Picture archiving and communication system overview

A PACS is an interlinked group of systems working together to send, retrieve, and archive medical diagnostic images electronically. With the advancements in digital radiography, PACSs have improved as well. This lesson discusses in detail the fundamental concepts of a PACS, along with its system and the peripheral system components common to all PACSs.

Fundamental concepts of a PACS

In general, a PACS is a connection of multiple systems working together to provide medical-imaging communication, image access, and storage. During the early 1980s, a PACS usually serviced only one modality at a time and was specific to whatever institution that had the system installed. Communication between modalities and other facilities was difficult because each system spoke (communicated) in its own digital language. As more vendors, physicians, and MTFs became interested in the concept of a PACS, a standard computer method for exchanging medical images became necessary. The standard method (protocol) used to transmit medical images across networked devices is called digital imaging and communication in medicine (DICOM).

When digital imaging systems are installed in a facility, the typical architecture in a USAF MTF includes the PACS, a voice dictation system, and a PACS broker, which integrates with the RIS. In USAF MTFs, the Composite Health Care System (CHCS) is the RIS of choice. The CHCS uses a standard communication method called Health Level 7 (HL7) to transmit and receive information. Some of this information includes radiology orders, updates into PACS, the radiology dictation system, and back-channel updating of radiology reports into the CHCS from the radiology dictation system.

Basic PACS components

When a PACS is fully operational, it allows personnel throughout the facility to acquire, view, interpret, and store digital radiographic exam information. The four basic components of a PACS are the acquisition device, display workstation, archival system, and an interconnected network.

Acquisition device

An acquisition device is any source (specialty of DI) that sends images to the PACS. Image acquisition can come from a variety of sources, all of which are required to transmit information using the DICOM standard protocol (language). Using units that communicate via the DICOM standard protocol is critical to maintaining a connection across multiple modalities (which can come from a variety of vendors/manufacturers).

The acquisition device is the radiographic digital imaging system. Today, all DI specialties are able to obtain radiographic images in a digital format. The first modality to use an early form of digital acquisition was ultrasound (US), followed by Computed Tomography (CT) and magnetic resonance imaging (MRI), and later came CR and DR. With the most recent advances in digital acquisition technology, you can now acquire digital mammography images.

During the acquisition of an image, worklists should be used whenever possible. The *worklist* displays a list of patients that have a radiologic exam in “ordered” or “arrived” status in CHCS. The worklist is available on your acquisition station and populated by the CHCS. Using the worklist to identify your patient in the PACS eliminates human error that is often associated with manually inputting patient

demographic information. Having the correct information in the PACS is a critical element of attaching the radiologist's dictation to the correct exam performed.

The information provided to you via the worklist is crucial to DI workflow. This data, at a minimum, includes the patient's name, social security number/DoD identification numbers, date of birth, gender, and the CHCS exam accession number, which are critical pieces of information that keep the images synced with the right patient data across the range of workflows. Internal to PACS work lists, PACS administrators can also use worklists to correct patient information when a mistake is made during acquisition or when the PACS comes back up after a failure.

Display system

Any computer monitor that allows digital radiographic images to be viewed is considered a display system. Computer monitors come in varying degrees of resolution levels, the resolution levels depends on what they will be used to view. In medical imaging, display workstations generally come in 1–5 megapixel (MP) resolution levels. For viewing CR, DR, CT, and MRI images, 2–4MP resolution monitors are the standard, while 5MP monitors are the standard for viewing mammography images. Being able to view radiographic images digitally on a computer monitor provides many benefits. One of the main benefits is the ability to manipulate the digital image during the post-processing phase. Image manipulation includes (but is not limited to) window and level adjustments, image stitching, image annotation, magnification, and pan, scroll, and zoom image visualization features.

Archival system

One of the most substantial advantages of PACS is the ability to archive digital information. Most of you reading this material have never experienced the toils of working in a film library. Filing, storing, loaning, and tracking hard-copy radiographs was labor intensive, and it demanded great attention to detail. Thanks to digital imaging and PACS, the days of lost or misfiled film jackets are a thing of the past. Just imagine taking a portable exam in the ICU, processing the image in the main DI department, taking it to the radiologist for a "wet" reading, and then finally taking the film and the wet reading back to the ICU for the requesting physician to visualize the image. Doesn't that process seem time consuming? Believe me, it was.

Now, the PACS archival system offers a centralized point for all facility providers to visualize the image as soon as it is loaded into the PACS. Films that used to be shuffled from person to person around the hospital, now get sent to a server or image manager that houses both short-term and long- term data that allows the digital images to be accessible via any workstation on the network within seconds.

Cache versus long-term storage

The *image manager* of a PACS is the master-filing system of everything within the archival system. It is responsible for receiving, fetching, and distributing the stored images throughout the archival system as well as controlling all the archival system's DICOM processes. Most PACS in USAF MTFs are very large, requiring gigabytes (GB) and terabytes (TB) of capacity. The following shows the size capacity relationship of digital storage terminology:

- Bit.
- Byte equals 8 bits.
- Kilobyte (KB) equals 1,024 bytes.
- Megabyte (MB) equals 1,048,576 bytes or 1,024KB.
- Gigabyte equals 1,073,741,824 bytes, 1,048,576KB, or 1,024MB.
- Terabyte equals 1,099,511,627,776 bytes, 1,048,576MB, or 1,024GB.

Once the radiologist reports a study and the report is transferred back to PACS from the CHCS, the study is considered finalized and fully cached. *Cache* is the PACS' short-term storage and can

average from 500GB–7TB of storage space, depending on the workload of the MTF. From the cache the study is sent to long-term storage (or the archive). At this point, two copies of the study exist—one in the cache and one in the archive. The cache follows a simple rule for making room for more studies when the space gets low. The cache starts to delete the oldest accessed study in a manner known as “first-in, first-out”. The archives themselves, though, are backed up to a secondary location for disaster recovery purposes.

Good stewardship of image storage

When looking at the long-term storage or the short-term cache, it is not uncommon to use TB in terms of total storage. Just because there are TBs available doesn't mean you shouldn't be mindful of what you're sending into the PACS storage. A CT, MRI, or ultrasound scan (without additional reformats or cine clips) can easily take up several GBs. Depending on the size of the long-term storage and the total number of exams performed in your MTF, filling up storage within your archival system can happen rather quickly.

The image file size is dependent on the modality type. An average single chest X-ray can be 15MB–25MB versus a CT chest study, which has hundreds of images, can start at 500MB. With this comparison, it is easy to understand how one modality can use up storage space a lot quicker than another modality. It is important to follow the storage policies as outlined by the PACS administrator at your MTF always; otherwise, you may inadvertently run out of storage space one day. Although spinning disk–hard drives have decreased in price, it is important to be mindful of the amount and quality of data you are planning to archive. The more data you have in your archive leads to a more complicated archival database.

Storage redundancies

Within the PACS, there should be a certain amount of redundancy. If, for example, you have a long-term archive that can hold 500TB of digital information, the PACS should be able to make a duplicate of every image. Making a duplicate of every image will cut your storage in half; however, you are protecting your data, as there will always be a second copy of an exam if a drive/disk array ever fails.

A redundant system is a system that has failover mechanisms, which prevents it from completely shutting down services. Within the various storage levels in the archival system, redundancy is built into the system to copy data across several other hard drives that allows for data restoration if one of the drives fails or becomes corrupt. This configuration redundancy is called redundant array of independent disks (RAID). There are seven levels of RAID technology and each is identified by stating RAID.

There are two main PACS configurations (levels) used: RAID 1 and RAID 5. RAID 1 requires a minimum of two disks and the data is mirrored to all drives. With this type of RAID setup, an exact system duplicate exists; therefore, if one drive were to go down, the other drive would immediately take over. The downside to RAID 1 is that it uses up almost all of the disk space.

As an example, you have two drives, which equal 600GB; you would only be able to use 300GB for production and the other 300GB would be used as a backup. RAID 5 uses a minimum of three disks. One disk acts as the parity controller that sends bits of information across the other drives. This information is then used to restore a failed hard drive. RAID 5 increases performance when reading and writing to the drives. In addition, if one drive were to fail, you would notice decreased PACS performance. When a system failure occurs, it will automatically route clients to the working server for access. The user does not know the difference and continues to work without hiccups.

Interconnected network

Today, many of you use interconnected networks to stay connected to friends, family, and events happening throughout the world. Remember, there are many aspects of a PACS; therefore, there has to be a way of connecting all these different areas together. An interconnected network does just that

(Fig. 1–13). A PACS system works across an interconnected computer network, which is defined as (1) two or more objects (digital/electronic) sharing resources and information, or (2) workstations (computers), acquisition devices (terminals), and servers (storage devices) that are interlinked via communication lines for the purpose of sharing data and program resources.

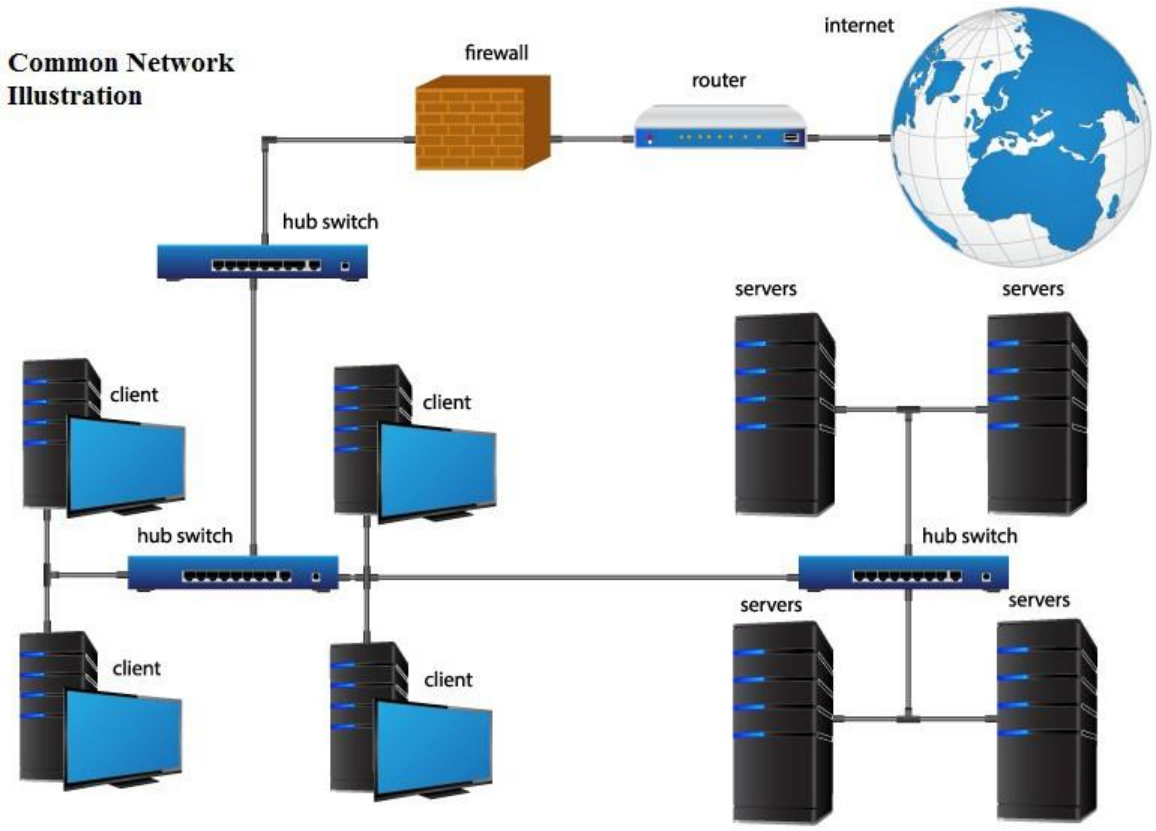


Figure 1–13. Computer network illustration.

Within a PACS network, images are available almost instantly to the quality control (QC) technologist, the physician, and the radiologist, all of whom are sitting at different locations throughout the MTF simultaneously. In addition, networks can connect MTFs in other cities, states, and countries via telephone lines or global satellites orbiting the Earth. What does that mean to you? Essentially, any digital image has the capability of being sent anywhere in the world electronically, allowing even the smallest Air Force imaging departments to have a radiologist look at an image within minutes versus days.

Network types and principles

A PACS system will be on either a local area network (LAN) or a wide area network (WAN). A LAN is what you have within the facility you're working. Once you complete a hand X-ray on Mr. Smith, his images are available throughout the MTF via the PACS network for visualization and interpretation.

Every device on the PACS has a network interface card (NIC) that acts as gateways to other devices and allows for data sharing. A PACS uses three pieces of information to interconnect PACS devices properly: an internet protocol (IP) address, a port number, and an application entity (AE) title. Each server and client within a PACS has a unique IP address that identifies each device on the network to make sure data is sent to the proper destination. The *port number* is relevant to the protocol (digital language) used to communicate with each device in the PACS.

The most known protocol is the reserved DICOM port 104, which is used for transmitting DICOM object data. Other protocols can include HL7, structured query language (SQL) database, hypertext transfer protocol (HTTP) and hypertext transfer protocol secure (HTTPS). The *AE title* is a case-sensitive, alphanumeric name unique to a DICOM device. The AE title for sending DICOM images and receiving modality worklists can be different if more than one vendor is used to build/run a particular device. The IP address, port number, and AE title are the minimum requirements needed when connecting devices to a PACS.

The best example of a WAN is when your facility transmits images to a radiologist located at another MTF (teleradiology) in another city, state, or possibly, another country.

Teleradiology

Aside from the ability to view images from various locations within a facility on a LAN, teleradiology allows digital images to be transmitted from MTF to MTF using a WAN connection. *Teleradiology* is the concept of sending digital radiographic images to another location for a radiologist to interpret. This concept enables a radiologist sitting in one location to see images acquired at another different physical location. This innovation has allowed civilian and military DI facilities alike to increase the amount of exams captured at their facility, even though a radiologist is not on site. In addition, money is saved as many small facilities now do not have to employ a dedicated radiologist to read images daily.

Due to downsizing at certain MTFs, you may work in one of these facilities that do not have a radiologist. Even with no radiologist on site, there is still a need for all exams to be read and dictated; therefore, teleradiology is how that is accomplished. At larger Air Force MTFs namely, David Grant Medical Center (Travis AFB, California), the USAF Academy (Colorado Springs, Colorado), and Wilford Hall Ambulatory Surgical Center (Joint Base San Antonio–Lackland AFB, Texas), radiologists provide a teleradiology service, acting as a hub for smaller MTFs and even various deployed locations around the world that do not have a radiologist on site.

If you send images from a location without a radiologist to a teleradiology site, make sure any relevant prior studies are also sent for comparison. In addition, be critical of your work to ensure image quality is of the highest regard before releasing the patient and sending the images out of your facility. Poor quality images will only delay interpreting and diagnosing the patient's condition. It might even result in you having to call the patient back the next day for a repeat exam.

Another beneficial application for teleradiology is that it provides a mechanism for images to be transferred electronically from one place to another. A good example of this usage is when images are taken in a deployed setting and an injured service member is transferred to the next level MTF as well as all of his or her radiographic images (CR, DR, and CT). Having this capability reduces the patient dose exposure levels and saves treatment time since similar exams do not need to be repeated every time the patient is transferred to a different level MTF.

Network security concerns

In the Air Force, medical and standard DoD systems all communicate using the same network backbone. The threat to Air Force networks is very real. If we get lenient by not securing a system that connects to the Air Force network, then we are vulnerable to an intruder that can hack-in and corrupt our files, steal information, or possibly crash (shutdown) the network, causing a work-stoppage event. The Air Force network is kept secure by making sure the latest security updates (patches) have been downloaded and applied, in addition to using digital certificates to sign-on and access information. Hardening an operating system means applying multiple security measures, such as changing default passwords, removing nonessential services or programs, and encrypting files. Vendors, under the guidance of the Air Force Information Assurance team, routinely do this.

At the Air Force Medical Operations Agency, an entire team is dedicated to making sure medical systems are safely attached to the master Air Force network and that they stay safe as updates become

available. Your local PACS administrator is responsible for verifying approved patches are applied to individual systems on a regular basis.

1.6 Composite Health Care System

The CHCS is a hospital-wide computer information system that is installed at MTFs throughout the Air Force. The CHCS is used as a means of scheduling, tracking, and reporting patient appointments, examinations, lab tests, pharmacy orders, and so forth.

Because it is a hospital-wide integrated system, any user with appropriate access can log onto a terminal anywhere in the facility and order X-rays, review lab results, or verify a patient's follow-up appointment was scheduled. In fact, MTFs within the same region, who routinely refer patients, can link systems so that they have access to appropriate patient information from the referral facility.
The CHCS also plays a part in the workflow of patient and image information in conjunction with a PACS. This lesson discusses general system characteristics, radiology-specific functions of CHCS, and workflow considerations.

General system characteristics

The CHCS uses passwords and electronic security keys to limit access to the various functions available on the system. Each user is assigned a password that consists of an access code and a verify code. The *access code* is usually a portion of the user's name and never changes. The *verify code* can be any combination of letters and numbers, and the user can change it any time he or she feels it is necessary. Using passwords restricts system access to authorized personnel only.

Security keys are assigned to a specific user's password that limits access to only the functions needed to perform his or her job. This way, only certain people have the ability to schedule radiographic exams, order lab tests, prescribe medications, and so forth. It is extremely important that you do not share your password with anyone, or attempt to find out someone else's password. Also, never leave a computer terminal unattended without first logging off the system. Any operation performed under your password is directly attributable to you, and you'll be held responsible for any inappropriate use of the system while you are logged in.

The CHCS is a menu-driven system, which means the functions you perform with your password will show up as a series of selections on a menu when you log onto the system. To perform a given function, simply select the appropriate option on the menu and enter the information requested by the system. The nice thing about the CHCS menu-driven system is that each user's password is assigned a primary menu, so if you, a DI tech, log onto a CHCS terminal in physical therapy, the radiology main menu will appear on the screen. Each user's password may also have secondary menus assigned to it that the user can access it from the main menu. Secondary menus can be hidden from view on the screen but can still be accessed with the appropriate command.

Also, because the CHCS is an integrated system with every terminal and printer device connected to the MTF network, any printing device can be accessed from any terminal in the hospital, given you know the designated name of the printer. For example, you can print patient exam labels in CT from a terminal at the front desk. This not only reduces the number of printing devices each department must have on hand, but it also streamlines workflow.

The CHCS is used for a number of functions within DI, including the following:

- Ordering exams.
- Viewing arriving- and departing-patient exams.
- Scheduling exams.
- Tracking exam progress.
- Transcribing and electronically signing reports.
- Tabulating workload.
- Looking up scheduling backlogs.

Calculating patient wait times

Ideally, the CHCS is designed to be a paperless system. In reality, though, the system has reduced paperwork but not eliminated it. For instance, health care providers can order radiographic procedures through the CHCS system without filling out a standard form (SF) 519B, Radiologic Consultation Request/Report, but most DI departments still print a hard copy of the order either when the patient arrives for the examination or to schedule a patient examination.

This simple system concept does not take into consideration the workflow of a DI department. To understand the purpose of a PACS in DI, you must learn the workflow. Every DI department in the Air Force has their own way of managing the radiography section. With this in mind, all DI departments are striving to provide excellent patient care while providing superior image quality and accurate final reports. Previously in this course, we discussed quality assurance; workflow takes into account many aspects of a quality assurance program to make sure patients, their images, and the reports are taken care of from beginning to end.

One of the biggest issues with the CHCS and Computed Radiography, though, is mixing up exams or accession numbers. A good example of this is if you are performing cervical, thoracic, and lumbar spine exams on a patient and inadvertently run the lateral thoracic spine under the cervical spine order (accession) number. While this is not an end-of-the-world type of mistake; however, it is still a mistake that takes time and attention to be fixed. Fortunately, your PACS administrator can correctly assign the lateral thoracic spine image under the correct CHCS accession number. Larger problems may occur if the radiologist dictates a report for a particular accession number; then it gets a little bit more difficult to fix the error. This scenario can be avoided by using good attention to detail, cross-checks, and taking your time with each exam.

Workflow

Workflow consists of all the materials, services, and information that are systematically organized to perform a repeatable pattern for doing a task from beginning to end. The radiology PACS workflow begins when the referring or requesting physician enters a radiology order into the RIS for a patient. At this point, an HL7 message is sent to the PACS broker, which initiates a DICOM request to the PACS to start fetching relevant prior studies for this patient from our regional archives.

The patient then checks into DI for the study; the receptionist or technologist must verify an order has been placed in the CHCS. Upon verification that an order exists, the study will arrive and an HL7 system message will be sent from CHCS to the PACS broker, which, in turn converts the message into the DICOM format and sends it to the PACS. The PACS uses this message, which contains the patient's demographics, procedure and order history, and makes it available to all of the acquisition devices—this is known as a modality worklist.

The technologist pulls up the patient order at the modality and proceeds with imaging the patient. Once he or she verifies the image and data quality, the study is then sent to the PACS. At this point, the study and relevant prior studies are available for the radiologist to interpret, using the voice recognition dictation system. Once the report is completed, the dictation system uses the radiology order information that was initially served and uploads the final report into the CHCS for distribution to the requesting physician. While patient workflow ends here, image workflow continues to the regional archives, which makes the study available to the entire Air Force.

When it comes to workflow, your PACS administrator plays an important role in the flow of information in and out of your digital radiography department. He or she must understand all of the acquisition devices at your MTF. The type of device will determine how he or she configures the PACS. As an example, a new mammography device is installed at your facility. The administrator cannot simply associate the device to the PACS using an AE title, IP, and port. Yes, the device will communicate and you will see an image appear on the PACS, but the workflow piece of the puzzle cannot be forgotten.

How will the image appear at the radiologist's reading station—like hanging protocols or demographic overlay specific to mammography? Will these images require any type of compression when storing to the archive or sharing through a web server? Do you need to increase your short-term storage space to accommodate the workload increase? These are all questions a PACS administrator has to answer prior to installing any new piece of imaging equipment. Understanding image workflow from beginning to end is the easiest way to see that every PACS user is taken care of and happy with his or her piece of the puzzle.

1.7 System downtime functions

There will often be connectivity issues within a PACS that can easily be troubleshot from an end-user perspective. If, for example, no acquisition stations are connecting, and the CHCS is also offline, then more than likely, the entire network is down. But, if there seems to be a connectivity issue with just one peripheral on the network, it could be something as simple as verifying the network cable has not become disconnected. This lesson dives into investigating system problems, using an SF 519B, and implementing contingency plans and disaster recovery.

Investigating system problems

As radiologic technologists, our primary purpose is providing the radiologist with high-quality diagnostic images while safeguarding our patients' safety. The patients are the reason why we go to work, and our mission is to make sure they are taken care of (even in cases of system disruption). The PACS and other technologies have made it much easier to take care of patients, and we sometimes forget these technologies are not fail proof. If you spend enough time in a DI department, you will soon realize that chaos erupts when the PACS goes down. "I can't see my orders on the modality," "The radiologist can't see my study," and "I can't see reports in CHCS" are all complaints you may hear that should notify you something is wrong. As a technologist, you are in the best position to understand what is going on when systems fail. The PACS administrator is responsible for figuring out the cause of the problem and finding a solution.

Time is always of the essence when dealing with systems that assist in diagnosing patients. The PACS administrator will work closely with you (the technologist) and will rely on your information to ultimately figure out the root of the problem.

Remember, a PACS consists of an acquisition device, viewing workstation(s), storage device(s) and peripheral components all connected in a network facilitated by servers that integrate to other vital systems like the CHCS and voice recognition. To understand a PACS, it is easier to break it down in parts. Let's go through a step-by-step troubleshooting scenario on a common disruption. While getting your room ready for a patient, you realize that you are not able to pull up your worklist on the modality. You then find out you are not the only one experiencing this problem and realize your information comes from the CHCS, and so you check to see if the CHCS is accessible.

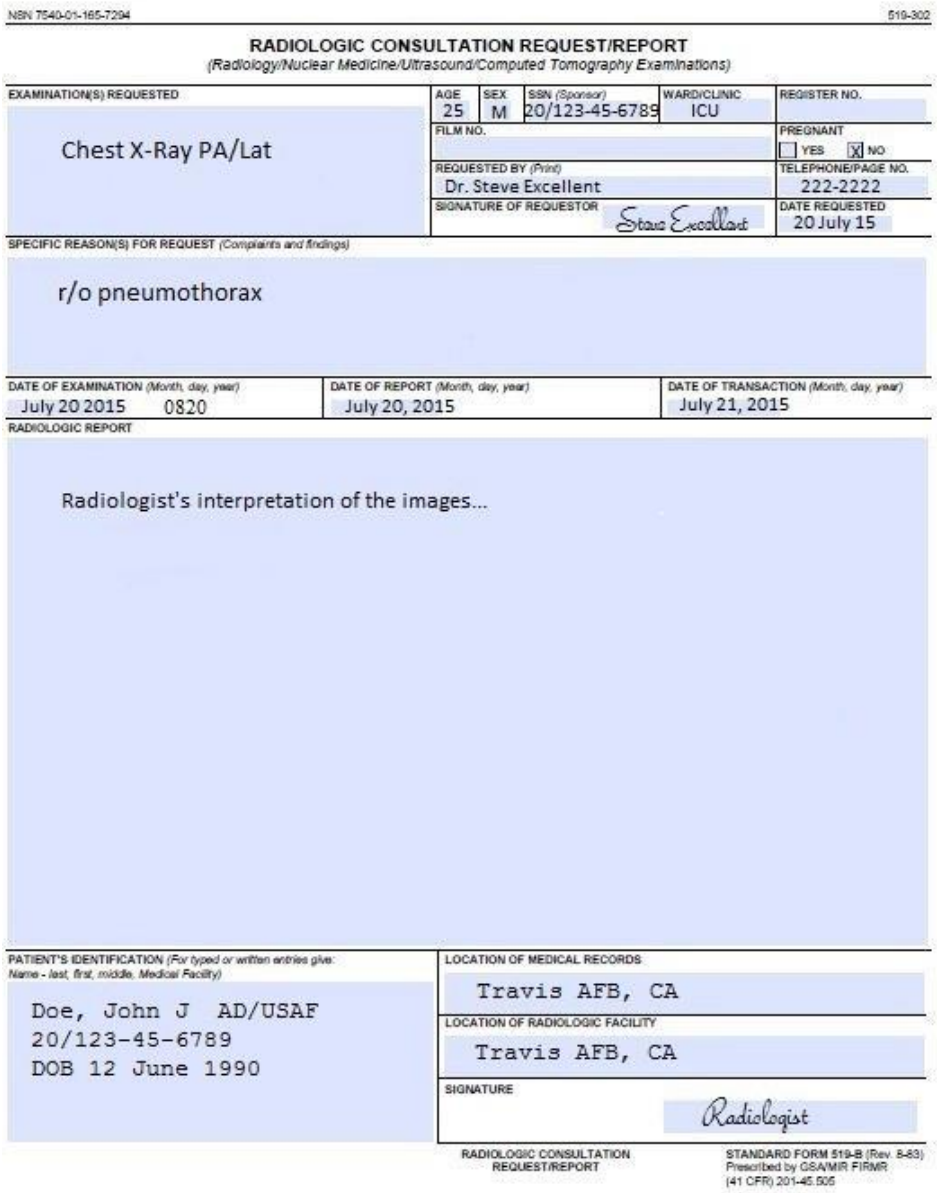
After verifying the CHCS is working correctly, you inform the PACS administrator of the issue. The administrator suspects the PACS broker is responsible for the problem because the broker is responsible for providing all the data to the worklist. The PACS administrator decides to restart the PACS broker components. Once these components are restarted, you check to see if the connection is restored and you find it is because you can access the worklist again. Since the problem is fixed, you realize the issue was the PACS broker. Whenever the system or connection goes down, this is your chance to be an investigator and help the PACS administrator figure out the problem.

Using the standard form 519B during radiology/hospital information system downtime

There will be times when certain PACS components will be down and times when the PACS is online but the CHCS is not. When this occurs, images can travel across the network but will not match up with the demographics from the modality worklist. You should take extra care when this happens for several reasons.

First, the only way to assign patient demographics to the images is by manually inputting the information into the acquisition station. Typographical errors (typos) are the most common mistake and can cause verification (matching) errors on the system once the hospital information system (HIS)/RIS connection is restored. Therefore, taking your time manually inputting the demographics will definitely save you time later on.

Secondly, when there is no HIS/RIS connection, technologists will have to track/record exams that have been performed using paper-based radiology requests. This is where the SF 519B comes into play (fig. 1–17). During an HIS/RIS outage, physicians should fill out an SF 519B for each patient. The SF 519B is simply a paper version of the electronic radiology order you're already using in the CHCS. When patients show up with a SF 519B for their radiographic exam, make sure all writing is legible on the form.



NSN 7540-01-165-7294 519-302

RADIOLOGIC CONSULTATION REQUEST/REPORT

(Radiology/Nuclear Medicine/Ultrasound/Computed Tomography Examinations)

EXAMINATION(S) REQUESTED	AGE	SEX	SSN (Sponsor)	WARD/CLINIC	REGISTER NO.
Chest X-Ray PA/Lat	25	M	20/123-45-6789	ICU	
	FILM NO.				PREGNANT ☐ YES ☒ NO
	REQUESTED BY (Print)				TELEPHONE/PAGE NO.
	Dr. Steve Excellent				222-2222
	SIGNATURE OF REQUESTOR				DATE REQUESTED
	Steve Excellent				20 July 15

SPECIFIC REASON(S) FOR REQUEST *(Complaints and findings)*

r/o pneumothorax

DATE OF EXAMINATION (Month, day, year)	DATE OF REPORT (Month, day, year)	DATE OF TRANSACTION (Month, day, year)
July 20 2015 0820	July 20, 2015	July 21, 2015

RADIOLOGIC REPORT

Radiologist's interpretation of the images...

PATIENT'S IDENTIFICATION (For typed or written entries give: Name - last, first, middle. Medical Facility)	LOCATION OF MEDICAL RECORDS
Doe, John J AD/USAF 20/123-45-6789 DOB 12 June 1990	Travis AFB, CA
	LOCATION OF RADIOLOGIC FACILITY
	Travis AFB, CA
	SIGNATURE
	Radiologist

RADIOLOGIC CONSULTATION REQUEST/REPORT

STANDARD FORM 519-B (Rev. 8-83)
Prescribed by GSA/MR FIRMR
(41 CFR) 201-45.505

Figure 1–17. SF 519B, Radiologic Consultation Request/Report.

In particular make sure the physicians' name, radiographic exam, patient history, and patient demographics are all clearly legible. Clarity is important because you will have to enter this information into the CHCS once the connection is restored hours or days later.

NOTE: Always annotate the date and time on the SF 519B for each patient.

Finally, once the HIS/RIS connection with the PACS is reestablished, you or another X-ray technologist will have to go back into the CHCS and enter all the exams performed using the SF 519B. Once all the exams are entered into the CHCS, you or someone knowledgeable of the PACS will begin the process of matching the exam information with the images that were acquired while the HIS/RIS outage occurred.

Contingency plans

Every DI department should have a contingency plan of operations in case of an extended PACS downtime. A contingency plan is a plan used to continue imaging operations in cases of emergency when the normal process (PACS) is disrupted for any reason. Consider it your plan B. A plan should exist specific to each scenario. As an example, let's imagine the hospital network goes down, which means no worklists are accessible and images cannot be transferred via the network. The network administrator warns that the expected downtime could take 24 hours. What is your plan of action to make sure the DI department continues functioning?

You cannot print, burn studies to CDs, or even view images on any workstation since nothing is communicating with the servers. One plan could be to physically move the printer and CD/DVD burner within proximity to the modality and have them communicate through a small switch. These are all tasks your PACS administrator, along with your systems flight, will be responsible for assembling; however, as a technologist, you should know how your department operates and understand the basics of what needs to be done to get it back up and running.

Disaster recovery

In cases of irreversible disasters, whether from natural or intentional actions, every DI facility should be prepared to recover and restore operations with minimal loss of information. This is the purpose of running intelligent services on our servers to backup both system data and patient information.

System backups (which include the database and other internal services) are normally set to back-up on a daily basis. It is crucial that administrators make sure backups are performed on schedule to maintain the integrity of all diagnostic medical data. Data can be backed up to physical magnetic tapes and stored in a safe location, or backups can be via a network to another server that stands ready to restore or take charge after an emergency. There are three basic forms of system backups: full, incremental, and differential.

A *full* backup is a complete backup of the entire system. It is the largest and most comprehensive type of backup. A full backup can take an extensive amount of time to perform but is fastest during the recovery process. All backups, whether incremental or differential, start out with a full backup. An *incremental* backup only backs up data that changed from the most recent type of backup, no matter the type. An incremental backup takes up the least amount of space but is slower in the recovery process since each day has to be individually restored. A *differential* backup copies data that changed from the last full backup. Though it takes up more space than an incremental backup, a differential backup is faster during the restoration process.

Air Force regional archive locations are spread throughout the world, and they serve as the patient- study backups for numerous local sites. It is very important that all DI sites pay attention to their system logs to see that studies are being backed up as soon as the study is finalized. Doing so ensures that when the local storage (cache) gets full that it deletes studies that are not archived to make room for new studies. These regional archives are also backed up by a secondary archive for disaster- recovery purposes, ensuring that if one regional site goes down, another stands ready to take its place.

Here are the current disaster-recovery backup sites for USAF DI departments worldwide:

- West region—Travis AFB, California.
- West central region—Lackland AFB, Texas.
- East central region—Scott AFB, Illinois.
- East region—Langley AFB, Virginia.
- European region—Ramstein Air Base (AB), Germany.
- Pacific region—Elmendorf AFB, Alaska.

Unit 2. Fluoroscopy, Mobile Radiography and Bone Densitometry

2A Fluoroscopy.....31
2.1 Digital fluoroscopy.....31
2.2 Image intensification.....36
2B Mobile Radiography.....38
2.3 Operating mobile equipment in inpatient care areas.....39
2.4 Operating mobile equipment in the operating room.....42
2C Bone Densitometry.....46
2.5 Bone-densitometry principles and performing common exams.....46
2.6 Quality-control features.....52

IN 1896, THOMAS Edison invented the fluoroscope and revolutionized the field of medicine. Edison's fluoroscope looked a more like a cartoon X-ray machine than a modern fluoroscope, but we still use the basic principles Edison devised then with our modern fluoroscopy (fluoro) imaging systems. The first section of this unit discusses digital fluoroscopy and image intensification. Though the imaging department performs most fluoroscopies, sometimes the patient's condition warrants a mobile imaging unit. In the second section of this unit, we will discuss mobile radiography for inpatient care areas and the operating room (OR). We begin with fluoroscopy.

2A Fluoroscopy

Like standard radiography, fluoroscopy uses X-rays to produce images of the body. However, the uses of fluoroscopy and the equipment involved in its performance differ significantly from routine radiographic work. Fluoroscopic systems are commonly combined radiographic and fluoroscopic units since they can perform both radiographic and fluoroscopic functions. Conventional fluoroscopy uses the cassette slot in the fluoroscopy tower (that is above the patient) to record images. In digital fluoroscopy, a computer is added and the cassettes are no longer used. In this section, we will discuss digital fluoroscopy and image intensification.

2.1 Digital fluoroscopy

Conventional fluoroscopy and digital fluoroscopy imaging systems look the same to the patient. Both imaging systems have a tower-looking apparatus (image receptor/image intensifier), table, and monitor(s) to view images. Here, we will discuss the various fluoroscopy system components, radiation protection, image recording/storage, and personnel roles and responsibilities during fluoroscopic procedures.

Fluoroscopy system components

The basic components of a digital fluoroscopy system include an X-ray tube (the source), an image receptor (fluoroscopy tower), viewing monitors, and an operator's console, table, and attachments (fig. 2–1).

Figure 2–1. Typical digital fluoroscopic room layout.

X-ray source

The X-ray tube is, of course, the source of radiation for producing the fluoroscopic image. In most fluoroscopy units, the X-ray tube is located within the patient-positioning table (fig. 2–2). The tube is connected to the fluoroscopy tower so that the two move together as one unit. The National Council on Radiation Protection and Measurements (NCRP) specifies that the tube-to-tabletop distance must be at least 12 inches and preferably not less than 15 inches to minimize patient skin dose. In addition, a filter is attached to the tube to bring the total permanent filtration of the fluoroscopic beam to at least a 2.5-millimeter (mm) aluminum equivalent. Also attached to the tube is a collimator that automatically restricts the beam to the size of the selected spot image, which may also be used to manually restrict the beam even further.

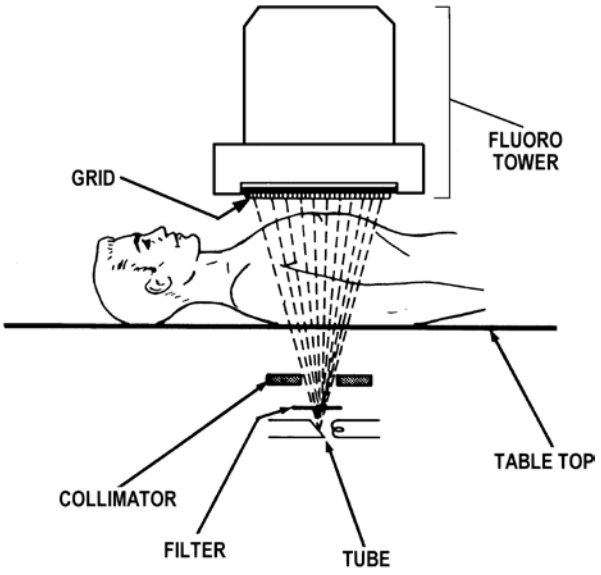


Figure 2–2. Standard fluoroscopic equipment design.

Conventional fluoroscopic X-ray tubes operate with a current normally less than 5 milliamperage (mA) since it uses image intensification.

NOTE: We discuss image intensification in the next lesson.

In digital fluoroscopy systems, the X-ray tube operates in a radiographic mode and it measures current in hundreds of mA. Digital fluoroscopy systems use an X-ray beam called *pulse-progressive fluoroscopy* to expose images. With pulse-progressive fluoro, the study is performed with reduced patient doses. Digital fluoroscopy systems require fast-acting X-ray generators that can turn the source on and off very quickly.

Interrogation time refers to the time needed to energize the X-ray tube to the selected kVp and mA settings. *Extinction time* is the time needed to turn off the tube. The high-frequency generators in digital fluoroscopy systems can perform tube interrogation and extinction in less than 1 millisecond (ms). This is just one feature of digital fluoroscopy that reduces patient radiation dose.

Image receptor (fluoroscopy tower)

The fluoroscopic tower performs several critical functions during fluoroscopy. First, it serves as the image receptor, converting the remnant radiation into an image through the process of image intensification (discussed in the next section). Second, it allows the operator to control many of the fluoroscopic settings and initiate/terminate the exposure. Finally, it houses the image-recording apparatus, such as the spot-image camera, video camera, and/or digital image receptor. Digital fluoroscopy normally uses one of two types of image receptors to capture the image: a CCD or a flat-panel image receptor.

Charge-coupled device

A CCD uses a layer of crystalline silicon to capture light from the image intensifier. As the silicon layer picks up light, it produces an electrical charge. The computer then surveys this electrical charge, pixel by pixel, to produce a digital image for viewing. The typical CCD arranges the pixels in a 2048 x 2048 matrix, allowing for excellent high spatial resolution. As its name alludes to, CCDs are coupled (or connected) to another part of the fluoroscopy system. Normally, a CCD is coupled with fiber optics to the output phosphor of the image intensifier, which allows the entire electrical signal to

be surveyed. The CD can also be coupled to the output phosphor through a lens that measures samples of light, creating an image.

Because of a CCD's high light sensitivity and low amount of electrical noise levels, the images produced have a high signal-to-noise ratio and excellent contrast resolution.

The following are other advantages of a CCD:

- No warm-up required.
- No image lag or blooming effect in images displayed.
- No maintenance required.
- Virtually an indefinite lifetime.
- Dramatic reduction in the radiation dose a patient receives.

Flat-panel image receptor

The latest advancement in digital fluoroscopy is the flat-panel image receptor. Flat-panel image receptors are made of CsI or amorphous silicon pixel detectors, like in digital radiography. Flat-panel image receptor systems are smaller, lighter, and allow for easier over-the-patient movement than the larger image-intensifier systems. Image-intensified images are limited by non-uniform spatial resolution from the center to the peripheral edges of a circle image. Flat-panel receptors capture the image information uniformly over the entire area of the receptor. Other advantages of a flat-panel image receptor system are distortion-free images, improved contrast resolution, and image acquisitions in a square or rectangle format that better associates to the image display monitors.

Image display monitor(s)

The conventional way to view fluoroscopic images is with a cathode ray tube (CRT). A CRT is a television with a large tube apparatus behind the viewing screen. Most departments are replacing CRTs with flat-panel monitors. Flat-panel monitors are lightweight, produce images that are easier to view with the human eye, and can be hung or suspended much easier than CRTs. Most flat-panel monitors used in DI (and fluoroscopy) are active-matrix liquid crystal displays (LCD).

Many times these monitors are just referred to as LCDs. Liquid crystal is a material state between a liquid and a crystal. It has the property of a crystal (highly organized molecular structure) and a fluid (characteristically viscous). Flat-panel monitors use an intensely bright backlit white light to illuminate each pixel of the monitor. Pixel size is characteristic of flat-panel monitors and is normally stated in the form of MP. Flat-panel LCD monitors increase and improve spatial resolution as higher MP monitors are used. The following table outlines the pixel matrix for common sizes of medical flat-panel monitors:

Flat-Panel Monitors' MP and Matrix Sizes	
MP Size	**Pixel Matrix**
1MP	1000 x 1000
2MP	1200 x 1800
3MP	1500 x 2000
5MP	2000 x 2500

Another positive factor of flat-panel–active-matrix LCDs is that they do a better job of reducing the negative effects of ambient light on images versus CRT monitors. The only disadvantage worth mentioning is with regards to angular dependency of viewing. In other words, you should view images on a flat-panel monitor straight on and not at an angle, whether side to side or up or down.

Use video to view the fluoroscopic image live. To view the image on a video monitor, place a video camera inside the fluoroscopy tower to capture the image from the image intensifier (fig. 2–3). The

camera converts the image into an electrical signal, which transmits the signal via cable to the monitor. The monitor then converts the electrical signal back into a visible image.

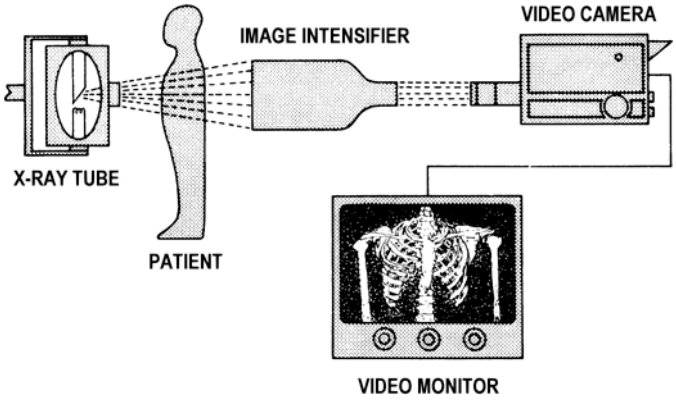


Figure 2–3. Fluoroscopic video monitor schematic.

In digital fluoroscopy, the camera reads the image in a progressive mode. In other words, the video camera's electron beam continuously scans the image from top to bottom. Background noise is inherent to all analog electronic devices because electrical current is always present. As you should remember, image noise serves no positive purpose; it only serves to degrade and blur the radiographic image. Video tubes for conventional fluoroscopy produce a signal-to-noise ratio of 200 to 1. This means that the output signal strength will be 200 times stronger than the inherent background noise. In digital fluoroscopy, it is required that video tubes produce an output signal of at least 1000 to 1 signal-to-noise ratio, so the video feed (signal) is not lost in the inherent noise. A video tube with a 1000 to 1 signal-to-noise ratio allows up to five times the video information to be present and is more suited for computer-assisted image manipulation.

The primary advantage of a video-viewing system is that it allows several people to view the fluoroscopic image simultaneously. Video-monitoring systems also offer the advantage of being able to record the live fluoroscopic exam for later viewing.

Operator's console, table, and attachments

The operator's console for a digital fluoroscopy system is more involved than with conventional fluoro. Since most fluoroscopy rooms also perform regular radiography exams, the console must have controls for both systems (radiographic and fluoro). In addition, the fluoroscopy system must be monitored; therefore, there is a timer built-in to keep track of the amount of time the fluoroscopy beam is on. This timer has an audible alarm that usually triggers after 5 minutes of fluoroscopy exposure.

The typical fluoroscopy table is essentially no different in how it looks as compared to conventional radiography; however, the table in a fluoroscopy room must be able to rotate up to 90 degrees, so the patient is fully in the upright position. At various times during a fluoroscopic study, the radiologist may need to place the patient in a slight trendelenberg position (head lower than feet) or stand them up entirely as is the case for upper gastrointestinal (GI) exams. While you are rotating the table, attachments make sure the patient is safe at all times. A footboard, placed on one end of the table, allows the patient to stand when the table is in the upright position. A shoulder rest (or handles) can also be attached to the table, opposite the footboard, to make certain the patient does not slide headfirst off the table while in the trendelenberg position. Always test the table attachments thoroughly prior to the exam to verify they are securely attached to the table. Some departments also

require you to demonstrate that the attachments are properly secured to the patient, so he or she trusts that he or she is safe.

Radiation protection

Because radiographers and/or physicians must work in the exposure room and subject themselves to scatter radiation during fluoroscopy, they must take additional radiation protection measures. The patient is the greatest source of scatter radiation during a fluoroscopic exam. For this reason, most fluoroscopic devices are equipped with a lead curtain that hangs from the front of the fluoroscopy tower to block scatter from reaching the operator. In addition, when you move the bucky tray to the end of the radiographic table, make sure the lead bucky slot cover appropriately closes off the approximately 5-centimeter (cm) opening where the table bucky (or digital image receptor), used in conventional radiography, moves back and forth the length of the table. Of course, you should never perform fluoroscopy without wearing a protective lead apron, and remember that lead aprons only work when the lead is between you and the source of radiation. If you are wearing only a front- covering lead apron, ***never*** turn your back to the fluoroscope while the fluoroscopy is on. When not actively assisting the radiologist (or patient), make sure to position yourself so that the radiologist is between you and the radiation source.

You may also elect to wear a thyroid collar, lead gloves, or leaded glasses for added protection. In general, digital fluoroscopy units use a lower dose on the patients than conventional fluoroscopy. This is because digital fluoroscopy beams use a pulsing effect instead of a constantly on beam. It is necessary to note, though, if the fluoroscopic beam-on time is excessive, reduction in patient dose advantages disappear. By using the devices mentioned, minimizing exposure time, and maximizing distance from the primary beam and patient, you should be able to keep your radiation exposure to a minimum.

Image recording/storage methods

Since fluoroscopy is primarily a real-time examination, the image is only available while the fluoroscopy is turned on. However, in conventional fluoroscopy, a cassette is loaded into the fluoroscopy tower to record individual spot images of pertinent anatomical structures. The cassette-loaded spot-image device sits directly beneath the image intensifier. It automatically moves a standard radiographic cassette into position for a conventional radiographic exposure on a moment’s notice during the fluoroscopic exam. Once the operator loads a cassette into the camera, the device positions the cassette out of the direct beam until the operator depresses the exposure switch. When the operator makes an exposure, the camera slides the cassette into position under the image intensifier and exposes the imaging plate (film), depending on the format the operator has selected.

The exposure is photo timed, but the radiographer must select the kVp setting in advance and separate the setting that will be used for fluoroscopy. Once the entire imaging plate has been exposed, the camera automatically ejects the cassette and the operator must replace it with an unexposed cassette.

With digital fluoroscopy systems, the cassette is replaced by an image receptor, as previously discussed. Now, each spot-image exposure is recorded digitally and can be manipulated using the computer after the exposure is sent to the PACS. Video recording software is installed in most digital fluoroscopy systems, which replaces rapid-film cameras and videocassette recorders used in conventional fluoroscopy. Once again, digital fluoroscopic systems offer the radiologist more advanced options to record images, make the correct diagnosis, and reduce patient exposure dose.

Personnel roles and responsibilities during fluoroscopic procedures

Fluoroscopy has many uses in modern medical imaging. Chiefly, it is used to evaluate dynamic physiologic processes within the body. Only radiologists or physicians should perform many fluoroscopic procedures because there is potential for patient injury or the exam itself is interpretive in nature. However, the scope of practice for radiographers is ever-changing and many states now recognize the capacity for trained radiographers to perform certain limited fluoroscopic procedures.

The Air Force also recognizes the ability of radiographers to perform limited fluoroscopic procedures, providing they have received adequate training and are authorized to do so by the supervising radiologist. Refer to your department's operating procedures to determine which, if any, fluoroscopic procedures radiographers may perform at your facility.

Physician-conducted fluoroscopy

Many types of physicians find fluoroscopy a useful tool in their practice of medicine. Orthopedic surgeons use fluoroscopy to guide them in open and closed reductions of many types of bone fractures. Pulmonologists use fluoroscopy during bronchoscope procedures. Gastroenterologists use fluoroscopy to aid them during an endoscopic retrograde cholangiopancreatography (ERCP) and many other gastrointestinal tract procedures. But, the radiologist is the primary physician-type trained in the performance of general fluoroscopic procedures.

Radiologists use fluoroscopy to perform a variety of both diagnostic and interventional radiologic procedures. By this point in your career, you have undoubtedly assisted radiologists in performing fluoroscopic examinations of both the upper and lower gastrointestinal tract. Radiologists also use fluoroscopy in more invasive procedures such as arthrograms, myelograms, and angiograms when the radiologist needs to observe the administration of a contrast media agent directly.

Radiographer-conducted fluoroscopy

The traditional role of the radiographer during fluoroscopy is to set up the equipment, gather all necessary supplies, and assist the radiologist during the procedure. However, as previously mentioned, many facilities are now training radiographers to perform certain limited fluoroscopic procedures. Radiographers should only perform procedures that are noninterpretive in nature. That is, the radiologist should not need information from the real-time fluoroscopic exam to make a diagnosis. Rather, radiographers should be performing exams in which fluoroscopy is used only as an aid in positioning the patient or when timing a necessary radiographic exposure; these are the type of procedures that radiographers may be trained to perform. Examples of these types of exams include oral cholecystograms, spot images of the terminal ileum during small-bowel exams, foreign body localization, and voiding images during cystourethrograms.

Radiographer-assisted fluoroscopy

Keep in mind, a technologist-performed fluoroscopy is rare at most Air Force facilities; therefore, the following is a list of typical duties you are responsible for performing during fluoroscopic studies:

- Performing the two patient-identifiers check, getting the patient changed into a gown, entering patient information into the system (for digital fluoro).
- Discussing the patient's history and the success of the bowel-cleansing preparation.
- Explaining the procedure to the patient and answering any questions he or she may have.
- Acquiring any scout/preliminary images.
- Attaching the table attachments, orientating the table appropriately for the study, and setting the fluoroscopy technique on the control panel.
- Preparing the oral contrast agent(s), as prescribed for the fluoroscopic study.
- Assisting the radiologist during the study and assisting the patient with intra-study positions.
- Acquiring post-procedure overhead radiographs (as necessary).
- Discussing and providing post-procedure care instructions to the patient and answering any questions he or she may have.

2.2 Image intensification

A fluoroscope is an X-ray imaging system used to view live-action X-ray images directly. The first fluoroscopes were very simple; they consisted of an X-ray tube under the radiographic table and a

fluorescent screen installed over the top of the patient. The fluorescent screen would glow when exposed to radiation; henceforth, an image would appear for the radiologist, or physician, to view directly or via a mirror system. It was normal for the X-ray image to be faint and dark when viewed via the fluorescent screen. For this reason, early fluoroscopic procedures were conducted in no-light situations and radiologists had to "dark adapt" their eyes before performing fluoroscopy to make it easier to view the fluoroscopic image.

The process of image intensification was developed to overcome the problems inherent in conventional fluoroscopy. An image intensifier increases the brightness of a conventional fluoroscopic image over 5,000 times to make it more easily viewable in a dimly lit room and to eliminate the need for dark adaptation. In this lesson objective, we will begin discussing the process of image intensification with the principle component, the image-intensifier tube.

Image-intensifier tube

The basic component used in image intensification is essentially a type of electronic tube (fig. 2–4). The image intensification process works like this:

1. Remnant radiation strikes the **input phosphor** at the input end of the image-intensifier tube. The input phosphor is made of CsI, a fluorescent crystal that glows when radiation strikes it. In this manner, the remnant radiation is converted into a visible image.
2. A **photocathode,** in direct contact with the input phosphor, converts the light image into an equivalent electron form through a process called photoemission. The photocathode is composed of a specific type of metal that emits electrons when exposed to light. The reason for converting the X-rays to light and the light to electrons is that X-rays cannot be focused or amplified (accelerated). However, once the image is converted into an electron image, it can be electronically amplified and focused.
3. An **anode**, placed near the output phosphor, places a potential difference of about 25–30 kilovolts (kV) across the tube, thereby, accelerating the electrons that comprise the image.
4. Electrostatic **focusing lenses** focus the electron image down to the size of the output phosphor while maintaining the true relationship of the image that is free from distortion.
5. The electrons strike the **output phosphor** with a high-kinetic energy and form a brighter but minified image on the face of the output phosphor. The output phosphor consists of zinc cadmium sulfide with a small aluminum layer plated to the screen of the output phosphor where electrons interact. This interaction is similar to the front of an older television picture tube that gives off light when struck by high-energy electrons and converts the electron image back into light.
6. An **objective lens**, which is actually part of the viewing system, collects the light image diverging from the output phosphor and converts it into a parallel beam image.

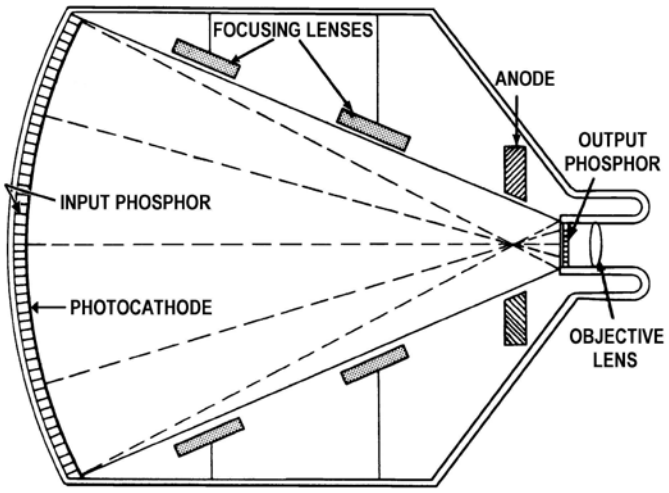


Figure 2–4. Image-intensifier tube.

Brightness gain

The total amount of image intensification, or *brightness gain*, is based on electron acceleration and image minification. By applying 25–30 kV across the tube, kinetic energy is added to the electrons emitted by the photocathode. This multiplies the light intensity 50–75 times. The increase in image brightness from this process is called *flux gain*. *Minification gain* results from the decreased image size from the input to the output phosphor. The ratio of the area of the input phosphor to the area of the output phosphor determines minification gain. To calculate this ratio, take the square of the diameter of the input phosphor and divide by the square of the diameter of the output phosphor.

For example, if the input phosphor diameter is 35 cm and the output phosphor diameter is 2.5 cm, minification gain is calculated as follows:

$$\text{Minification Gain} = \frac{35^2}{2.5^2} = \frac{1225}{6.25} = 196$$

NOTE: The brightness of the image would be magnified 196 times just from minification.

The total brightness gain is equal to the flux gain times the minification gain. So, a tube with a minification gain of 196 and a flux gain of 70 would have an overall brightness gain of 13,720 (196 x 70). This means that the intensified image would be almost 14,000 times brighter than the image produced by the input phosphor. The standard range-of-brightness gain for most image intensifiers is between 5,000 and 30,000 times brighter.

Image magnification

Most image intensifiers are capable of magnifying the fluoroscopy image. Such intensifiers are called multifield tubes and are somewhat standard in digital fluoroscopy. The process of magnification involves focusing a smaller central portion of the input phosphor onto the output phosphor. This results in a smaller portion of the image filling the entire viewing screen. The benefit of magnification is increased spatial resolution. The disadvantage of image magnification is a reduction in minification gain, resulting in a dimmer image that must be compensated for by increasing mA, which, in turn, ultimately results in a higher patient exposure dose.

Multifield tubes usually come with either two or three field-size capabilities. The specific field sizes vary according to manufacturer, but one common combination is 9/6/4.5 inch. The smaller the selected field size, the greater the degree of magnification.

2B Mobile Radiography

By now in your DI career, chances are you have performed many mobile radiographic examinations in different areas of your facility. No doubt, you have learned to draw upon your knowledge of radiographic fundamentals to produce high-quality diagnostic images in less than ideal patient care situations. With the use of direct capture (direct radiography) imaging machines (fig. 2–5), especially in the mobile realm, you are now able to see your image(s) before even leaving the patient's bedside. With mobile DR, processing time is almost eliminated, excluding the amount of time needed for the image to appear on the portable machines' monitor. In addition, primary care providers are able to see a preliminary image on the portable machines' monitor (during emergencies), which allows potential life-saving treatments to get initiated much faster.

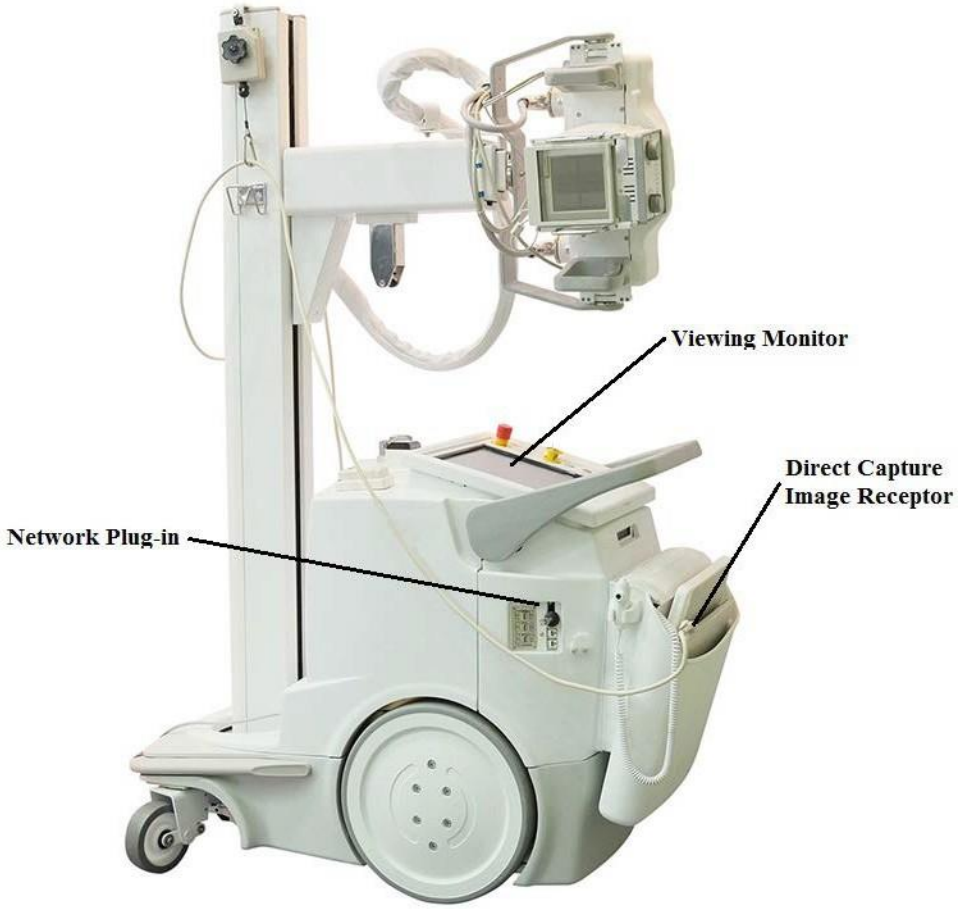


Figure 2–5. Direct capture (direct radiography) mobile imaging machine.

This section discusses unique situations you may encounter while imaging patients in inpatient care areas and in the OR.

2.3 Operating mobile equipment in inpatient care areas

Most facilities have inpatient care areas set aside for patients who need special nursing attention. These areas vary, depending on the size of the institution, but most hospitals have at least a neonatal nursery and an ICU.

Mobile imaging in the neonatal nursery

The neonatal nursery is a place equipped to monitor newborns during the first critical hours and days of life outside the womb. While most infants are born with good health, some have congenital problems or problems associated with premature or complicated delivery. These problems often require radiographic examination. Some examples of neonatal conditions requiring radiographic examination include newborn atelectasis (failure of lungs to expand completely), fractures from birth trauma (e.g., clavicle fractures), hydrocephalus (excess fluid in the ventricles of the brain), and other fetal malformations.

Since newborns gradually acquire immunity to certain infections, reverse isolation often protects them from external sources of infection. Reverse isolation, as you may remember from earlier in this course, is a method of infection control that protects the patient from outside sources of infection. For this reason, radiographic examinations are normally requested as mobile exams to maintain reverse isolation, which protects the newborn from potential sources of infection.

Once you arrive at the neonatal nursery, do not enter the unit with your mobile unit right away. Leave your mobile unit in the hallway next to the nursery or near the nurses' station (depending upon the design of the unit) before entering the neonatal nursery. Find the neonatal nurse and identify him or her which infant you are imaging. Survey the unit for any hazards, and scan the nursey to determine how much room you have to maneuver the portable unit around the nursery. Make note that while surveying the neonatal unit, you will notice some infants may be enclosed in an incubator (an isolation device) while others may not. Regardless of the bed the infants are laying in, all of them are normally designed as a cart with wheels to move the infant around easily without having to physically pick up the infant.

An incubator is a device designed to provide an infant extra warmth, moisture, and oxygen to facilitate growth, while reducing the possibility of a newborn's exposure to an airborne infectious agent. Some infants may be removed safely from the incubator for brief periods to be radiographed; however, you should *never* pick up, handle, or move an infant without first getting permission from the neonatal nursing staff.

If your patient is in an incubator, determine whether the infant can be removed from the incubator for the radiographic exam. If not, have nursing personnel position the baby, so you can radiograph the baby in the incubator. Most incubators come equipped with an imaging tray underneath the incubator. When available, you should use the imaging tray rather than placing the cassette/image receptor directly under the infant, which is the best way to reduce the risk of infection to the infant. If the incubator is not equipped with an imaging tray, you will need to clean the cassette/image receptor with an antiseptic solution (or facility-approved germicidal wipe) and place it in a clean pillowcase or other suitable cover before placing it under the infant. Always have the nursing staff lift the infant while you place the cassette/image receptor under the infant.

Another aspect to consider, since the infants are in carts with wheels, is having the infant wheeled to an area more easily accessible for the mobile unit but especially away from other infants. Some neonatal units have a designated X-ray exposure area where you can take your image without exposing any other infants to unnecessary radiation. Once you've determined where you're going to image the patient and whether to place the image receptor under the patient or in a designated tray, retrieve the mobile X-ray unit and bring it into the nursery.

NOTE: Be careful driving and maneuvering the mobile X-ray machine through the neonatal unit, so you don't bump into any of the other infants' carts/incubators.

You must always radiograph an infant's bedside under the strictest of radiation protection practices. Always show a collimated field of radiation on the radiograph and, whenever possible, shield vital organs for each exposure. Many radiologists prefer to see the lead shielding device on the edge of the image. Including the lead shielding device within the edge of the collimated X-ray field serves as documented proof that shielding was used. However, do not open the collimator field beyond what is needed just to show the shielding device.

When selecting your exposure technique, use the least amount of radiation necessary to produce a properly exposed quality image. If you feel your image is not the correct quality, show the image to your radiologist first before performing any repeats. Though the image may be substandard in quality, any additional radiation exposure should be scrutinized. Always pay close attention to the positioning of the infant as even small amounts of rotation on infant chest images can make evaluating fetal heart size difficult for the radiologist. Don't be afraid to have the nurse adjust the infant patient more than once.

Mobile imaging in the intensive care unit

The ICU is specially designed for patients who are critically ill or whose treatment requires constant nursing attention. Patients in the ICU are rarely brought to the radiology department for routine radiographs because of the tremendous difficulty in transporting all of the equipment required for

patient treatment and monitoring. For this reason, ICU patients are usually radiographed with a mobile X-ray machine.

Some special circumstances you may encounter in the ICU environment involve a large amount of life-sustaining equipment connected to the patient by a maze of cables and tubes, which can create problems when performing mobile radiography. Although you do not need to be familiar with the operation of all of the various respirators, catheters, pumps, and monitors, you must be especially careful not to disturb the function of any of these devices. Undoubtedly, you will need to move or adjust some of the equipment to obtain the requested images, but you should always first discuss the situation and the patient's condition with nursing personnel to find out what actions are tolerable for the patient and the equipment before attempting the exam.

Some of the common devices encountered in an ICU include nasogastric tubes, closed-chest drainage tubes, specialized catheters for patient monitoring and/or drug therapy, and tracheostomy tubes connected to a ventilator. Each type may pose a problem in positioning a patient and an image receptor to obtain an exposure. When it comes to moving the patient to position the image receptor, seek assistance from the ICU staff. If you need to roll or lift a patient for image receptor placement, always move the patient toward a tube, especially if it is a breathing or chest tube. Moving a patient away from a tube may dislodge it and jeopardize the patient's condition. Other drainage devices may be situated near the patient or attached to the side of the bed. To avoid a serious accident, always survey the immediate area around the patient's bed before you bring in the mobile X-ray unit.

Though you should accomplish the portable X-ray as quickly as possible, never put the patient at risk by going too fast and being careless. Avoid crimping, bending, or removing any tube or line from the patient accidentally. Doing so could jeopardize the patient's condition.

Lastly, do not forget patients are a human beings. Treat them with respect and dignity at all times as they fight for their health (or life). A patient may or may not be conscious, but you should always speak to the patient and inform him or her of what you will be doing. Some patients are aware of what is going on even if they are unable to respond.

Mobile imaging orthopedic-traction patients

Orthopedic traction may be applied by any one of a number of devices that use weights and pulleys to constantly pull on a part of the body. The lumbar or cervical spine may be placed in traction to relieve muscle spasms or spinal stress, or a fractured long bone, such as the femur, may be placed in traction to keep the fragments aligned until muscle spasms subside and the patient can be taken to surgery for open reduction/fixation.

You must be careful when working around a traction device. An accidental bump against the bed or the traction device can cause severe pain to the patient. Always ask the patient if a certain motion is tolerable before positioning, and let the patient assist as much as possible with any moving or lifting when you are positioning for the radiograph. If you are unsure what movements are allowable for the patient's condition, check with nursing staff who are familiar with the patient's condition. The sudden release of traction can cause serious complications, such as bone fragments lacerating a blood vessel or pain-induced shock. You should never release traction without the assistance of nursing staff.

In some instances, a traction device will require you to alter your beam-part-receptor alignment or SID. Be creative in attempting to obtain the necessary views. Often times, the cross-table technique will be the only way to obtain laterals.

Bedside mannerisms

A very important, yet often overlooked, aspect of mobile radiography is your bedside manner with patients. Bedside manner is how you show courtesy, respect, and consideration for the patient while communicating and performing an exam on him or her. When performing *routine* portable radiographic exams, contact the patient's nurse before leaving the DI department to make sure, upon

your arrival, that it is a good time for the staff and the patient. Most routine portable exam orders do not need to interrupt a patient's mealtime, nap, or visitation time with family and friends.

When you reach the ward, check with the patient's nurse and ask about the patient's condition before proceeding to the room. Do not enter the room with your mobile X-ray machine before first entering alone to introduce yourself and explain the procedure. This also gives you a chance to move any obstacles out of the way, like an IV pole, before you bring the X-ray machine into the patient's room. Above all, treat the patient as you would want your mother or father to be treated in the same situation. Show a genuine interest in the patient and continue a polite conversation with him or her while you work. Being courteous and respectful will go a long way in gaining patient cooperation.

Radiation protection considerations

Sometimes, when performing mobile radiography, it is not possible to achieve normal SID because of conditions beyond your control, such as the presence of traction devices and other patient-care apparatuses. In these circumstances, you may reduce the SID as necessary, as long as the source-to-skin distance (SSD) is not less than 12 inches. Federal guidelines limit the minimum SSD to 12 inches because of skin dose. The SSD is the distance from the focal spot to the patient's skin. Most mobile units have collimators, which protrude 12 inches from the tube to make it impossible to fall short of this requirement.

Always practice the radiation protection concepts of time, distance, and shielding. When setting your exposure technique, use the shortest amount of time necessary to achieve a quality image. Use distance to reduce your exposure to radiation and make sure other staff or family members do the same. The minimum recommended distance to stand away from both the radiation source and patient is 6 feet. It is also recommended to stand at a right angle to the primary beam and patient, as less scatter radiation is produced at this position. To help achieve the six-foot distance, make sure mobile X-ray unit exposure cords are at least 6 feet long, as required. Using distance is one of the best protective measures against exposure that you can employ.

Federal guidelines also require you wear a protective apron of at least 0.25 mm lead equivalent. For this reason, all mobile X-ray units **must** have a lead apron stored with them. If you are going to an open bay area, such as a surgical recovery unit, you will need to bring extra lead aprons to protect other patients and personnel in the immediate vicinity. In addition to time, distance, and shielding, never forget to practice the other prevalent radiation protection concept, ALARA, which stands for *As Low As Reasonably Achievable*. Remember, ALARA aims to produce high-quality images while using the least amount of technique needed to do so.

Finally, always remember to announce that you are about to make the exposure so that other hospital personnel can step away. The proper method of announcing you are ready to make an exposure is to say "X-ray" loudly. After waiting 15–20 seconds (time for people to step away from the X-ray machine vicinity), announce "X-ray" a second time right before giving any breathing instructions to the patient. After the exposure has been completed, have the patient relax and breathe, then announce "clear" loudly to inform other staff members that it is safe for them to return to the area.

2.4 Operating mobile equipment in the operating room

The surgical environment is very different from almost any other environment the radiographer encounters. The first several trips to surgery can be especially apprehensive for a new technologist. With experience, knowledge of OR policies, and confidence, you too can feel just as much at ease in an OR suite as you do in a fixed radiography room in the main DI department. This lesson outlines the fundamentals of performing mobile exams in the OR, to include maintaining asepsis, sterile versus non-sterile OR areas, and performing OR exams.

Maintaining asepsis

As previously learned in this course, asepsis means the absence of infection. Maintaining asepsis in the OR suite is the act of preventing the spread of infectious microorganisms in the sterile setting. Although the hospital setting uses many techniques and methods that fit under the heading of aseptic technique, nowhere in the hospital is asepsis more important than in the OR.

Surgical attire

One important method, which is changing into special surgical clothes prior to entering the restricted area in the OR, reduces the amount of bacteria introduced into the OR. All surgery departments have special surgical clothing, commonly referred to as "scrubs," which must be worn in the restricted area. Most times, you will change into scrubs in the main DI department and then make your way to the OR. Once you arrive at the OR and step into the limited access area, a cart is usually present that holds other articles you must don before being permitted to enter a surgical suite.

These items include a disposable mask that covers your mouth and nose, elastic bouffant head/hair covers, and disposable shoe covers. These items are worn for the duration you are in the OR suite. Of course, latex-free, nonsterile gloves are donned in keeping with practicing standard precautions whenever handling any item that is potentially contaminated with blood or bodily fluids. Another aspect, sometimes overlooked, is the type of clothing worn in the OR. All scrubs are made of cotton because cotton is considered a neutral material that does not build up static electricity. Nylon is a material that tends to give off electrons, and polyester is a material that tends to attract electrons. For these reasons, all clothes and undergarments worn in the OR should be made of cotton to prevent the discharge of static electricity, which could cause a flash fire because of the oxygen and other flammable gasses used by the anesthetist. Full-length lab coats (or cover gowns) are sometimes required to be worn over surgical scrubs when leaving the OR area. This is a policy based on a specific; therefore, make sure you are aware of and follow the established scrub-wear policies for your facility. Scrubs worn uncovered to the dining hall or outside the facility have to be changed out prior to being worn back inside an OR suite.

Disposable articles (mask, hair bouffant, and shoe covers) should be removed when exiting the OR suite and disposed of in appropriate receptacles. It is important to state that your mask and hair bouffant can be reused if you have to reenter the OR suite from the limited access area. However, shoe covers must be discarded once worn outside the surgical area.

Cleaning the mobile unit

Another potential source of bacteria and other infectious microorganisms is the mobile X-ray unit. Many larger facilities will keep mobile X-ray units in surgery at all times to reduce the possibility of contamination in the OR. If your hospital does not, you must thoroughly wipe down the mobile unit, or C-arm machine, with a germicidal wipe (fig. 2–6) before entering the restricted OR area.
Make sure to disinfect the entire piece of equipment, making certain to concentrate on areas of the mobile unit that are inherently the dirtiest (e.g., the wheels and power cord).

Figure 2–6. Germicidal wipes.

The need to clean your mobile unit is not difficult to understand when you

consider the tube head is usually positioned directly over the operative site. Even though the site is usually covered with sterile drapes while you perform your radiographs, dust particles falling from your tube head might contaminate the sterile area. Some surgeons may require you cover the tube head with a sterile pillowcase or clear plastic cover *after* the machine has been cleaned to reduce the danger of further contamination. Clear plastic is preferred because it permits visualization of the light field from your collimator.

In general, equipment should be cleaned before entering an OR suite and again after leaving the OR suite to eliminate the spread of infection by cross-contamination from procedure to procedure. Always wear disposable latex-free gloves when handling germicidal wipes and cleaning the equipment.

Sterile versus nonsterile areas

During "open" surgery, where an incision is made into the body, the OR is considered to be divided into two areas: sterile and nonsterile.

Sterile area

The area in the OR suite that is the most critical for practicing aseptic techniques is the sterile area. The sterile area is concentrated around the operating site, including areas immediately surrounding the patient, his or her incision, the surgeon and the surgical assistant, surgical instruments, and the tables, trays, and stands that hold the instruments. In addition, there is a *sterile corridor* between the patient drape and the instrument tables.

The only people allowed in this corridor are the surgeon and the surgical assistant. Since you, the radiographer, are not considered "sterile," you must *never* enter the sterile corridor. As well, never allow your machine or clothing to come in contact with any part of the sterile area in the OR or the surgeon or surgical assistant's sterile gown.

Nonsterile area

The nonsterile area is everything in the OR outside the sterile area. People and equipment in the nonsterile area include the anesthesiologist, the OR nurse, you, the mobile unit, and various other support staff and equipment items commonly used in the OR suite. As you do the radiographic examination, you must avoid contaminating or contacting any part of the sterile area. Usually, it is a good practice to extend the horizontal tube arm as far as possible so that when you position the tube head over the patient, the remainder of the unit is as far from contaminating the sterile field as possible.

Performing radiographic exams

Numerous surgical procedures require radiographic support. Discussing all of them in this course is impractical. Instead, this area discusses some basic characteristics that pertain to working in the OR.

Technical considerations

Imaging body parts in the OR tends to require a better understanding of anatomy and X-ray physics than in routine fixed radiography. In the fixed radiography room, you can instruct most of your patients to achieve the prime anatomical position for each radiographic exposure. In the OR, the arm, leg, or body will unlikely be in the best position for radiographic imaging, and you are the one who has to position your tube head and image receptor in a manner that provides a true representation of the body part. Your skill, as a radiographer, will be tested and on display for everyone in the OR suite to evaluate at this point. It is imperative that you understand how to line up your central ray to the anatomical structures you can visualize, as most aspects of the patient will be covered with the sterile drape. Another consideration is *beam-part-receptor alignment*. Whether your image receptor is in a tray under the surgical table or held for a cross-table exposure, you must align the X-ray beam (tube head) perpendicular to the image receptor so as not to cause any shape distortion of the body part.

Another consideration is technique selection. When imaging open-wound sites in the OR, it is normal that more blood is in the region because of the procedure being performed. In addition, the area of imaging interest may have gauze or metal surgical devices in the immediate vicinity that you cannot remove. All of these things will absorb more X-ray photons during the exposure; therefore, it is customary you may need to increase your technique selection (a station or two), as compared to a normal exposure of the same body part. With on-the-job-training and experience, selecting a technique in the OR will be as routine as it is for you in fixed radiography.

Whenever you must repeat a radiograph made in the OR due to poor image quality, you are effectively increasing the length of the operation. Accordingly, the patient remains under anesthesia for a longer time. It is critical that you achieve the proper density levels and scale of contrast, along with correct positioning. Incorrect exposure is probably the most common reason for repeating mobile radiographs, though digital imaging now helps to reduce repeats for this reason. Very seldom is there a technique chart available for you to reference, so you should maintain your own notebook of techniques (whether in paper or electronic format).

To be successful in the OR, you will need practice. In the beginning, though, an experienced OR-trained imaging technologist should accompany inexperienced technologists in the OR to reduce repeats and accelerate the learning process as much as possible. Whenever possible, scout images taken in advance of the OR procedure serve to improve your ability to select an appropriate technique, and improve image quality and accuracy.

Speed

Surgeons and anesthetists or anesthesiologists try to finish surgery as quickly as possible to minimize the anesthetic time (the amount of time the patient is under anesthesia). During some surgical procedures, the surgeon cannot continue to work until he or she examines the radiographs you produce. This means you should efficiently and accurately perform the radiographic examination(s) and display the images as quickly as possible for the surgeon to review. The surgical staff will greatly appreciate your assistance in reducing the patient's anesthesia time, even though the gratitude is almost never verbalized.

Using grids in the OR

Larger body parts require that you use grids to produce a quality radiograph. Make sure you know the technical details for the grid you're using. Though not always achievable, get as close to your grid radius (focal distance for a focused grid) as possible to avoid grid cutoff. One way to help prevent grid cutoff is to use a grid with a low grid ratio; doing so increases the tolerable amount of lateral decentering.

Some technologists prefer to mark the location of the wheels on the floor when taking a scout image, so they can return the mobile unit to the same location. Naturally, the position of the X-ray tube, with respect to the grid, must be correct for the scout radiograph if this concept is helpful.

Radiation protection considerations

Don't forget to employ the same radiation protection practices in the OR as you would with any other mobile radiographic exposure. When surgical cases will need X-ray support, sterile personnel normally don lead gowns first before putting on their sterile gowns. It is your responsibility, prior to making an exposure, to make sure sterile members of the surgical team don lead gowns. For other nonsterile members, make sure they have lead gowns or have the opportunity to step back from the source of exposure.

Make sure to wear your thermoluminescent dosimeter (TLD) for ***every*** mobile radiography procedures. When you don a lead gown and wear only a *single* dosimeter, remember (as mentioned from a previous lesson in this course) that the dosimeter is worn at the collar level and outside of your clothing and your lead gown. If your DI department uses the two-dosimeter system, wear the collar dosimeter at the collar level and outside of your clothing and your lead gown/thyroid shield.

Secondly, wear the body dosimeter on the front of the body outside of your clothing but *under* your lead gown at the level of the waist. For accurate exposure readings, it is important to wear the correct dosimeter always in the correct body region.

Finally, announce when you are about to make exposures so that members of the OR team can step away or position themselves behind lead. If using a portable X-ray unit in the OR, the proper method to announce you're ready to make an exposure is the same as with a regular mobile radiography. Announce "X-ray" loudly once, wait 15–20 seconds (time for people to step away from the X-ray machine vicinity), and then announce "X-ray" a second time right before making the exposure. After you complete the exposure, announce "clear" to inform everyone in the OR suite that it is safe for them to return to their work.

When using a mobile fluoroscopy machine (a C-arm unit), the surgeon may use a foot pedal switch to activate the X-ray source during the procedure. If you are running the C-arm unit, each time the surgeon wants an exposure, you should state "X-ray on," hold the exposure button long enough for a quality image to appear on the display monitor, and then terminate the exposure. Once the X-ray source is off, state "X-ray off". Stating "X-ray on" and "X-ray off" not only communicates the need for OR staff members to step back and seek lead protection, but it also serves to communicate with the surgeon that you heard and performed his or her request for an image.

2C Bone Densitometry

Osteoporosis is a condition that involves the gradual loss of calcium, causing bones to become more fragile and more prone to fracture. Though osteoporosis mostly affects postmenopausal women, it is estimated 2 million men have the disease with the possibility of 12 million more at risk of developing the disease. Different bone-mass quantification methods have been used through the years to evaluate osteoporosis like radiographic absorptiometry and radiogrammetry.

In the 1970s, quantitative CT used specialized software-processing techniques to measure bone loss in the center of a vertebral body. By the early 1980s, the first dedicated bone-densitometry scanners began to be used to measure bone-mineral content. These early bone-density scanners used single- and dual-photon absorptiometry technology and a highly collimated beam generated from a radioisotope. By the late 1980s, dual-energy X-ray absorptiometry (DXA) began to appear for commercial use. DXA scanners improved detection of lower density levels and overall image quality and reduced costs associated with this type of procedure. In this section, you will learn about basic bone-densitometry principles, common exams, and associated automatic QC measures. We begin with densitometry principles and common exams.

2.5 Bone-densitometry principles and performing common exams

Bone densitometry is a technique used to measure the mineral content and density of bones. Once measured, the density values are used to evaluate bone strength, diagnose low bone-density conditions (like osteoporosis), monitor low bone-density treatments, and determine fracture-risk levels. Bone-densitometry scanners use low-dose ionizing radiation to measure mineral-content levels in specific areas of the body common to frequent fractures. Improvements in technology have helped advance the field from examining plain X-rays with the naked eye to using highly sophisticated computed analytics to graph photon absorption.

The most common sites scanned are the lumbar spine, proximal femur, and forearm. Manufacturers provide instructions to perform and position patients for different types of DXA studies that can be performed on their devices. Manufacturers' recommendations should always be considered when determining scanning protocols. Before learning the steps to perform a bone-density exam, we must first discuss the principles of this radiologic technique.

Principles of bone densitometry

Bone densitometry, unlike plain radiography, is a quantitative measurement technique. This means the primary focus is on the measurement of *bone mass* (or density) versus structural integrity.

Accuracy and precision of the imaging system are two areas of importance when performing bone densitometry. *Accuracy* refers to the ability of a bone-density system to calculate the true mineral value (density) of a bony structure. *Precision* refers to the ability of a bone-density system to reproduce the same result for a certain bony structure repeatedly. When bone densitometry is used to diagnose osteoporosis or predict the risk for fracture, it is imperative the initial scan be accurate.
However, when tracking change in bone density, precision becomes the focus.

Bone structure and characterization

Bone is alive and constantly remaking itself through a process in which old bone is replaced with new bone. Though bone structure was discussed earlier in this course, we must review two structural areas of all bones and, in turn, introduce how bones are characterized specifically for bone-densitometry exams. For this lesson, we are only concerned with two basic structural components of bone: the cortical and trabecular.

Cortical

Cortical bone is the dense, outermost portion of a bone. It is present on all bones but is most recognizable on the shaft of long bones. Cortical bone encompasses bones to create a strong shell, which helps support weight and resist the forces of bending or twisting. Cortical bone makes up approximately 80 percent of our skeletal mass. Some predominant cortical sites are the femoral neck, the distal third of the forearm, and the phalanges. Figure 4–4 illustrates the approximate cortical versus trabecular bone make-up for various, common bone-density regions of interest.

Trabecular

Trabecular bone is the delicate, web-like material located inside the bone. The web-like material adds to the overall strength of the bone without adding excessive weight. Trabecular bone is the essential structural element that is needed to help support all the compressive weight forces put on the spine, hip, and calcaneus regions.

Bone characterization

In the field of bone densitometry, the skeleton is additionally categorized by purpose and location as follows:

- **Weight-bearing or nonweight-bearing**—The spine, lower extremities, and portions of the pelvis are weight-bearing while all others are considered nonweight-bearing.
- **Axial or appendicular**—Axial bones are those that comprise the spine and are directly connected to the spine. Appendicular bones are all the appendages of the human skeleton, like the upper/lower extremities, shoulder girdle, and pelvic girdle.
- **Central or peripheral**—Central sites are the thoracic and lumbar spine and the proximal femur. Peripheral sites are the distal forearm, phalanges, metacarpals, tibia, and the calcaneus.

Density measurements

A bone-density scanning system measures three quantities during a scan: (1) the bone-mineral density (BMD), (2) the bone-mineral content (BMC), and (3) the actual area of the bone (width and depth of the bony structure). The bone-mineral density is expressed as grams per centimeter squared (g/cm^2), the bone-mineral content as grams (g), and the area as centimeters squared (cm^2). To associate a patient's BMD with the population BMD mean, the bone density system software determines two scores: a T-score and Z-score.

The *T-Score* is a number that represents a comparison of the patient's BMD for a specific anatomical site to that of a healthy 30-year-old same gender young adult. A T-score of negative one (–1) is considered normal. An osteopenia (low bone mass) patient will have a T-score between –1 and –2.5. A patient with a score below –2.5 is considered to have osteoporosis. Radiologists use the T-score to estimate the patient's fracture risk. The *Z-score* is a number that represents a comparison of the patient's BMD to that of other individuals of the same age, gender, and ethnicity. If the radiologist determines the Z-score is too high or low, further medical tests may be needed to diagnosis the patient's symptoms/condition properly.

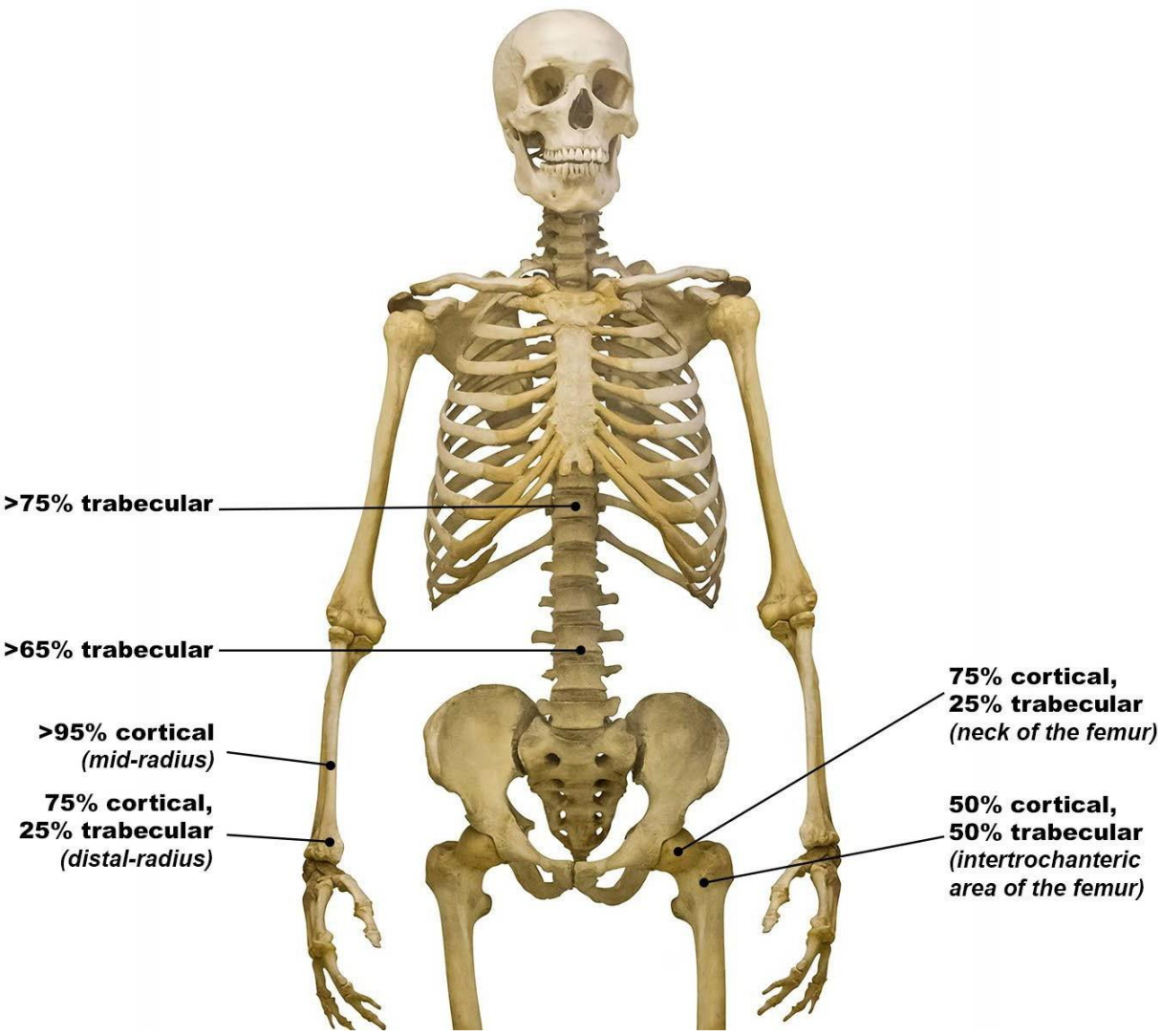


Figure 2-7. Cortical versus trabecular bone-structure percentages.

Methods of determining bone-density levels

Radiographic absorptiometry (RA) is an early version of bone densitometry that involved two X-ray exposures of the left hand on nonscreened film taken at slightly different exposures, such as 50 kVp at 300 mA for 1 second and 60 kVp at 300 mA for 1 second. An aluminum-alloy reference wedge was placed parallel to the middle phalanx of the index finger. Both exposures were then sent to a laboratory to be digitized, analyzed, and reported to the physician for interpretation. Introduced in the 1960s, *radiogrammetry* was widely used because it was inexpensive; however, radiogrammetry was very labor intensive and not very precise. In recent years, this form of BMD analysis has been reinvigorated with the application of modern computer methods. By the early 1980s, the first dedicated bone-density scanners were introduced using photon-absorptiometry technology.

Photon absorptiometry is the basis for modern bone densitometry. Single-photon absorptiometry (SPA) was the first type of absorptiometry to acquire accurate and precise readings successfully and to help radiologists diagnose bone-mineral diseases. Over time, technological advances have led to the development of DXA, which currently, is the most commonly used scanning technique. The following discussion breaks down four different ways the photon absorptiometry technique is used in the field of BMD analysis.

Single-photon absorptiometry

SPA determines bone density by sending a single-energy photon through the bone and soft tissue. The difference between the initial beam intensity and the intensity after attenuation is to quantify the amount

of mineral in the bone. SPA is both accurate and precise but is no longer performed due to improvements and ease of use in single-energy X-ray absorptiometry (SXA) and DXA.

Dual-photon absorptiometry

Dual-photon absorptiometry (DPA) has the same basic principle as SPA to quantify the attenuation of the photon energy beam. However, DPA used either a single isotope that emitted photon energy at two distinct peak values or two isotopes that emitted photon energy at the same peak value. DPA proved to be more useful in measuring total body-bone density, the spine, and proximal femur. Like SPA, DPA is no longer performed.

Single-energy X-ray absorptiometry

SXA is the X-ray counterpart of SPA and is used to measure bone density in the distal radius and calcaneus. The radioactive isotopes have been replaced with an X-ray tube. Using an X-ray tube instead of radioactive isotopes has many advantages. First, X-ray tubes are more cost efficient because there is no source decay, which accounted for radioactive isotopes frequently being replaced. Secondly, source decay also contributes to drift-in patient values, which lowered the integrity of the scan. Third, X-ray tubes have great source intensity and smaller focal spots that allow for better beam collimation, which results in less overlap between scan lines, greater image resolution, and shorter and more precise scans. SXA required a patient to either have a water bath ahead of time or to use a tissue-equivalent gel on the part being evaluated. SXA is extremely precise and accurate but is now obsolete due to portable DXA.

Dual-energy X-ray absorptiometry

The basic principle of DXA is the same as described with the DPA technique. A DXA system uses a thin pencil- or fan-type beam array consisting of low-dose X-rays with two very distinct energy levels emitted from an X-ray tube to measure the BMD of the region of interest. Figure 4–5 illustrates a typical DXA imaging unit (system), while figure 4–6 shows a sample DXA exam room. The theory behind DXA technology is that the peak of one energy level is absorbed by the soft-tissue structures, while the other energy level peak is destined to be absorbed by the bone. The scanning software formulates the T- and Z-scores (discussed previously) by subtracting the amount of ionizing radiation absorbed within the soft-tissue structures from the total amount introduced to the bony structure by the two energy levels. The result is the patient’s BMD.

Despite SPA and SXA being more accurate and precise, DXA is the most common type of bone-densitometry machine manufactured for clinical use, making DXA the preferred technique used in the field of bone densitometry.

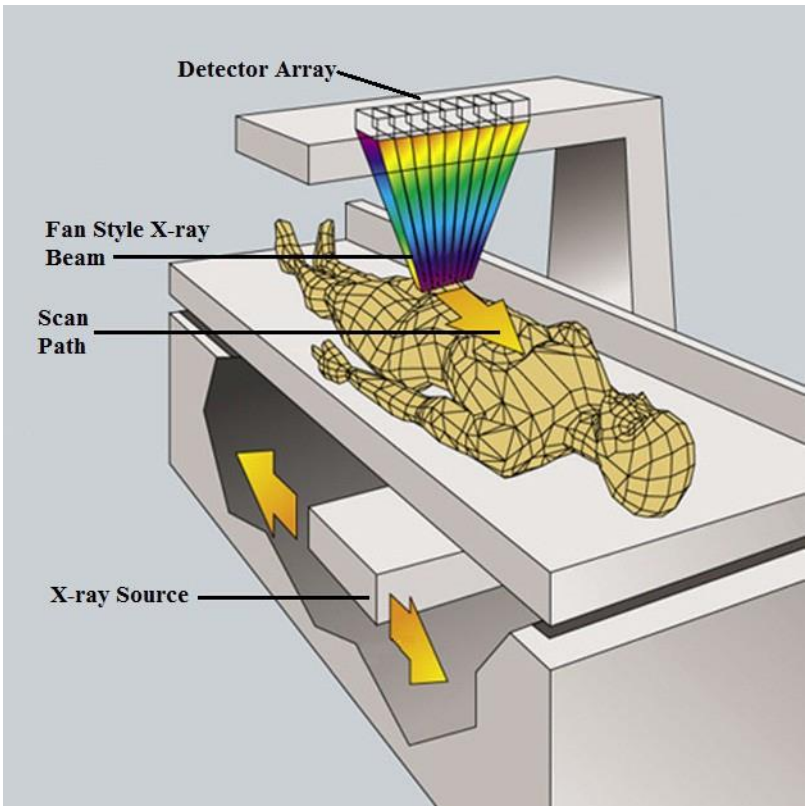


Figure 2–8. Illustrated DXA system.

Figure 2–9. Sample DXA exam room.

Common bone-densitometry examination sites

The three most common sites for a bone-densitometry scan are the lumbar spine, proximal femur, and forearm.

Lumbar spine

The lumbar (L) spine is classified as a weight-bearing, axial, and central site. The ideal positioning goal for an L-spine density scan is a straight spine and clear separation of the vertebrae, level iliac crest, and visible ribs.

Positioning

Lay the patient flat on his or her back (supine), as straight as possible on the exposure table and with his or her knees bent (flexed) upward at an approximate 45°–90° angle. With the knees bent upward, the curvature of the spine is reduced and the intervertebral disc spaces are more open. You can place a positioning sponge under the patient's knees to help achieve this position. Check to make sure the patient is straight and palpate for the crest to make sure he or she is level. Also, make sure the pillow, if the patient uses one, is not under the shoulders to verify the entire spine is on the same plane. As you start the scan, look to make sure the vertebrae are straight and centered. Try to avoid scans that migrate (lean) to one side. In the case of scoliosis, try to keep the spine as centered as possible and follow the manufacturer's guide as to how to mark the vertebral spaces properly.

Anatomy

The scan should include the 12th thoracic vertebrae through the first sacral segment to ensure all of L1 through L4 (fig. 4–7), and their disc space, are included. Patients with severe thoracic kyphosis or arthritic changes may have limited vertebral spacing and this should be noted to the radiologist.

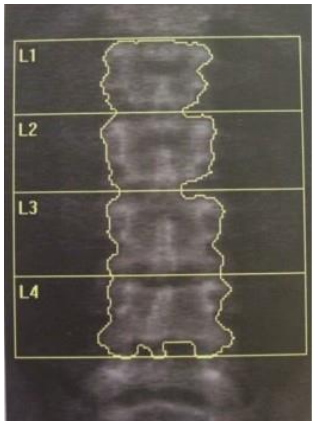


Figure 2–10. Sample L-spine DXA scan.

Proximal femur

The proximal femur (or femoral neck) is classified as a weight bearing, appendicular, and peripheral site. Unless the technologist has been instructed to perform a bilateral study, the first decision should be to determine which femur to scan. The left femur is the default due to the accessibility on the table. The main indicator of performing a right femur over a left is if the patient has a known fracture or orthopedic hardware in the left side. Also, if the patient has known scoliosis, unilateral osteoarthritis may be present. If this is the case, scan the less affected hip.

Positioning

Lay the patient supine on the table with the femur parallel with the table. Rotate the feet internally, approximately 20°, to reduce the appearance of the lesser trochanter. Most manufacturers include a positioning device with a strap to hold the patient's leg in place. If the device does not allow for enough rotation, use the "cross-ankle" technique. The cross-ankle technique is accomplished by first rotating the leg of interest to the desired angle; then second, have the patient place his or her other leg over top the leg of interest at the ankles.
Instruct the patient to use his or her foot on top to hold the lower leg in place. Make sure the femur is properly rotated and that the femoral shaft is straight.

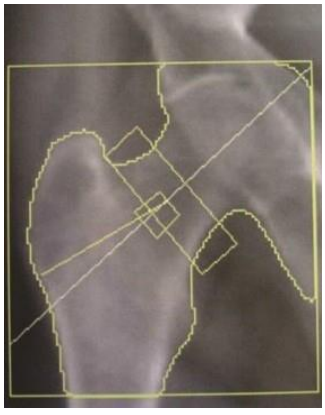


Figure 2–11. Sample hip DXA scan.

Anatomy

The entire femoral head and acetabulum as well as the entire greater and lesser trochanter (fig. 4–8) should be visualized. Once you start the scan, if you realize that the lesser trochanter is too large, rotate the leg more medially.

Forearm

The forearm is classified as a nonweight-bearing, appendicular, and peripheral site. If there is no contraindication, the nondominant forearm should be scanned. The dominant forearm tends to have a higher bone-density level.

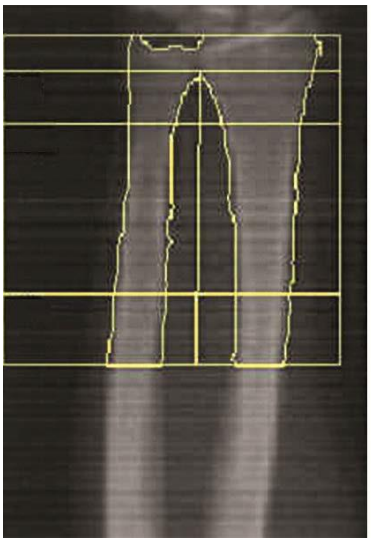


Figure 2–12. Sample distal forearm DXA scan.

Positioning

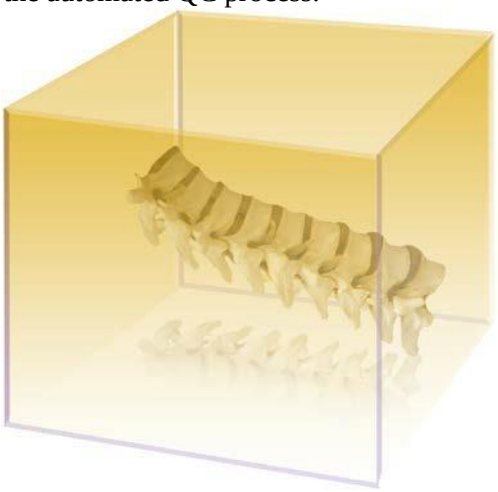
Unless you have a unit dedicated to peripheral structures, position the patient by seating him or her next to the table with the forearm of interest resting on the table. Use a chair, in which the height can be adjusted, to accommodate short and tall patients so they are seated comfortably with their forearm resting on the table's surface. Some manufacturers provide a positioning device to properly position the forearm. Place the forearm flat on the table, centered to the exposure field with the fingers slightly curled under to relax the carpal bones. If the patient's arm is too short, you can have the patient lean-in. If this is the case, be cautious that the arm of the machine will not hit the patient in the head while performing the exam.

Anatomy

The forearm should appear straight, centered, and unrotated. The study should include the radial styloid as well as the distal forearm (fig. 4–9). All of these factors are achievable and completely necessary.

2.6 Quality-control features

Strict QC guidelines are paramount to precision and accuracy of the bone-density data. Poor or absent QC measures can lead to an incorrect or inaccurate diagnosis of bone-mineral diseases and repeat exams (increased patient dose). QC is the most effective way to detect when a machine is starting to lose accuracy and precision. The software included with densitometry systems now performs the most common QC methods automatically. The technologist's role is to scan a QC phantom (fig. 4–10) in
which the software uses and plots the test-scan data to determine if the system is performing within specifications. The data is plotted internally and evaluated using one of two densitometry QC applications: the Shewhart-rules chart or the cumulative sum (CUSUM) chart. First, we begin with the automated QC process.



Automated quality control

For ease and safeguarded QC, almost all densitometry systems have been manufactured with automatic QC procedures built-in. These automated QC procedures are internal to the unit and make sure densitometry systems consistently perform to stated specifications. Your role in this process is to scan the phantom, according to the manufacturer's guidelines.

Once you scan the phantom material using the QC software, the system plots the data for you and informs you if the densitometry system is performing up to specifications. Your role in the automated QC process can be broken down into these six basic steps:

1. Power on the machine and retrieve the phantom.
2. Position the QC phantom on the exposure table correctly, according to the manufacturer's specifications.
3. Run the QC program scan included with the densitometry system software.
4. Read the results thoroughly and note any error messages or values identified as out of compliance.
5. Document, by signing and dating your local tracking mechanism, that the QC tests were accomplished and state the results.
6. Store the phantom for safekeeping.

   Once you have completed the phantom scan, the data is automatically applied to either the Shewhart chart or CUSUM chart to interpret how the unit is functioning.

Shewhart rules

As part of the automated QC process, Shewhart charts (and rules) are applied to the system during the phantom scanning. After evaluation, the QC software will send a pass, fail, or warning message to you on the computer monitor via the system's software as a pop-up message. Do not ignore the automated QC messages. Make sure to record them in your QC tracking mechanism, according to your department policies. If an error or out-of-compliance message is received, report it to your imaging floor supervisor and medical equipment repair center (MERC) for appropriate servicing.

Even though the QC process is automated, you should understand how the phantom scan data is applied using the Shewhart rules. To apply the Shewhart-rules chart, you must first establish a baseline set of parameters for the QC program to be useful. A baseline can be established in two ways: (1) the preferred method is to scan the phantom for 15–25 consecutive days, according to the manufacturer's QC recommendations, or (2) scan the phantom 10 times in the same day, according to the manufacturer's QC recommendations. The software then calculates and plots the machine's average precision value and standard deviation (SD) on a Shewhart chart.

You should be aware of the following five rules that the software applies to the phantom scan data. These rules are used to determine if the densitometry system is performing within specifications.

1. If a phantom BMD value exceeds the average by ±3 SD (3 SD or 1.5 percent rule).
2. If two consecutive phantom BMD values on the same side of the average exceed the average by ±2 SD (2 SD twice or 1 percent twice rule).
3. If two consecutive phantom BMD values differ by more than ±4 SD (range of 4 SD or range of 2 percent rule).
4. If four consecutive phantom BMD values on the same side of the average exceed the average by ±1 SD (four ±1 SD or four ±0.5 percent rule).
5. If 10 consecutive phantom BMD values fall on the same side of the average, regardless of their distance from the average (mean times 10 rule), report them to the MERC (or the manufacturer), so the machine is serviced appropriately.

NOTE: Until the service is completed and any QC issues are corrected, you should not perform any bone-density scans.

Figure 4–11 shows a sample Shewhart-QC chart. Make sure to always reference the manufacturer's guidelines and steps for monitoring equipment performance.

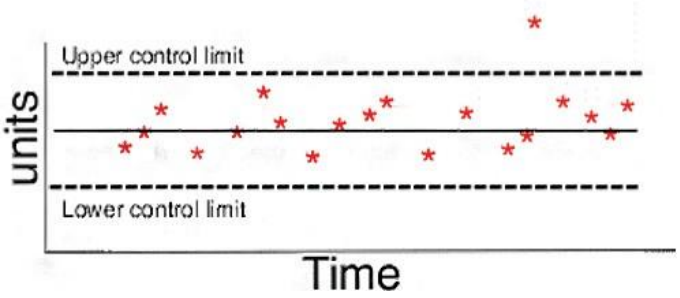


Figure 2–13. Sample Shewhart-QC chart.

Cumulative sum charts

CUSUM charts are also used to monitor QC of densitometry systems. It is a manufacturer's decision as to which QC method is used for monitoring its densitometry system. CUSUM charts are not as easy to use as Shewhart charts and are often employed by professional densitometry QC centers.

Again, though, you must establish a baseline set of parameters for the system to apply the QC program. The baseline, as we mentioned, is a set of phantom scans over a 15–25 day period. The QC program software then calculates the mean level and SD, and then a graph is created to visualize the results. All subsequent scans are calculated by finding the difference between the machine's average precision value and all subsequent precision (QC) values.

Though more difficult to use, the CUSUM charts typically make it easier for you to visually monitor the densitometry system performance via the graph displayed. As with the Shewhart chart, document and report any error or out-of-compliance messages the QC software provides via the monitor. If the system fails a QC test, notify your imaging floor supervisor and MERC for servicing.

Unit 3. Computed Tomography

3A Fundamentals of Computed Tomography..... 57
3.1 Technical aspects of computed tomography image formation..... 58
3.2 Types of computed tomography scanners..... 63
3.3 Cross-sectional anatomy..... 68
3B Computed Tomography System Components..... 74
3.4 Gantry assembly and patient couch apparatus..... 74
3.5 Computer system..... 77
3.6 Operator's console..... 79
3C Patient Preparation and Radiation Safety..... 84
3.7 Patient preparation..... 84
3.8 Radiation safety in computed tomography..... 88

COMPUTED TOMOGRAPHY has been perhaps the most significant advancement in the field of radiology since Wilhelm Roentgen discovered X-rays in 1895. CT provides a means of obtaining cross-sectional images on live patients for diagnosing and treating disease(s). Since its invention in the late 1960s, the technology behind CT has been adapted for use in MRI, nuclear medicine single-photon emission CT (SPECT) imaging, and positron emission tomography (PET) imaging, providing a wealth of diagnostic information previously unavailable to clinicians. Over the years of development, CT has been called computerized axial tomography (CAT) scans, computerized transverse axial tomography, reconstructive tomography (RT), and computerized tomography, or computed tomography. CT is the term that has been commonly accepted to identify this diagnostic tool.

CT has been used in the clinical setting since the early 1970s. The first CT scanner, a dedicated head unit, was installed at Atkinson Morley's Hospital, London, England in 1971. The Mayo Clinic and Massachusetts General Hospital obtained the first units for the United States in 1973. Georgetown University Medical Center installed the first whole-body scanner in 1974. Since then, with the rapid advancements in computer technology, CT has undergone many improvements; however, the basic operational principles remain the same.

In this unit, we cover the fundamental aspects of CT and CT system components, and look at some patient preparation and radiation safety aspects.

3A Fundamentals of Computed Tomography

Because of technological limitations, early CT scanners were only capable of imaging the head and were very slow at doing so. Extremely long scan times of up to 5 minutes per slice precluded imaging other parts of the body because of involuntary patient motion. Technological advances over the past 30 years now allow CT scanners to image every part of the human body in a very short amount of time. In fact, for most CT exams, it takes longer to prepare the patient and set up the exam protocol than it does to acquire the CT images physically. Today, CT is one of the most widely used DI modalities. The most common body parts imaged with CT are the head, cervical spine (C-spine), chest, abdomen, and pelvis. In this first section, we will cover the technical aspects of CT image formation, outline the different types of CT scanners, and dive into understanding cross-sectional anatomy. The first lesson opens with discussions on some of the technical aspects (physics) of image formation.

3.1 Technical aspects of computed tomography image formation

CT is still a radiation-based imaging modality that produces images as slices of the body. Computers are used to perform a tremendous amount of mathematical equations, simultaneously, to reconstruct viewable images from electronic signals. Here, we will discuss how CT images are acquired, image visualization creation, how the image matrix pieces together electronic signals into a viewable image. We will also cover Hounsfield units, advantages of CT over conventional radiography, and some image quality factors to consider.

Computed tomography acquisition simplified

CT is a radiation-based imaging modality that produces cross-sectional images (slices) of any part of the body. As a radiation-based imaging modality, CT uses the same physical principles as conventional radiography but applies them in a unique way. A computer using X-ray absorption measurements, collected at multiple points and angles throughout the scanned body part, creates the images produced by the CT.

The CT scanner does not record an image in the conventional way. Conventional X-ray positions a stationary X-ray tube over the body part, creating a two-dimensional image; and an image receptor (whether film, a computed radiography cassette, or via direct radiography) captures a beam of X-ray photons that are directed through the body part. However, during a CT scan, an X-ray tube is rotated around the body in a 360-degree (°) circle, exposing all aspects of the body part to ionizing radiation. The rotating tube produces either a collimated thin beam or a fan-style beam that exposes the body part. A detector assembly is positioned on the opposite side of the rotating tube. The detector assembly captures the remnant radiation that makes it through the patient. The information captured by the detector assembly is then sent to the main computer in the form of electronic signals for processing and forming into an image that is displayed on a computer monitor for visualization.

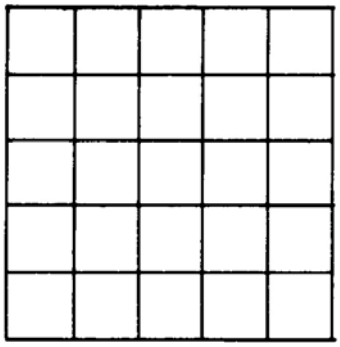
Image visualization creation

As the tube rotates around the body part, it exposes the area of interest at multiple points and angles. As each detector assembly captures remnant radiation, it creates a signal; whole numbers are assigned to each of these signals. The whole numbers represent the measured amount of radiation received by the detectors; this is otherwise known as the *raw data* of an image. The raw data is then digitized and sent to the main CT computer as an electronic signal that is directly proportional to the intensity of the remnant radiation (or strength of each signal). The CT computer then processes the electronic signal by calculating the density of the object based on the *linear attenuation coefficient* of the X-ray beam. The linear attenuation coefficient represents the amount of radiation that was absorbed by the body part. The CT computer, using a preselected algorithm, assembles the electronic signal into a *matrix* to create an image.

The process of assigning numbers to represent the density levels of body parts at a specific point and angle is repeated several thousand times for the part being imaged. After all the raw data has been gathered, the CT computer processes all the numbers it has collected, using extremely complex mathematical algorithms. The information generated by the computer is then converted into a format that is used to produce a visible image on a monitor.

Image matrix

The CT image is actually a composition of small blocks, or cells, arranged in rows and columns called a *matrix*. As discussed previously, the computer assigns a number that represents the density of the structure contained in each cell of the image. Figure 3–1 illustrates a 5 x 5 matrix. If each number represents a shade of gray and projects the matrix onto a monitor, we end up with a viewable image of the body part. The most common matrix sizes used in CT scanning are 256 x 256, 512 x 512, and 1024 x 1024. As the image matrix gets larger, the individual cells become smaller on the screen, and the image detail (resolution) increases.



37	62	82	7	16
12	18	98	31	22
41	8	39	73	3
14	48	66	53	49
28	82	71	33	19

Figure 3–1. Image matrix.

Each of the cells of a matrix is called a *pixel*, which stands for **pic**ture **el**ement. A pixel on a CT image is a two-dimensional representation of the average density of a volume of tissue (fig. 3–2). The volume of tissue the pixel represents is called a *voxel* (*vo*lume *el*ement). A voxel is the area of a pixel multiplied by the thickness of the slice.

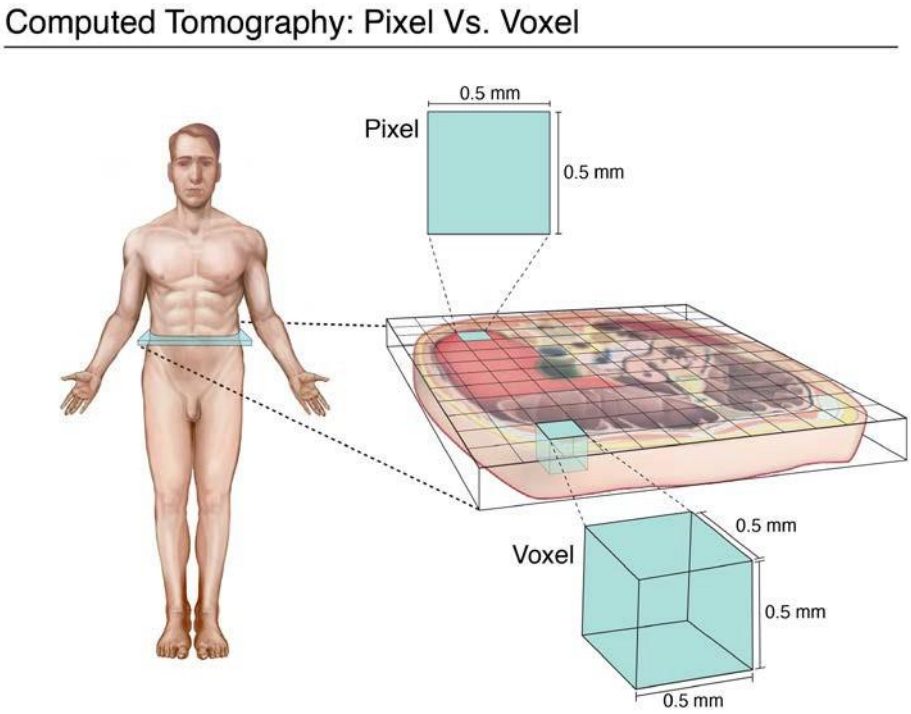


Figure 3–2. Pixel and voxel CT slice illustration.

Hounsfield units

As previously mentioned, each pixel in the matrix of an image is assigned a number representing the linear attenuation coefficient of the tissue density within each voxel. These numbers are called Hounsfield units (or CT numbers). The Hounsfield units are scaled to range from –1000 to +1000 (see table below) with water as a reference point because it is sufficiently available throughout the body, and it has a consistent density. On the Hounsfield scale, water is assigned a value of zero.

Dense tissue, or matter, within the body that absorbs more X-ray photons is assigned positive numbers; whereas, less dense tissue is assigned negative numbers. Notice the Hounsfield scale extremes where air is assigned a CT number of –1000, while dense bone is assigned a value of +1000.

The Hounsfield Scale	
Tissue	**CT Number**
Air	–1000
Lungs	–250 to –850
Fat	–100
Water	0
Fluid	0 to 25
Blood (old)	10 to 15
Brain Matter	20 to 40
Blood	20 to 50
Muscle	35 to 50
Bone	150 to 1000
Metal	2000 to 4000

When an image is displayed on a monitor, each pixel is assigned a shade of gray. However, even after the image is displayed in shades of gray on the screen, the operator has the ability to call up the actual CT number assigned to a pixel or group of pixels. This is called a *region of interest* (ROI) measurement. Using the software on the CT imaging system, you can take an ROI measurement using an elliptical circle or even the cursor itself (fig. 3–3). When an elliptical circle is used, the software measures the tissue density within the oval and a CT number (average Hounsfield unit) is assigned for that area.

When using the cursor, the density of a voxel is measured at the point where the two lines intersect (like crosshairs). Again, a CT number is assigned, demonstrating the density of the tissue the cursor has been placed over top of. The radiologist often uses ROIs to help determine the exact composition of an unidentifiable mass displayed on an image.

Figure 3–3. ROI elliptical circle and typical cursor identifier used for Hounsfield measurements.

Computed tomography imaging versus conventional imaging

A conventional radiograph, as you know, produces a single, two-dimensional image of the body. An exact location of masses or other objects requires two exposures made at right angles. Soft-tissue structures, while seen, are not visualized optimally, and superimposing structures often obscure desired anatomy.

By comparison, a CT exam produces a series of two-dimensional, cross-sectional images that may be contiguous with one another or even overlapping. By viewing the sequence of scans, the examiner is provided with three-dimensional (3D) information that is completely free from superimposing structures.

CT is also better at detecting and displaying minute tissue differences in density necessary for imaging soft-tissue structures. For example, conventional radiography needs a minimum difference in tissue density of around 10 percent (depending on the kV used) to delineate between structures. CT can differentiate adjacent structures that have a difference in tissue density as low as 0.25 percent. This makes CT an excellent tool for showing contrast differences of soft-tissue structures within the brain, chest, and abdominal areas.

Low density, soft tissue that is normally superimposed by higher density structures on a conventional radiograph can be clearly visualized with CT. This is why CT is excellent for demonstrating the brain,

as shown in figure 3–4. A conventional radiograph of the skull is of little value in trying to visualize the brain because the high-density cranial vault obscures low-density brain tissue.

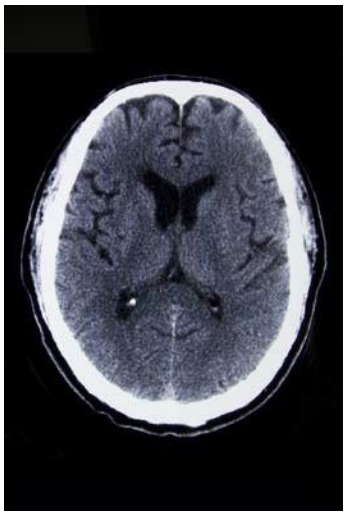


Figure 3–4. Axial CT scan through the middle of the skull.

Notice in figure 3–4 some similarities between CT and conventional radiography. Because both use radiation, dense structures, such as bone, appear white, while air appears black. Soft-tissue structures appear as varying shades of gray.

Another advantage that CT has over conventional radiography is that the image can be manipulated and enhanced to better visualize one area versus another, using various post-processing techniques. For example, a CT operator can adjust the density and contrast of the image, rotate and flip the image, and even magnify the image for improved visualization on the monitor. Furthermore, CT units can reconstruct the data from a series of axial scans to produce additional images in different planes (coronal, sagittal, and oblique) and even change the thickness, or spacing, of a body part image with no additional radiation exposure to the patient. Another post-processing technique is 3D imaging; CT systems can produce 3D models of a body part that can be rotated and viewed from any angle. This feature is extremely helpful in mapping blood vessels or in planning reconstructive facial surgeries.

Image quality factors

There are four main factors affecting image quality in CT: spatial resolution, contrast resolution, noise, and artifacts.

Spatial resolution

Compared to conventional radiography, CT is not as good at providing good spatial resolution. *Spatial resolution* refers to the degree of blur that is apparent in a CT image. CT achieves better spatial resolution with smaller pixel size and thinner slice thickness. Of all the factors that can affect spatial resolution in CT, detector aperture width is the greatest contributing factor.

Contrast resolution

Contrast resolution is referred to as the ability to differentiate one soft-tissue structure from another without regard to shape and size. CT is excellent in delivering high-contrast resolution because of its ability to amplify differences in adjacent structures that are similar in tissue composition. Contrast resolution in CT is dramatically better than conventional radiography.

Noise

Noise on a CT image appears as graininess. An image with high noise will look spotty or blotchy, while an image with low noise will appear smooth. Quantum noise is the most common cause of noise on a CT image. Noise affects the contrast resolution of a CT image—as noise increases, contrast resolution decreases.

Artifacts

Artifacts refer to components of an image that do not reproduce actual anatomic structures because of distortion, addition, or deletion of information. Artifacts degrade the image and may cause errors in diagnosis.

Volume averaging

Volume averaging is present in every CT image and must always be considered in image interpretation. Data obtained and averaged from a 3D volume of patient tissue creates the displayed

two-dimensional image. Slices above and below the image being interpreted must be examined for sources of volume averaging that may be misinterpreted as pathology.

Beam hardening

Beam-hardening artifacts result from greater attenuation of low-energy X-ray photons than high-energy X-ray photons as they pass through tissue. The average energy of the X-ray beam increases (the beam is "hardened"), resulting in less attenuation at the end of the beam than at its beginning. Figure 3–5 shows beam-hardening artifacts as streaks of low density extending from structures of high–X-ray attenuation, such as the patient's arms when left by his or her side during an abdominal CT scan. Other high-attenuation areas that can cause beam-hardening artifacts are the petrous bones, shoulders, and hips.

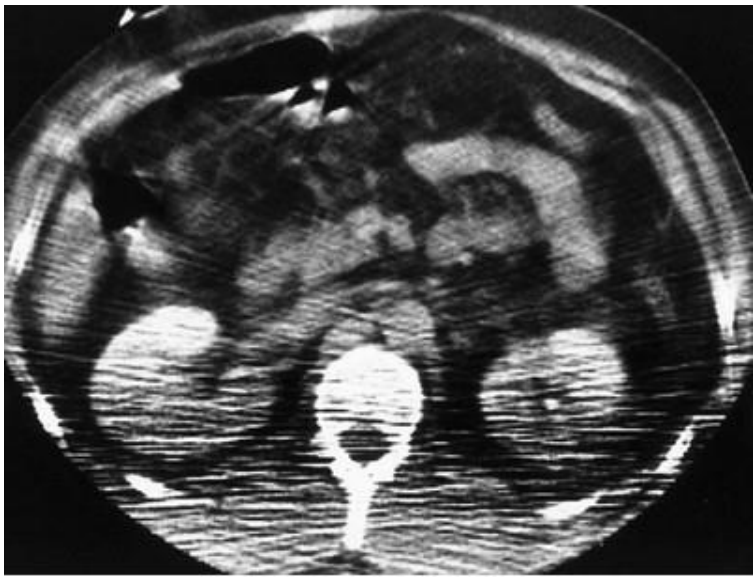


Figure 3–5. Beam-hardening artifact.

Motion

Motion artifacts result when structures move to different positions during image acquisition. Motion occurs as a result of voluntary or involuntary patient movement, such as breathing, heartbeat, vessel pulsation, or peristalsis. The image will show motion either as prominent streaks from high- to low-density interfaces or as blurred or duplicated images.

Streak

Streak (or starburst) artifacts originate from high-density, sharp-edged objects, such as vascular clips and dental fillings. Reconstruction algorithms cannot handle the extreme differences in X-ray attenuation between very dense objects (like metal) and adjacent soft-tissue structures.

Ring

Ring artifacts occur when the CT scanner is out of calibration, and detectors give erroneous readings at each angle of rotation. The image will show ring artifacts as high- or low-density circular rings.

Quantum mottle

Quantum mottle artifacts produce noise in the image and are seen as a salt-and-pepper pattern of random dark and light specks throughout the image. The image noise is a result of insufficient X-ray transmission data caused by inappropriate radiation settings for the size of the patient.

3.2 Types of computed tomography scanners

For years, CT systems have been identified by generations, which represent the level of technology used in designing the tube and detector assembly. Although modern scanners are no longer categorized in this manner, it is helpful in explaining the historical development of the CT scanner. This lesson will review the main generations of CT technology. We also discuss more recent technological advancements, including multi-slice and dual-source CT scanning systems. We begin by learning about the first four generations that led up to CT as we recognize it today.

Computed tomography scanner generations

Though CT scanners manufactured today are more often classified by their tube and detector movement, it is still necessary to understand the different CT generations (technology) that got us to this point. First-generation scanners were the most basic.

First generation

First-generation scanners used a basic configuration. It consisted of an X-ray tube that was connected to a detector array mechanically. The detector array consisted of two scintillation crystal detectors (some had only one) coupled to a photomultiplier. The X-ray beam was collimated to a pencil-shaped beam (fig. 3–6) measuring about 2 x 16 mm.

The scanning motion consisted of *translation* and *rotation.* Translation means to move across the body without a change in angulations; rotation means to change angulations. The X-ray tube/detector array assembly thus moves directly across the body part (fig. 3–7); it then rotates 1° and repeats the translation, rotates 1° and translates again, and so on until it transverses 180° of angulation.

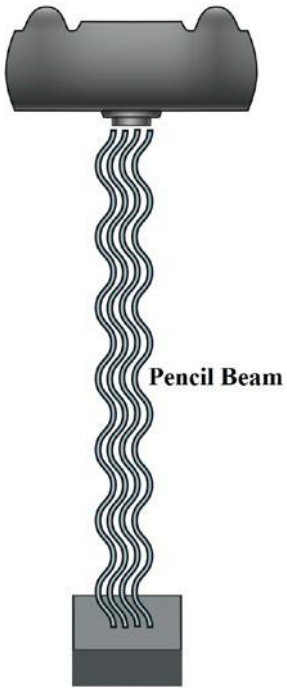


Figure 3–6. First-generation scanner pencil beam.

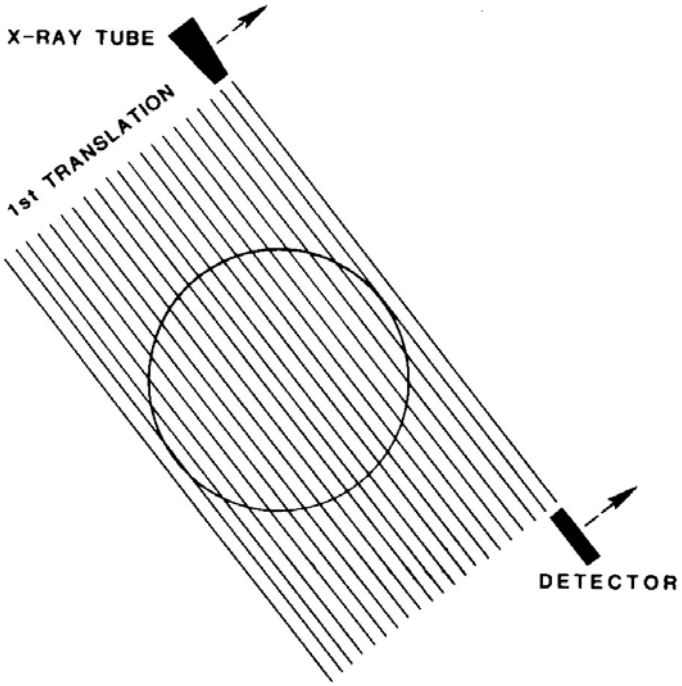


Figure 3–7. First-generation scanner translation movement.

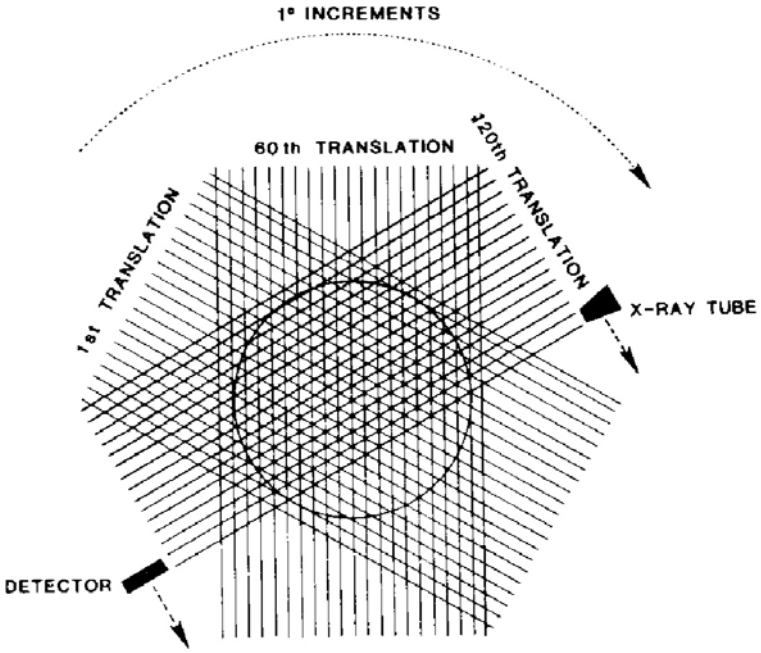


Figure 3–8. First-generation scanner translation and rotation movements.

Figure 3–8 shows this translation/rotation process. During this period, the detector array senses the remnant radiation and sends electronic signals to the computer. These first-generation scanners offer accurate data readings for reconstructing images. This is due to its geometry—specifically 1° rotations. The main drawback to these units was the 3–5 minutes required to complete one scan.

Second generation

A second generation of scanners was developed to reduce scanning time. The second-generation scanners used a fan-shaped beam, rather than the pencil beam of the first scanners, and a linear detector array (fig. 3–9). With the linear detector array, multiple scintillation detectors were connected to the tube head assembly for coordinated movement. The translation-rotation movement of the first-generation units was also used in second-generation units.

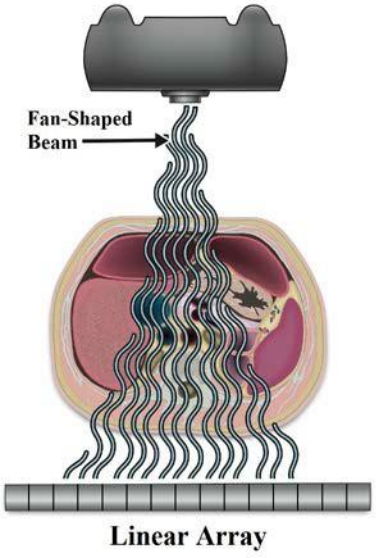


Figure 3–9. Second-generation scanner fan beam and linear detector array illustration.

The major advantage of second-generation scanners was increased speed. A single translation with the fan beam and multiple detector arrays gave the same number of data points as several translations with a first-generation scanner. Also, each translation is separated by rotation increments of 5° or more. This means that fewer exposures were needed for a 180° scan. Scanning times were reduced to around 20 seconds per slice.

Third generation

Third-generation units further reduced examination time through 360° rotation-only movement. This category of scanner uses a curvilinear detector array of at least 30 detectors and a fan beam. Both the number of detectors and the width of the fan beam are substantially larger than second-generation scanners.

In third-generation scanners, the fan beam and detector array view the entire patient slice thickness at all times. In the second-generation unit equipped with a linear detector array, the source-to-detector path length is shortest for the central detector and increases as you move to the periphery of the detector array. This increase in distance affects the linear attenuation coefficient upon which the CT image is based. The curvilinear detector array gives a constant source-to-detector path length, which is an advantage for good image reconstruction. Figure 3–10 shows the curvilinear detector arrays.

The major advantage of third-generation scanners is they reduce scanning time to 10 seconds or less. A disadvantage is the malfunction of a single detector or bank of detectors that cause occasional appearances of ring, or circular, artifacts.

Fourth generation

Like the third-generation scanner, the fourth-generation scanner uses a fan beam and 360° rotation- only motion. However, only the X-ray tube rotates in this unit; the detector array is stationary. In this machine, remnant radiation is detected by a fixed circular array (fig. 3–11) that may hold more than 1,000 individual detectors. This geometry gives fourth-generation scanners excellent image reconstruction and exposure times as low as 1 second. Unfortunately, one disadvantage of a fourth-generation scanner is a higher patient radiation dose per slice.

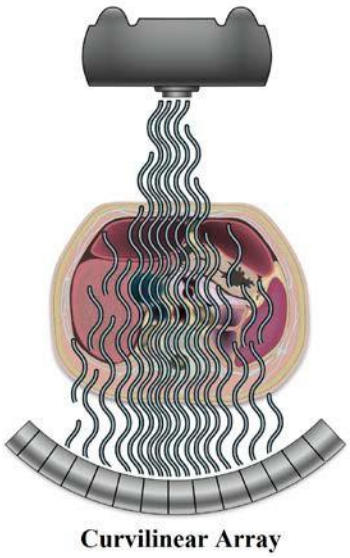


Figure 3–10. Curvilinear third-generation detector array illustration.

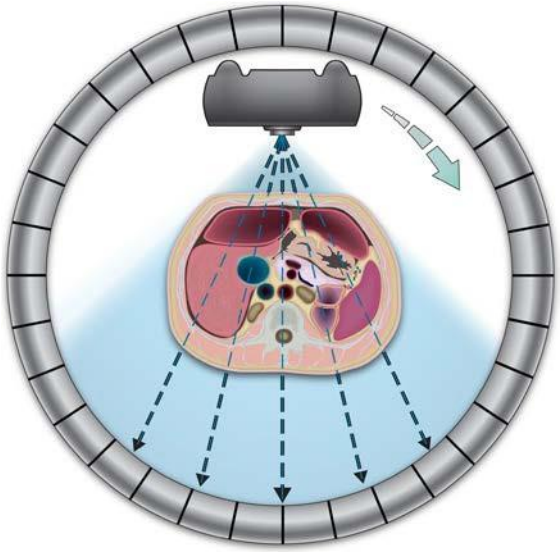


Figure 3–11. Fourth-generation CT scanner detector configuration.

Slip-ring technology

Another technological advancement in the area of CT tube/detector assemblies is slip-ring technology. Previous scanners required cables to connect the X-ray tube to the high-tension transformer. Because of these cables, the tube could only rotate one time around before having to stop and reset to its beginning position. With slip-ring technology, the cables are eliminated and the X-ray tube receives power from a continuous circular track, which allows for constant tube rotation without having to reset to a starting position between slices. Constant tube rotation combined with faster, more powerful computer technology, provides for even faster scan times, greatly reducing total scan times.

Today, it is normal for a head CT scan to take only 1 minute or less to acquire 30–35 separate axial images (slices) of the brain. When scanning the chest or abdomen, most routine scans can be completed within one breath-hold and it takes less than 30 seconds to acquire roughly 80 axial slices. A significant advancement that has accompanied slip-ring technology is helical, or spiral, scanning.

Single-slice versus helical computed tomography

Single-slice (or conventional) CT obtains image data one slice at a time. This method is sometimes referred to in the CT system software as axial mode. Basically, with the CT couch (table) not moving, a slice is acquired, then the table moves into the next position where another slice is acquired, and the table moves again and so on until all individual axial plane slices have been acquired.

Helical (or spiral) CT images are acquired while the table moves the patient at a constant speed through the exposure area (the gantry), while the X-ray tube continuously rotates around the patient in a “corkscrew” manner. Helical CT scanning allows large volumes of chest or abdominal tissue to be scanned on a single breath-hold, thereby, eliminating respiratory motion and improving detection of small lesions. Volume acquisition, using a helical scan mode, enables high-quality postprocessing reconstruction of multiple overlapping slices. This improves visualization of small pathology and allows for high-detail 3D imaging.

Multidetector helical computed tomography imaging systems

Multidetector helical CT (MDCT) is a major technical advancement in CT imaging. It uses the principles of helical scanning while incorporating multiple rows of detector rings. This technique allows you to acquire multiple slices per tube rotation, increasing the area of the patient that the X-ray beam can cover in a given time. Available systems have moved quickly from 2-slice to 64-slice, which covers 40mm of patient length for each 1-second or less of tube rotation. Though 256-slice scanners have been developed, the current workhorse MDCT scanner in most departments is the 16-slice scanner, with 64-slice scanners becoming increasingly popular for cardiac applications like coronary angiography.

The key advantage of MDCT is speed. It is 5–8 times faster than single-slice helical CT units. For body scanning, 1mm slices can be obtained, creating isotropic voxels (voxels that are a perfect cube; equal in length, width, and height [e.g., 1 x 1 x 1 mm]) that allow image reconstruction in any anatomic plane without loss of resolution. Broad area coverage allows for high-detail CT angiography, “virtual” CT colonoscopy, and bronchoscopy. However, nothing is free and a significant disadvantage of MDCT is radiation dose, which can be 3–5 times higher with MDCT than with single-slice CT. Thin slices (some as small as 0.4mm) and multiple-detector acquisition add great diagnostic capability, unfortunately, at the cost of increased radiation dose to the patient.

MDCT introduced *pitch* (or spiral pitch) to the field of CT. Pitch refers to the movement of the patient couch and the width of the X-ray beam relationship. Pitch also allows the patient couch to be moved faster or slower while the tube continues to rotate around the patient for continuous exposure. Being able to use pitch is a major advantage of MDCT. Pitch allows for a larger volume of tissue to be imaged in a single scan or breath-hold (chest or abdomen). Pitch is stated as a ratio, such as 0.5:1

(0.5 to 1), 1:1 (1 to 1), 1.6:1 (1.6 to 1), and so on. A pitch of less than 1:1 (e.g., 0.5:1) slows the couch movement, which allows images to overlap but includes a higher radiation dose to the patient.

When a pitch of greater than 1:1 (e.g., 1.6:1) is used, the table movement speeds up, resulting in greater coverage of the area being imaged and a reduction in radiation dose to the patient. Most times, in multidetector helical CT scanning, the pitch is 1:1. However, in some cases, the pitch may routinely be adjusted, either to acquire more data for postprocessing needs or to shorten the time in which a patient must hold his or her breath. Always refer to your department's CT scanning protocols or consult your radiologist before adjusting the pitch for a routine CT scan.

Computed tomography fluoroscopy

CT fluoroscopy is an advancement in CT technology that allows for real-time CT imaging. This technique dramatically improves the ability to perform percutaneous interventions quickly and at a generally lower radiation dose than with conventional CT. The operator (typically your radiologist) can step on a floor pedal while moving the CT table or observing patient motion. Rapid image reconstruction provides real-time images of the anatomy, lesions, and needle or catheter placement. CT fluoroscopy is now routinely used to guide biopsy, drainage, and interventional procedures anywhere in the body. It is particularly useful in guiding needle placements where there is physiologic motion, such as in the chest and abdomen.

Figure 3–12 is an example of real-time CT imaging. The top three images were imaged at 5-mm slice thickness and every time the operator depressed the floor pedal, three new images were acquired.

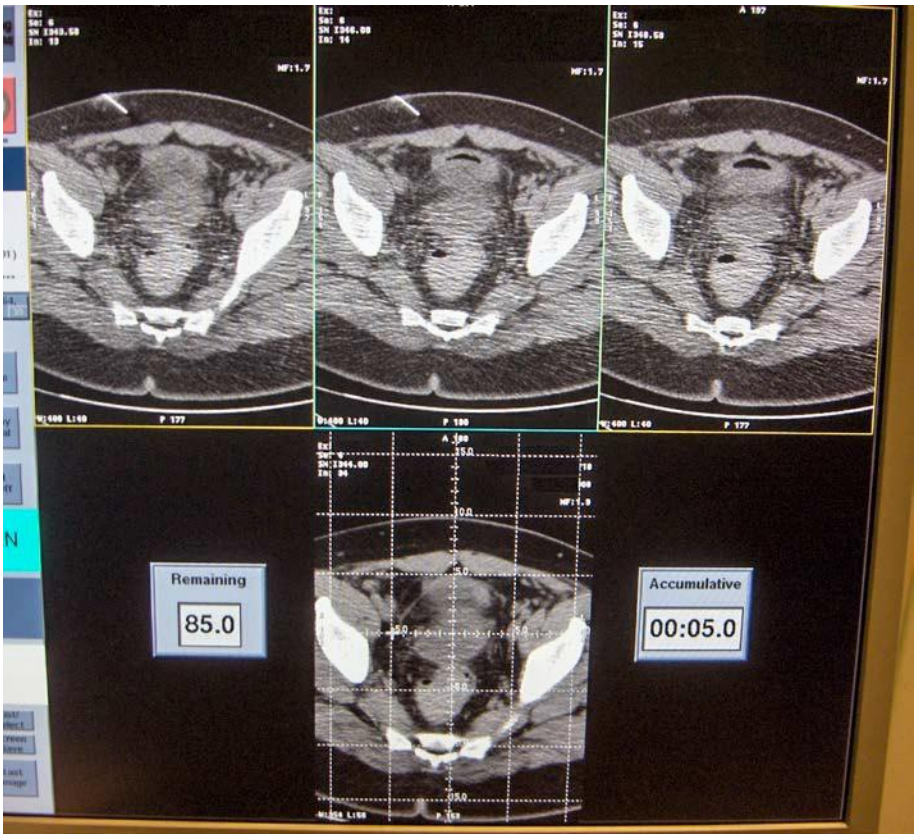


Figure 3–12. Sample images using real-time CT imaging.

Dual-source computed tomography imaging systems

Dual-source CT, or dual-energy, CT (sometimes referred to as sixth-generation scanners) uses two X-ray sources (tubes) and two X-ray detectors that expose tissues simultaneously to determine how

tissue behaves at different radiation energy levels. This technique allows the addition of information about tissue composition. Differences in fat, soft tissue, and contrast agents, at different energy levels expand lesion identification and characterization. Image data can be captured in half the time required for MDCT. This vastly improves the ability to image the heart without using potentially dangerous beta-blockers (a drug used to slow the heart rate).

Dual-energy CT can now determine the chemical composition of urinary calculi, giving the patient an opportunity to select medical versus surgical treatment. Though it seems a patient's radiation dose would dramatically increase with the addition of a second X-ray tube (source), radiation dose is actually reduced due to the reduction in total scan time and may be reduced even more if certain precontrast scans are eliminated in conjunction with multiphased studies.

3.3 Cross-sectional anatomy

Since CT uses radiation to image the body, there are some similarities between it and conventional radiography. However, there are also many differences. Comparing CT to conventional radiography helps explain the value of CT.

Fundamentals

Cross-sectional imaging refers to imaging techniques based upon images viewed as cross-sections (or slices) of the body. For example, imagine a sliced loaf of white bread. Each slice of bread represents an image similar to that obtained during a CT study. The outside of the loaf, the crust, is the skin and the white bread itself is the anatomy of the bread. When cross-sectional images are obtained, they are acquired at right angles to the long axis of the body (or body part). CT cross-sectional images are acquired parallel to the axial (or transverse) plane. The axial plane transects the body from anterior to posterior, side to side, and divides the body into superior and inferior portions.

On-the-job training and studying beyond the scope of this course is necessary for you to become proficient in reading and identifying anatomy on cross-sectional images. As you look at cross-sectional images, you must transition your thought process from two-dimensional (2D) to 3D anatomy visualization. The main part of this transition is understanding how a certain 3D anatomical structure corresponds to other adjacent 3D anatomical structures. In making the adjustment, remember to imagine actually slicing the body into thin sections just like a loaf of bread. When viewing axial cross-sectional CT images, the images are displayed as if you are looking up from the patient's feet so that the CT image is oriented with the patient's left on your right, just the same as with a conventional radiograph.

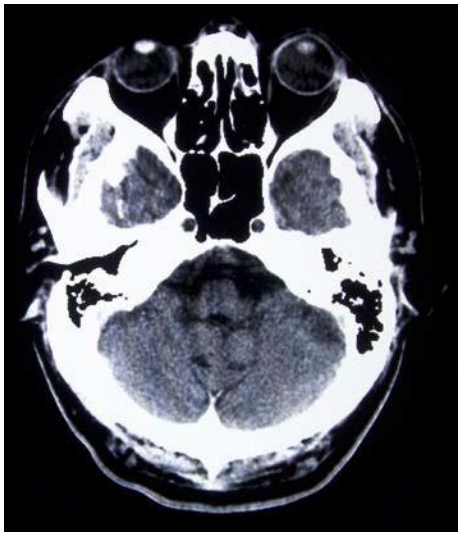


Figure 3–13. Lower brain axial CT image.

Brain anatomy

Provided are two sets of images to help familiarize you with some basic cross-sectional anatomy of the brain. Figure 3–14 identifies anatomy within the lower portion of the cranium/brain for the axial image displayed in figure 3–13. Likewise, figure 3–16 identifies anatomy within the middle portion of the cranium/brain for the axial image displayed in figure 3–15. You should recognize the value of CT for imaging the brain. Before CT, radiographers could only image the brain, and all of its complex structures, indirectly with the cranium superimposed over all the structures of the brain. Invasive procedures like pneumoencephalography and cerebral angiography were performed to see if pathology was affecting the ventricular or vascular systems of the brain. CT allows for excellent visualization of the soft-tissue structures of the brain.

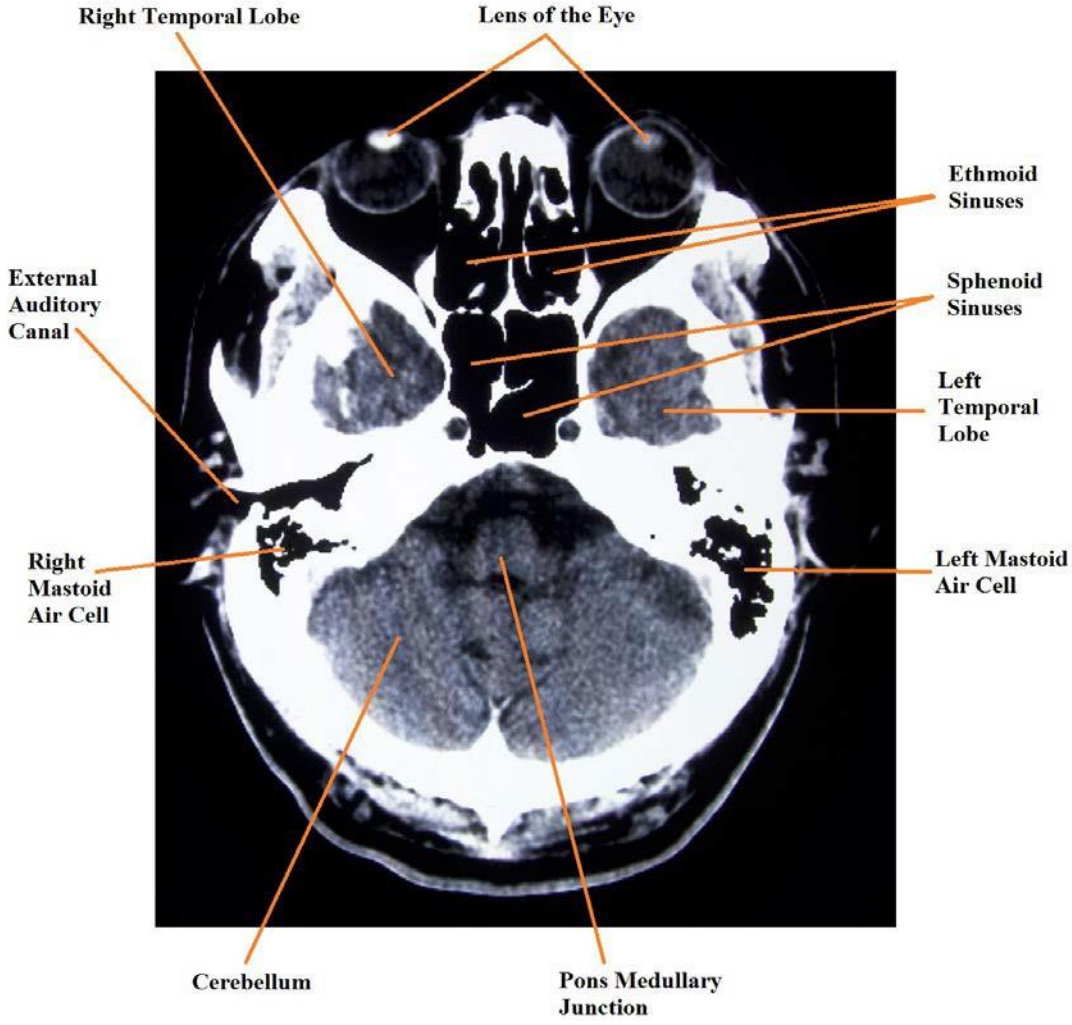


Figure 3–14. Illustration of cross-sectional anatomy displayed within figure 3–13.

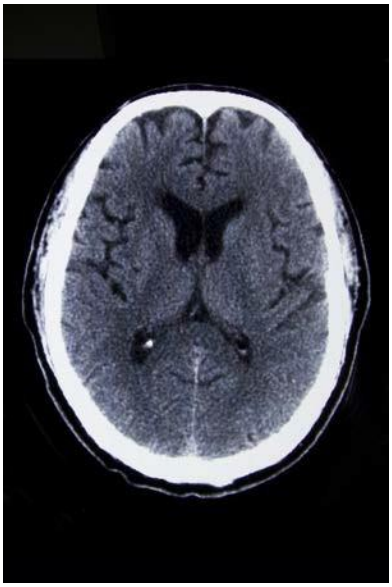


Figure 3–15. Middle portion of the brain axial CT image.

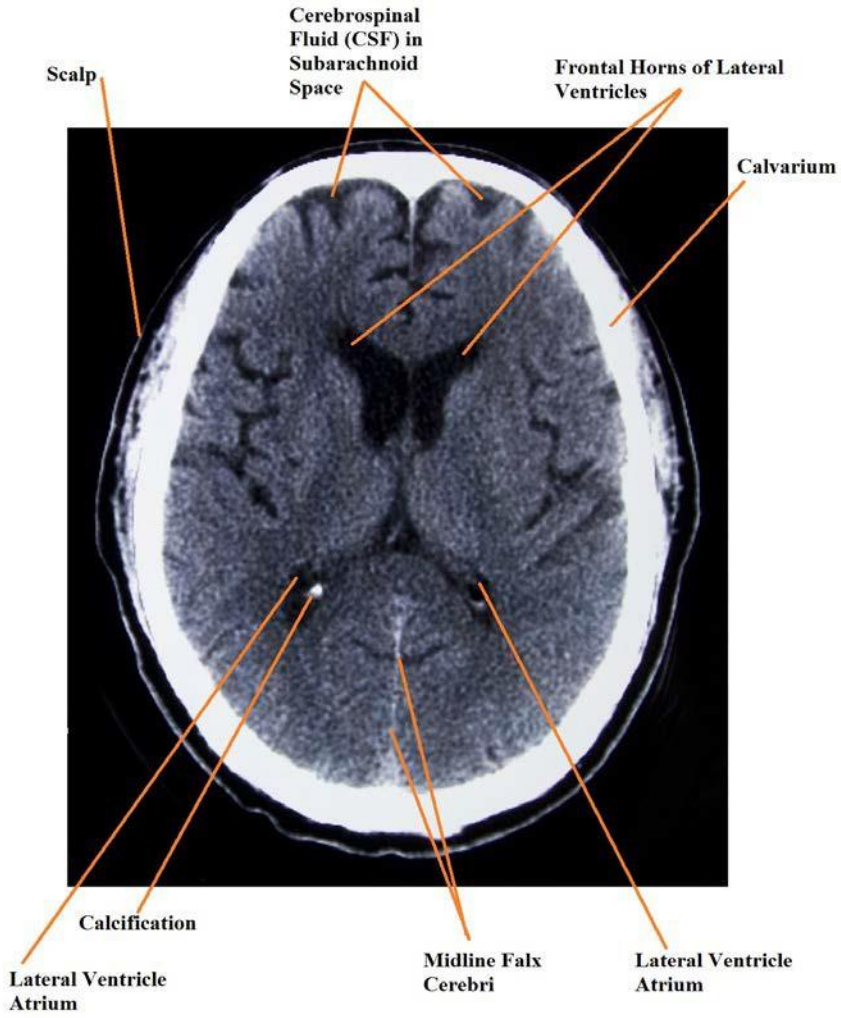


Figure 3–16. Illustration of cross-sectional anatomy displayed within figure 3–15.

Chest anatomy

Figure 3–17 is an axial CT image of the chest through the level of the mediastinum displayed in a soft-tissue window setting, which is normal whenever IV contrast is injected. Notice how, when displayed in a soft-tissue window setting, the lungs are black in figures 3–17 and 3–18; whereas, in figure 3–19, the image is displayed with a lung window setting. In figure 3–19, the lung tissue is well visualized; although, now the soft-tissue structures cannot be seen diagnostically. Both figures 3–18 and 3–19 are available with some basic cross-sectional anatomical structures identified for your familiarization. Notice the appearance of the ribs in figure 3–17; because the ribs angle downward from the vertebrae, we only see a short section of each rib on a true axial image.

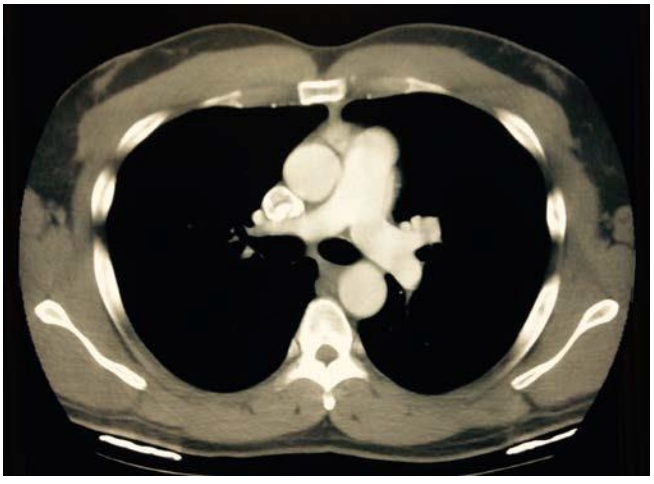


Figure 3–17. Axial CT image of the chest displayed in a soft-tissue window setting.

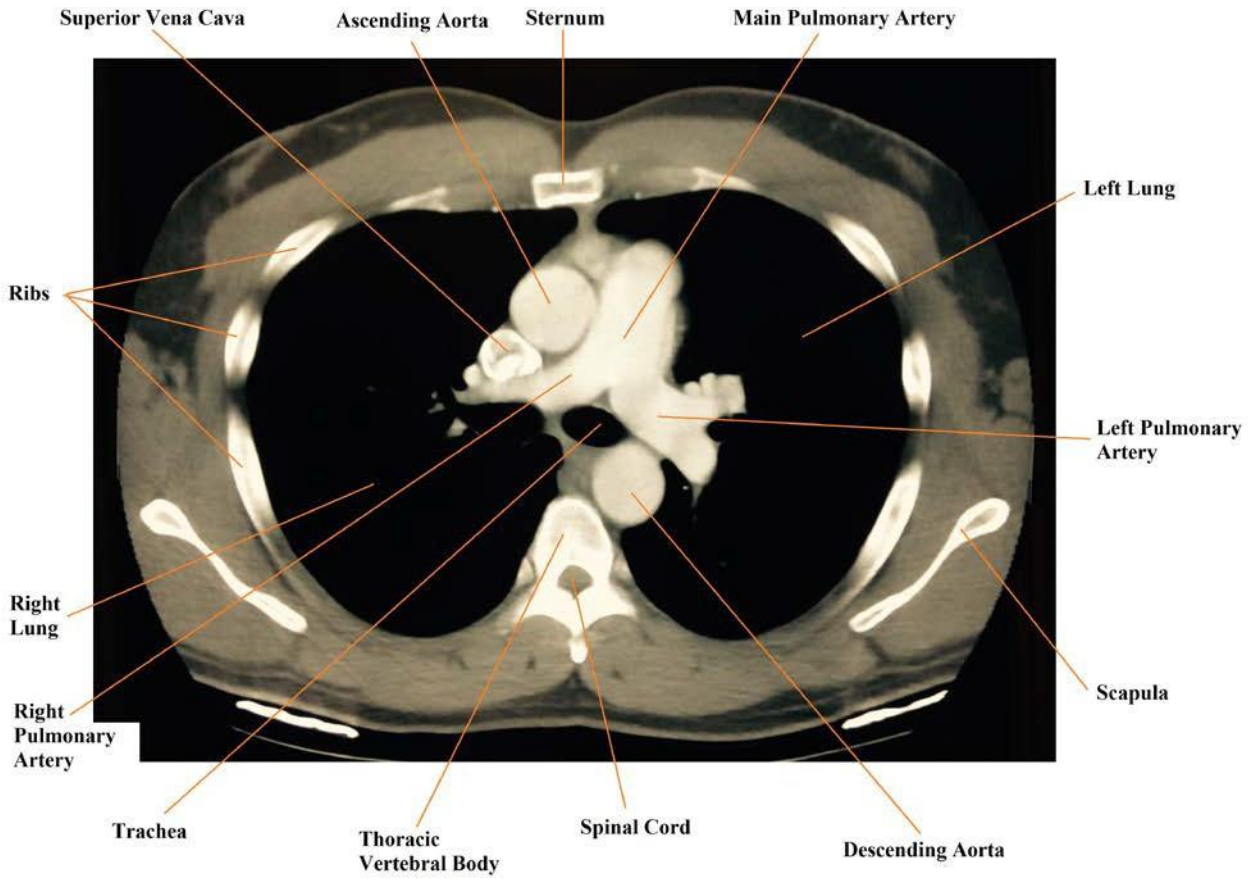


Figure 3–18. Illustration of cross-sectional anatomy displayed within figure 3–17.

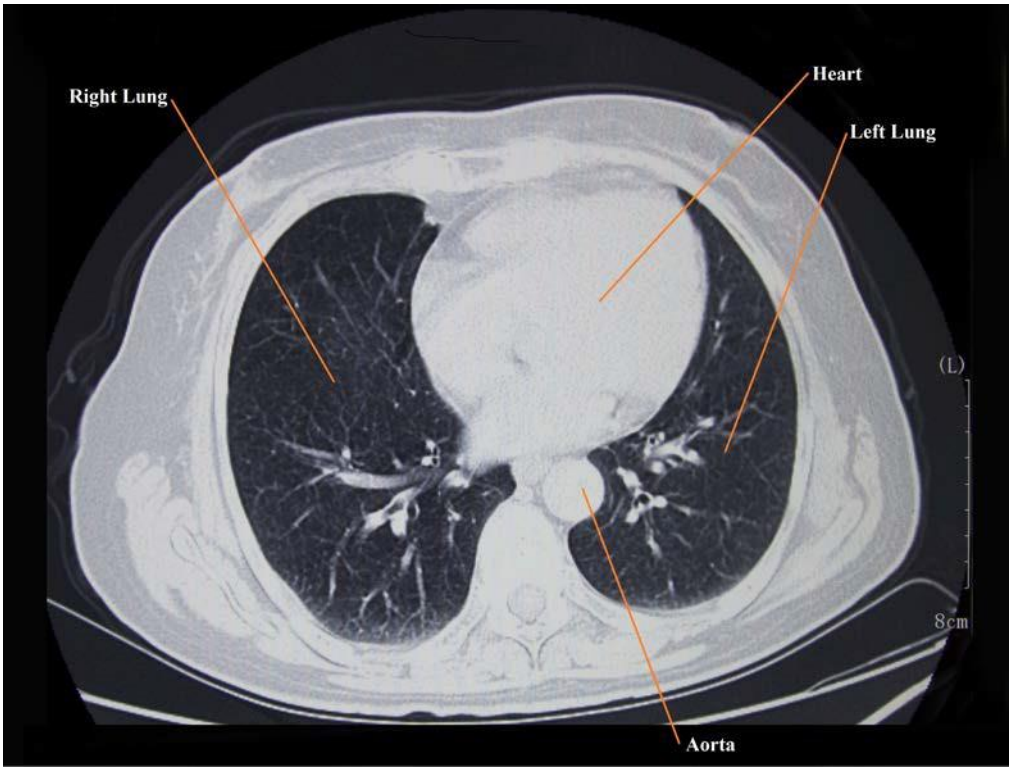


Figure 3–19. Illustration of cross-sectional chest anatomy displayed with a lung window setting.

Abdominal and pelvic anatomy

Just like the thoracic cavity where the heart and lungs are located, the abdominal cavity houses many anatomical structures available for identification. Figures 3–20 and 3–22 are axial CT slices through the upper abdomen and pelvic regions, respectively. You should be able to determine the approximate level of the slice displayed in figure 3–20 by noticing the presence of the liver and spleen. In figure 3–22, the ilium bones of the pelvis are present, which means the image is from the lower abdominal region. Figures 3–21 and 3–23 have been included, so you can familiarize yourself with some of the various anatomical structures available for visualization within these cross-sectional axial CT images.

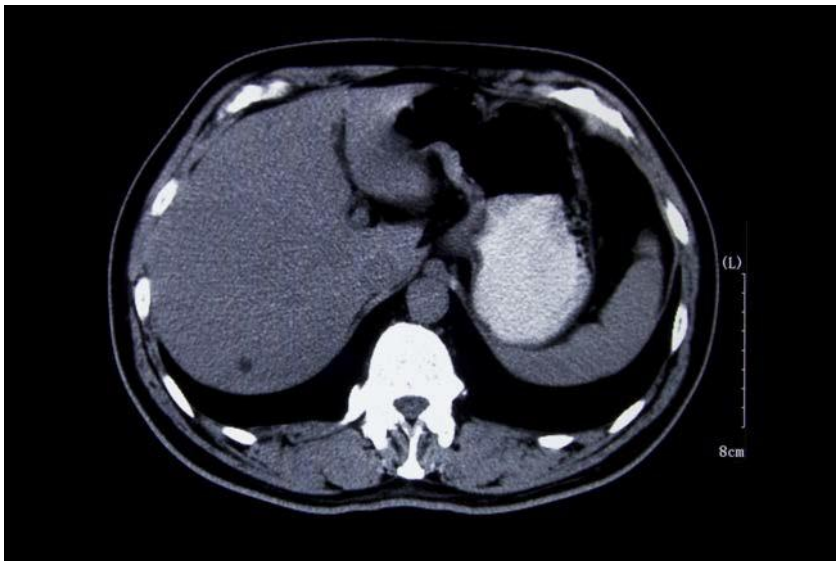


Figure 3–20. Axial CT image of the upper abdomen.

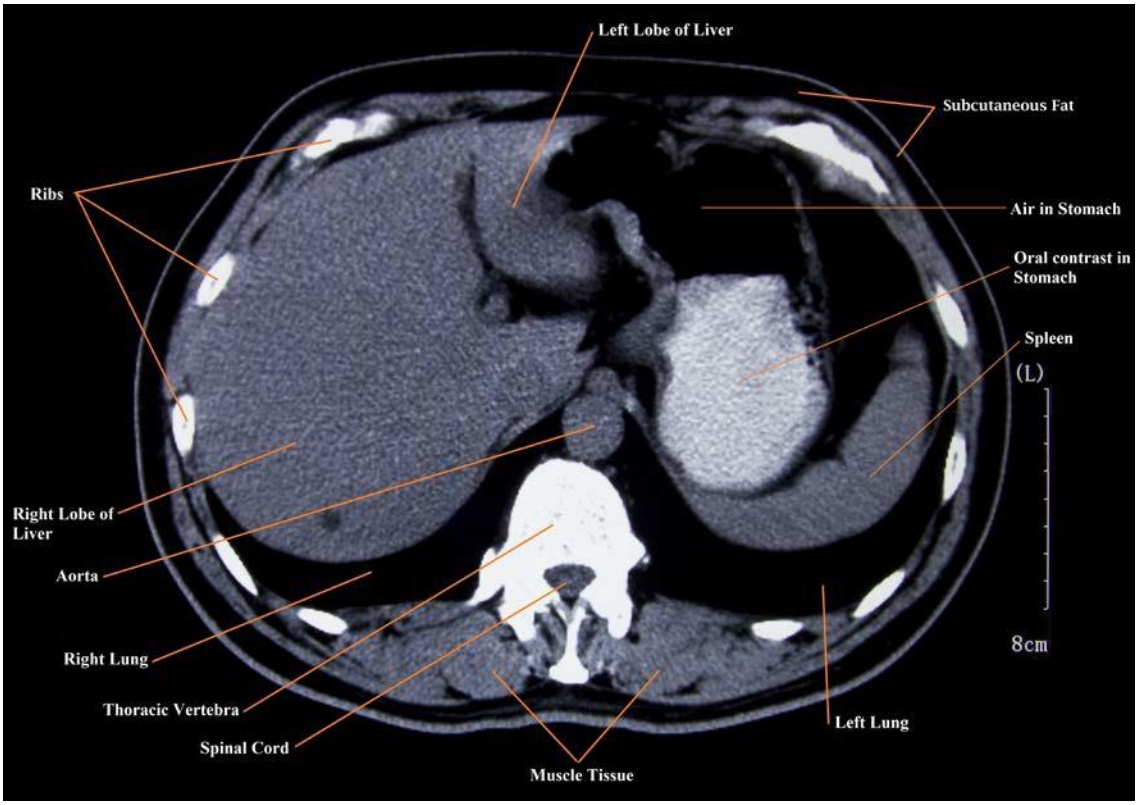


Figure 3–21. Illustration of cross-sectional anatomy displayed within figure 3–20.

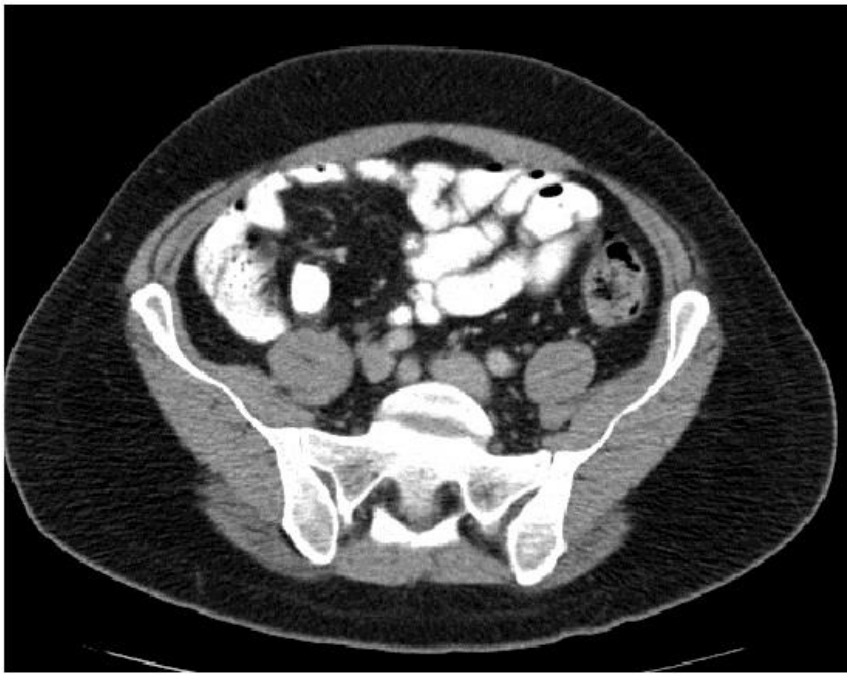


Figure 3–22. Axial CT image of the pelvic (lower abdominal) region.

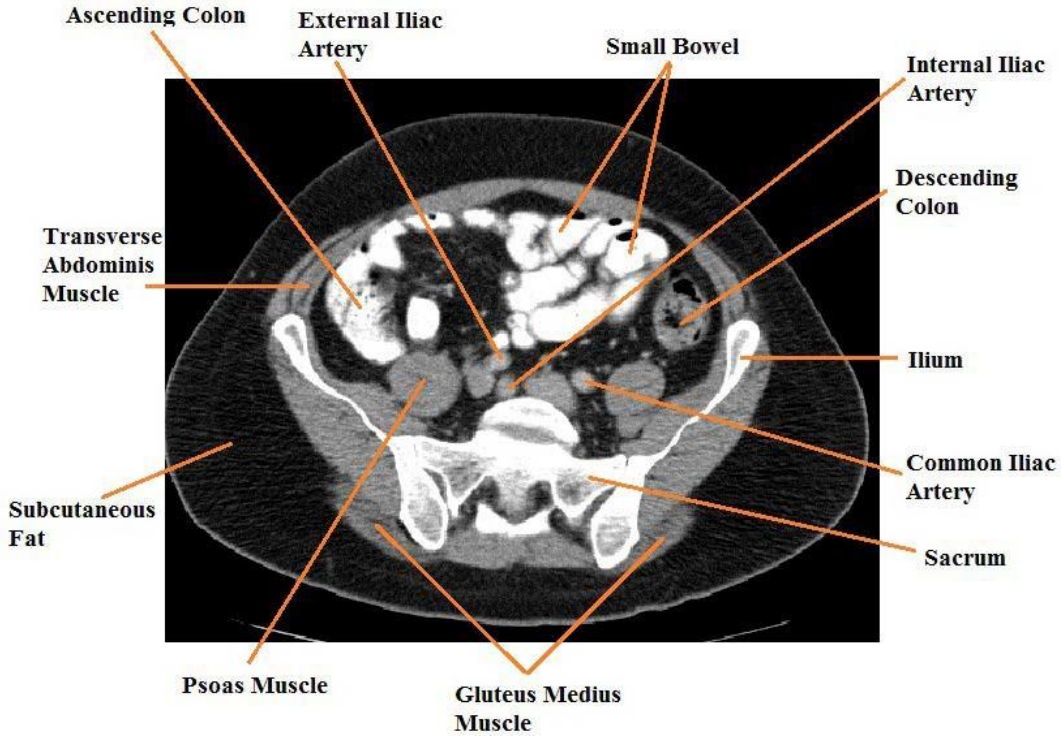


Figure 3–23. Illustration of pelvic cross-sectional anatomy displayed within figure 3–22.

Figure 3–28. CT axial cross-sectional image of the pelvic region.

3B Computed Tomography System Components

In this section, we discuss the various components of a CT scanner. Then we see how the three main components—the gantry, computer, and operator's control console—relate to one another.

3.4 Gantry assembly and patient couch apparatus

The gantry assembly is the vertical, floor-mounted apparatus that surrounds the patient. It houses all the CT exposure system-imaging components. Working in conjunction with the gantry, the patient couch provides support for positioning the patient. These subsystems receive electronic commands from the operating console and acquire and transmit data to the computer for analysis and image production.

Gantry

The gantry itself is the largest component of CT scanner systems. It contains the X-ray tube, the detector assembly, slip rings, collimators, and the data acquisition system (DAS). The gantry has a hole in its center, named the *aperture* (nicknamed the doughnut), into which the patient transverses in and out of for the CT scan. Although it is large enough to accept most patients, claustrophobic patients may still be very anxious about being placed inside the aperture. Patients often get CT and MRI confused, especially when the patient is claustrophobic.

In MRI, the aperture is quite narrow and resembles a tube versus a doughnut hole. To gain a claustrophobic patient's cooperation for a CT scan, thoroughly explain the exam to include exactly what portion of the patient's body will be placed into the CT aperture and how long the person will remain inside. Most times, the explanation will be enough to calm the patient and gain his or her cooperation. However, in severe cases, a nurse or physician may have to sedate the patient before being placing him or her in the gantry. You must exercise patience and understanding of the feelings/emotions that a patient may feel when attempting to use CT on severely claustrophobic patients.

Several other features are common to most gantry systems. The gantry may be tilted, forward or backwards up to 30 degrees, to obtain a more accurate cross-sectional image of an angled body part; the gantry tilt feature is most often used when imaging the head and spine. Also, laser lights are projected onto the patient's body in the form of a line—crosswise (vertical to the floor) and parallel to the table (horizontal to the floor). These laser lights are used to position the patient for the scout scan and, in turn, set the coordinates for the rest of your CT scan. The patient should not move (left, right, inferior, or superior) on the table once the scout image is acquired. The coordinates acquired during

the scout scan correctly identify what area you are scanning in the part by identifying the exact location of the axial slice plane of the body.

Three axes exist in CT; they are identified as X, Y, and Z (fig. 3–29). CT images are transverse sections (or axial slices) through the body part in the XY plane. When the patient is positioned supine, the X-axis' coordinates increase positively from the patient's right to left; the Y-axis' coordinates increase positively from the patient's posterior to anterior aspect; and the Z-axis' coordinates increase positively from the patient's inferior to superior aspect.

The CT scout image (scan) is acquired by moving the body part along the Z-axis, through an X-ray beam projected (from the tube within the gantry) parallel to the XY axes (plane).

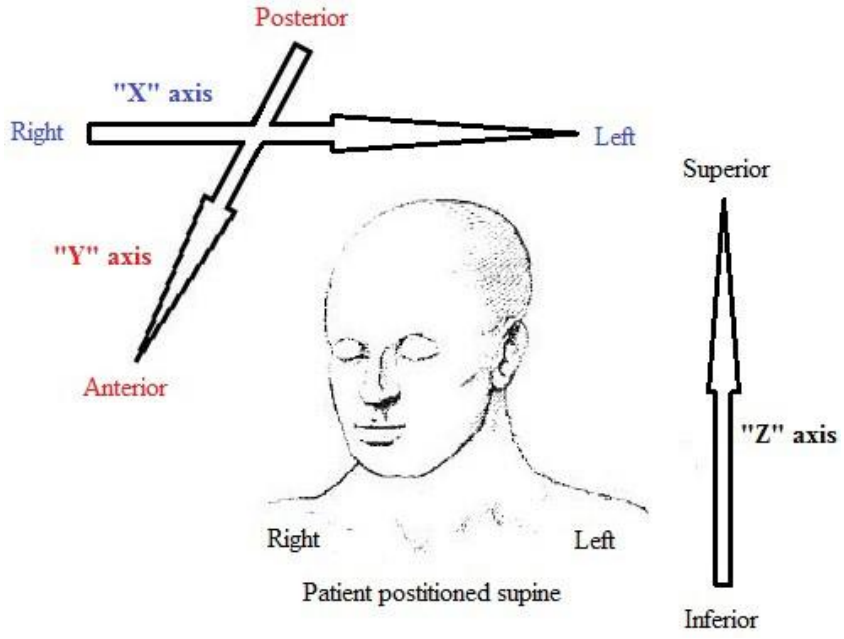


Figure 3–29. CT scan axes.

X-ray tube

X-ray tubes designed for use in CT imaging systems have one major performance characteristic distinguishing them from conventional radiography tubes. That characteristic is that CT tubes must be able to withstand and dissipate enormous amounts of heat units produced during CT examinations because of the repeated high-technique exposures required for CT. All modern CT units use *megatubes* capable of storing millions of heat units (mega means million). Extremely efficient cooling systems are used to help dissipate the heat. X-ray tube failure is a principle cause of scanner malfunction and is the primary limitation in doing multiple, high-technique exposures. All CT scanner manufacturers provide tube warm-up procedures that must be performed to prevent tube damage from thermal shock whenever the tube has been idle for a significant period.

Detector assembly

CT uses very sensitive detectors to sense remnant radiation and transmit an output signal to the computer. While early CT scanners used only one or two detectors, modern units may use thousands of detectors packed tightly together in an arc, or circling, the entire gantry aperture.

There are two categories of detectors: solid-state scintillation and xenon-gas ionization. A scintillation detector consists of a crystal connected to a solid-state detector assembly. The crystal, usually sodium iodide, emits a flash of light when irradiated. Each flash of light is directly proportional to the amount of radiation reaching the detector. The solid-state component changes these light flashes into

electrical impulses and transmits them to the computer. The primary advantage of a solid-state detector assembly is that it is extremely efficient, converting 99 percent of the absorbed photons into light. This results in less image noise and fewer image artifacts.

Gas-filled ionization detectors have a large chamber with baffles spaced at about 1mm intervals. These baffles are like grid strips that divide the large chamber into many small chambers. Each small chamber acts as a separate radiation detector. The entire unit is filled under pressure with a high–atomic number gas, such as xenon, and then sealed. When irradiated, the gas releases electrons that produce an electrical impulse, which can be transmitted through an electrode. Although not as efficient as their solid-state counterparts, gas-ionization detectors are much less expensive, which make them quite popular to manufacturers.

Data acquisition system

The DAS converts the electrical impulses from the detectors into digital information (numbers). The number represents the strength of the electrical impulse and actually is a measurement of the structure's density through which the beam passed. Once the DAS converts the electrical signals into digital information, the data is sent to the CT computer system.

Patient couch

The patient couch (or patient table) is where the patient lies for the duration of the CT study. The patient table is linked (connected to the gantry and computer system. The couch must be strong and rigid enough to support the patient's weight, yet comfortable enough to allow the patient to lie in one position for the entire length of the CT study. The patient couch is built of a material with a low atomic number (usually carbon fiber) that will not negatively attenuate the X-ray beam. Initially, the table is positioned directly over a support base or pedestal unit. The base unit moves up or down to properly position the patient couch (and patient) at an appropriate level for advancement into the gantry aperture.

When the patient is advanced into the gantry aperture, the base stays put and only the table moves along the Z-axis. A motor assembly is responsible for moving the table in and out of the gantry aperture throughout the CT study. It should operate smoothly and accurately so that the patient can be positioned precisely within 1mm increments. Most couches have a weight limit of between 300 and 600 pounds. Always check the operator's manual for your system to make sure you do not exceed the maximum weight limit. Exceeding the maximum weight limit for the patient couch apparatus may damage the motor drive of the table. Figure 3–30 shows an example of common gantry and patient couch push-button controls.

Figure 3–30. Common gantry and patient couch push-button controls.

Accessory devices are attached to the end of the table closest to the gantry. For head imaging, a U-shaped cradle is used. The purpose of the cradle is to center the head to the patient table and to help hold the head still in a comfortable position. For non-head-related studies, a table extender is used. Typically, patients are positioned feet-first (towards the gantry) for non-head-related CT studies, and the heels of their feet are placed just over the end-edge of the installed table extension.

3.5 Computer system

The CT computer system is the link between you and the rest of the CT components. The CT computer system controls data acquisition, performs image reconstruction, stores image data, and is responsible for displaying the CT images on a monitor.

Computed tomography system attributes

The CT image system uses a unique computer, capable of performing in the neighborhood of 250,000 mathematical equations simultaneously to reconstruct cross-sectional images of the body part being imaged based off remnant radiation measurements received by the detector array in the gantry. In simple terms, the basic function of a CT computer is to receive and analyze information from the DAS and convert it into a video form so that an image can be displayed on a monitor. A key component in all CT computer systems is the *array processor*.

The array processor consists of dedicated circuitry capable of performing high-speed mathematical calculations. As the computer receives the digital information from the DAS, the computer processes the data to reconstruct cross-sectional anatomy images. Once you select the CT scanning parameters, the computer tells the DAS how to interpret your commands (scanning parameters); tells the patient couch to move; applies power to the X-ray tube to generate the production of X-rays; controls the detector array; processes and transfers the electronic data signals; and in general, oversees the performance of the whole CT system while providing feedback to the user.

Image reconstruction

Image reconstruction is the actual operation the computer performs when mathematical equations turn the raw data (matrix of whole numbers) into a cross-sectional image. The array processor performs the mathematical calculations; therefore, it frees up the host computer for other operations. Most CT computers and array processors work so fast that scans are acquired in less than a second, and then the image reconstruction phase only takes a few more additional seconds to complete.

The computer room

The computer system being referred to here is not your normal two-foot tall personal computer tower. The CT computer system is typically one or two large floor-mounted cabinets (towers). The computer system, along with the high-voltage generator and system transformer(s) are housed in an enclosed, climate-controlled room, due to the high amount of heat generated by these machines. The room, commonly referred to as the computer room, is kept colder than patient care or technologist areas.
Heat is the enemy of a CPU within computers and when CPUs get hot, they slow down. The colder air temperature serves to cool the CPUs because computers run more efficiently in cool versus hot environments. The recommended temperature for a dedicated computer room is around 65–68° Fahrenheit.

Host computer

The host computer holds the operating system for the CT imaging system. The *operating system* controls the hardware components (like the gantry and patient couch) and runs accessory programs loaded into the primary memory of the host computer. Many host computers now use large array parallel processors to run sophisticated processes and applications simultaneously. CT software loaded onto the host computer continues to be developed, which allows more advanced applications to be used to enhance the images produced by CT imaging systems. Various post-processing software applications are available for use across the spectrum of manufacturers like the following:

- Multiplanar reformation.
- Maximum or minimum intensity projection.
- 3D reconstruction.
- Quantitative CT angiography.

- Brain perfusion.
- Calcium scoring.
- CT endoscopy.
- Dental planning.

Multiplanar reformations are the most common post-processing function you will likely perform in CT. Using the system software and multiplanar reformation application, axial plane images can be reformatted into coronal, sagittal, or oblique planes. Figure 3–31 illustrates the multiplanar reformat application. Beginning with the top right image, this is the original axial image selected from the series of images acquired during the CT scan. The top left and bottom right quadrants display the axial image reformatted into the coronal plane. Lastly, the bottom left quadrant of the illustration shows the axial image reformatted into a sagittal plane. Another function of this type of application is that the reformatted images can be sent digitally to a laser printer, or, more commonly, saved as an additional series of images within the study itself and, in turn, sent to the PACS.

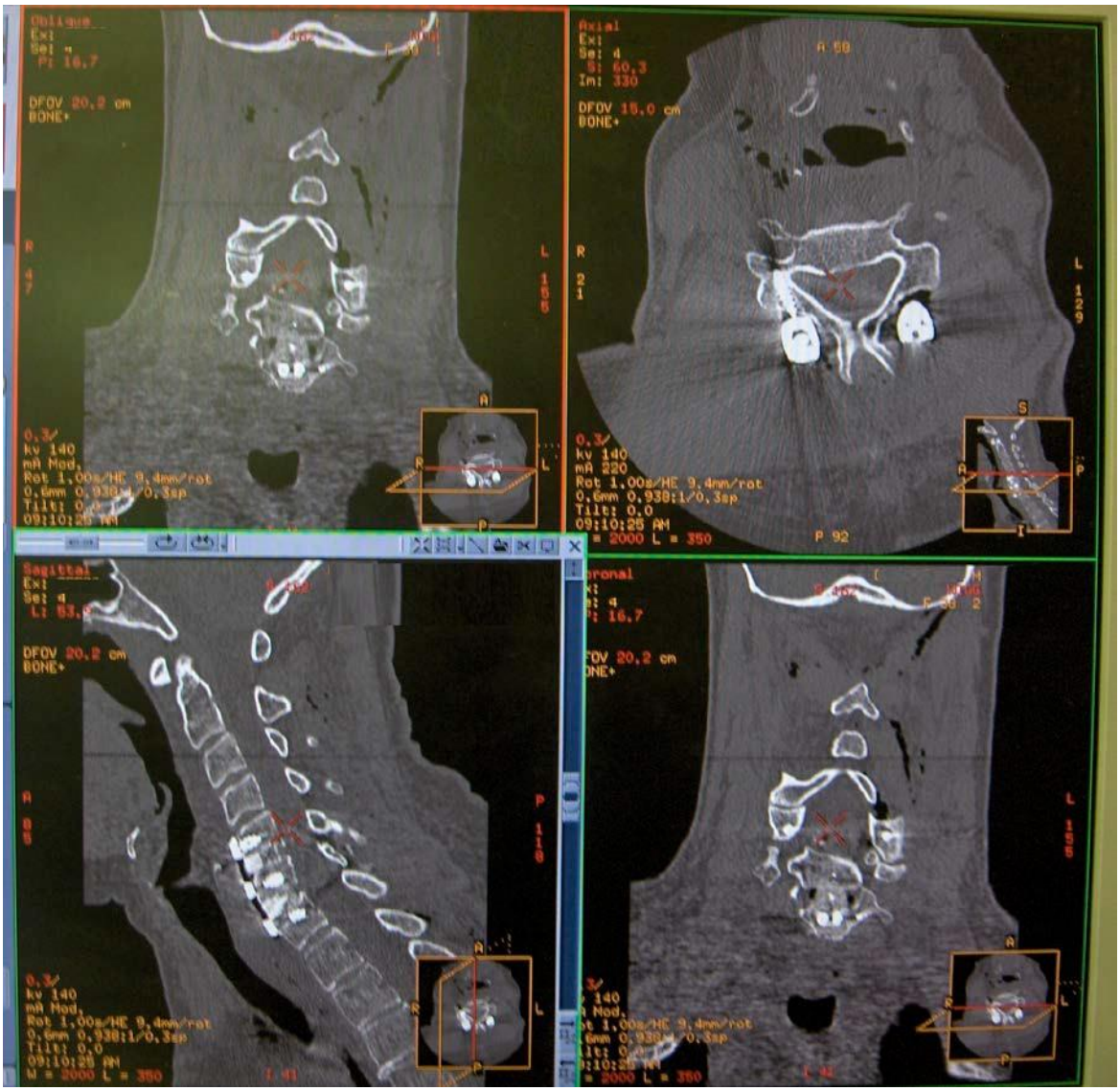


Figure 3–31. Multiplanar reformation application illustration.

Storage capacity on the host computer is not large. The memory available is for the operating system, image enhancement applications, and temporary image reconstruction storage. *Archiving* is the term used when CT images are transferred from the host computer to a long-term data storage device like a magnetic tape or optical disk. Finally, the host computer facilitates what is displayed on the computer's monitor. Users (technologists, radiologists, and physicians) are then able to access the various post-processing applications to manipulate the image for optimum visualization and pathology interpretation.

3.6 Operator's console

The operator's console is the technologist's link to the scanner. It allows the technologist to control the CT scanner to produce images, display images, use post-processing application (image manipulation), archive images, and send images to PACS for medical professionals throughout the facility to view the finished product.

Console

The typical operator's console (fig. 3–32) contains a keyboard, mouse, and two monitors, from which the appropriate software menus are accessed, exam protocols are selected, and images are displayed. Using the console, the operator enters the patient information, selects scanning parameters (including kVp, mA, time, slice thickness, scanning mode, reconstruction algorithm, etc.), initiates the CT scan, monitors the scanner performance, and views the images on the computer monitors.

Figure 3–33 shows some common applications the technologist can access and use to manipulate the displayed CT image. Also available to the technologist is the ability to use an intercom system that links the keyboard to the gantry. Using the intercom, the CT technologist can speak to the patient by giving instructions or updates on the progress of the scan. Figure 3–34 shows the speaker, microphone, and three types of volume adjustments (keyboard speaker volume, gantry volume, and prerecorded message volume) the technologist can manipulate. The keyboard also allows the operator to tilt the gantry without having to go into the CT suite, use the buttons on the gantry itself, and change the window/level settings, which is discussed later in this section.

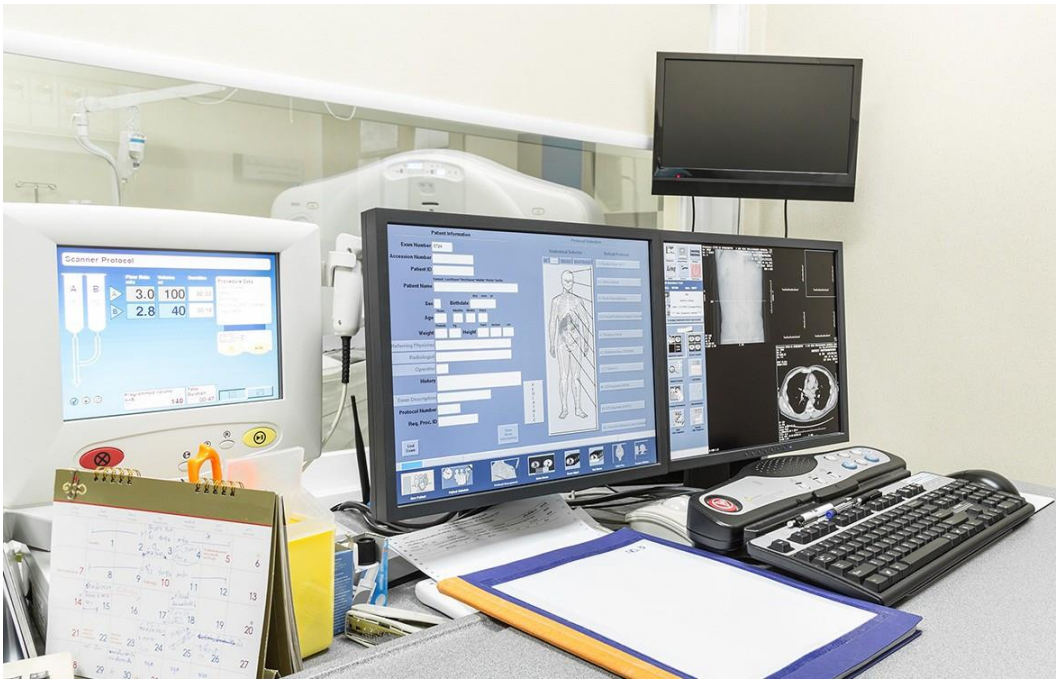


Figure 3–32. Typical CT operator's console.

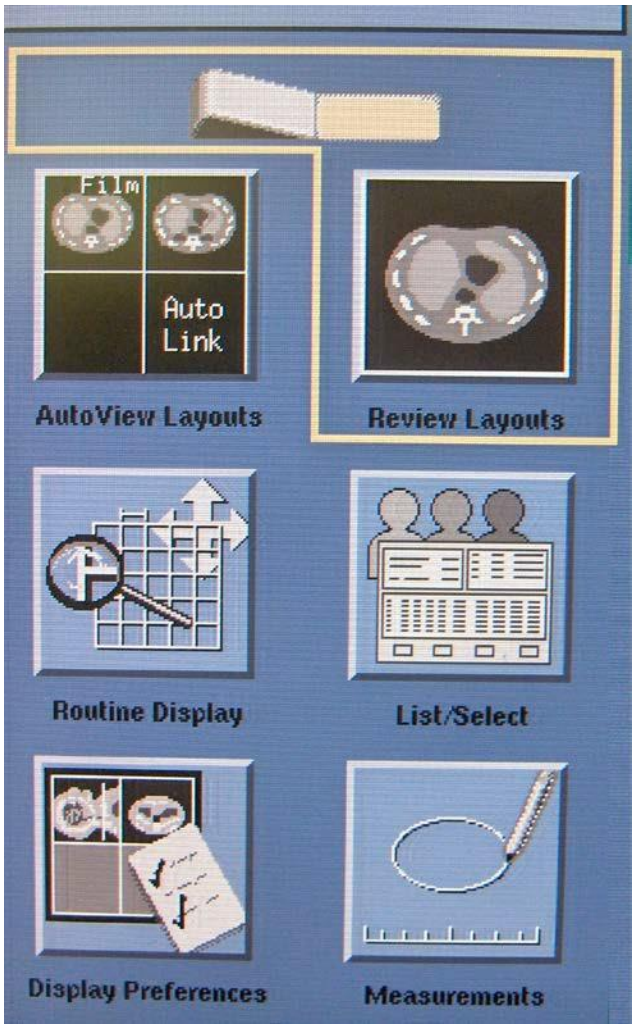


Figure 3–33. Common CT system applications.

Figure 3–34. Keyboard-controlled patient-intercom function.

Image display monitor

When a CT image is displayed on the monitors, it is the culmination of all the processes taking place in the gantry and computer system via input by the CT technologist at the operator's console. Most operator consoles consist of a dual-monitor set-up.

Window and level settings

Another function performed at the operator's console is the ability to adjust the window and level settings for the various CT images. After the image is acquired, the technologist can view and manipulate it from the console, using the keyboard and mouse. One nice feature about CT (and all forms of digital imaging) is that you can change the image contrast scale and density after the exposure is made to optimize visualization of specific anatomy. In CT, this is done by adjusting the window and level. The *window*, otherwise known as window width (can be abbreviated simply as "W" or as "WW"), is used to set the number of shades of gray (CT numbers) you want to display on the image. If you want to display a narrow window (fewer shades of gray and high contrast), use a lower number value with the window setting. On the other side, if you want to display a wide window (many shades of gray and low contrast), then increase the value of the window number setting.

The anatomy scanned helps determine where the window value is set. For example, when viewing the brain, the range of CT numbers is normally limited; therefore, set the window to a relatively low number (80–150) for displaying high contrast. On the other hand, if bony detail is desired, the window must be set much higher (2,000 or more) to lengthen the scale of contrast because of the wide range of tissue-density differences between the organic and mineral bone content. The increase in the window number provides an increase in the number of shades of gray (long scale of contrast).

The *level*, otherwise known as window level (can be abbreviated simply as "L" or as "WL"), setting determines where on the Hounsfield scale the window will be centered, or in other words, it sets the density of the structures shown on the image. For example, the screen will display shades of gray, ranging from –50 to +50, with a window of 100, if the level is set at zero (water density). In other words, the level sets the mid-portion of the gray scale to control the overall density of the image and is used in conjunction with the window to alter the appearance of the image. As you increase the level, you center on the higher CT numbers, which represent higher density structures. Therefore, to visualize the denser structures, such as bone, you will set a relatively high level (500 or more). To visualize the less dense structures on the image (soft tissue), set a low level (50 or less).

Compare the window and level settings used in figure 3–35 with figure 3–36 of the thoracic region. These two images are of the same approximate thoracic area; however, they are displayed differently, due to the change in the window and level setting, which allows for different cross-sectional anatomy to be visualized in one image versus the other. Figure 3–35 has a low-level number (–500) and a high-window number (1,500). This low level centers the window on the lower density tissue of the lungs, which are filled with air. The high window provides the long-scale contrast needed to visualize both lung tissue and vascular markings. Figure 3–36 has a higher level (+40), which centers the window closer to soft-tissue density, and a low window (400) to create a shorter-scale contrast. In this scan, the short-scale contrast is needed to show contrast between soft-tissue structures of the heart and mediastinum.

Most all operator consoles come with the ability to have programmed, preset window and level settings at the touch of a button. This feature comes in very handy for CT studies in which you or the radiologist are looking at both lung and soft-tissue windows (for a chest CT), or soft tissue and bone windows (for spine or orthopedic studies). Figure 3–37 uses the function keys at the top of a normal keyboard. The manufacturer preprograms the preset window and level values are pre-programmed by the manufacturer; however, the settings can be adjusted to your radiologist's preference by accessing the software included with your CT scanning unit.

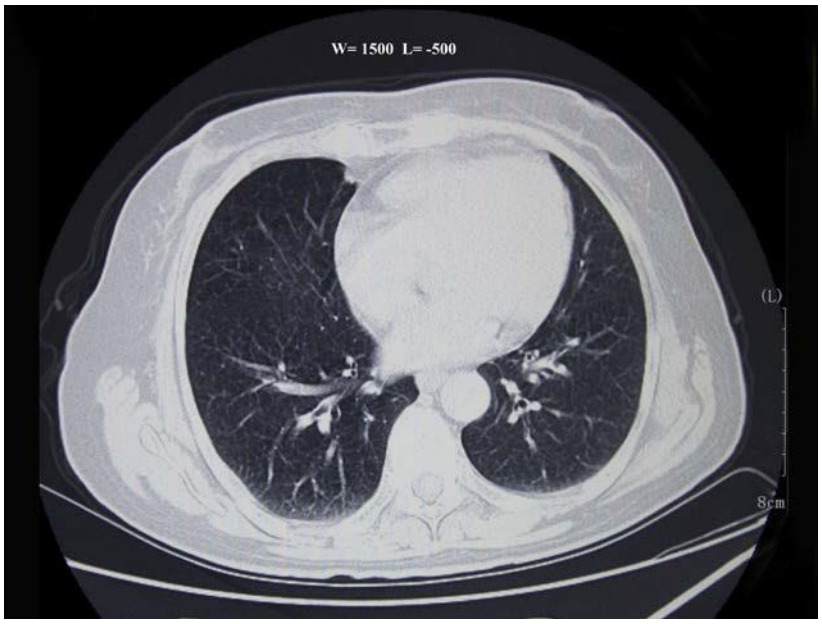


Figure 3–35. Axial CT image of chest (lung window).

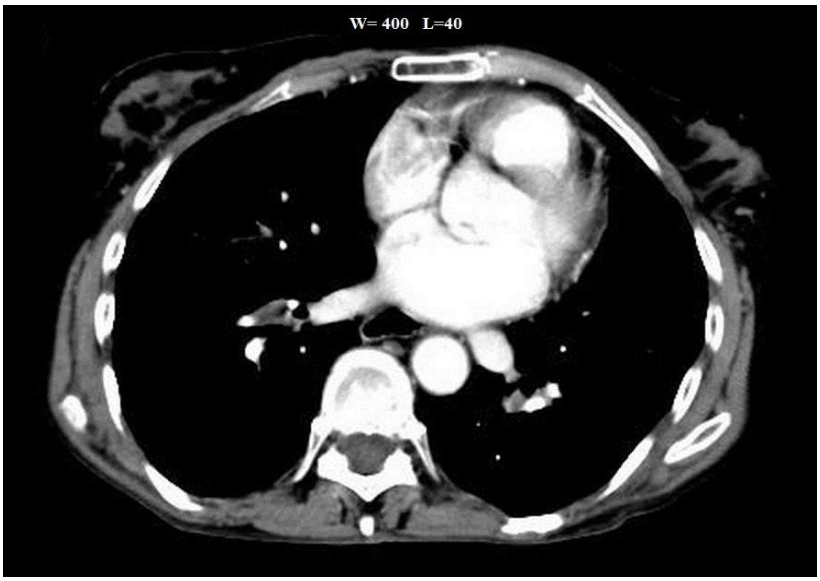


Figure 3–36. Axial CT image of chest (soft-tissue window).

Figure 3–37. Keyboard function keys used as preset window and level settings.

Accessory equipment

In addition to the standard scanner components already discussed, certain accessory equipment is vital to the operation of every CT department. Among these devices are the image storage device and automatic injector.

Image storage device

Image data is stored temporarily on the host computer's hard drive to facilitate rapid image recall for viewing and manipulating. However, the hard drive can only hold so many images. For this reason, electronic data is transferred periodically to a more permanent digital storage medium, such as a CD, magnetic tape, or optical disk. A CD can be used to store data from a single patient; whereas, magnetic tapes and optical disks can store examination data from many patients. Optical disks tend to be the storage medium of choice in most departments since their capacity to store images/data is dramatically more than that of magnetic tapes.

No matter the image storage medium, it is labeled and stored relatively close to the CT scanner, so historical images can be retrieved for additional manipulation. It is important to note that a good method of record keeping is necessary to identify which exams are saved on each medium. Typically, this is your CT examination logbook.

Automatic intravenous contrast injector

Some CT examinations require the injection of IV contrast media to visualize vascular structures within the body. To perform these injections consistently from examination to examination, automatic injectors are used. *Automatic injectors* are devices that introduce controlled amounts of contrast medium into the circulatory system, using a specific flow-rate setting. The function of an automatic injector is to provide a mechanism to deliver IV contrast media rapidly for visualization during a CT scan. While single-syringe injectors are still manufactured, most facilities use dual-head injectors (fig. 3–38). The syringes used on automatic injectors are special high-pressure disposable syringes that have a capacity to hold up to 200 milliliters (ml) of fluid.

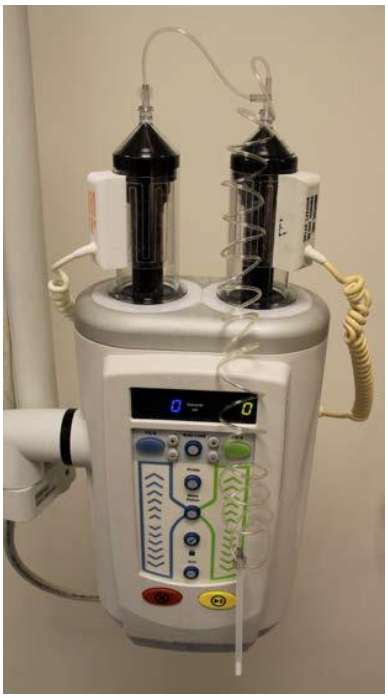


Figure 3–38. Dual-head automatic IV pressure injector.

Once a syringe is attached, a mechanical plunger connects to the base of the syringe. The plunger is responsible for pushing the fluid out of the syringe and into the patient at a constant flow rate. *Flow rate* is the amount of contrast material delivered per unit of time. The flow rate for a given procedure is dependent on the size of the peripheral IV, the condition of the patient's vessel, and the type of study desired. Flow rates are expressed in cubic centimeters (cc) per second (sec)—for example, 3 cc/sec. A heating device is clipped onto the syringe(s) to warm the contrast material to at, or near, body temperature. Warming the contrast reduces the viscosity (thickness) of the contrast, allowing faster flow rates.

The injector-control console (as viewed in fig. 3–32 to the left of the computer monitors) is always positioned near the CT operator's console to allow a single operator to control both contrast injector and the scanner from one location. Using the injector, the technologist can inject up to 5 cc/sec of IV contrast media, saline, or a combination thereof, through the patient's IV line. CT scans can be performed simultaneously with the injection to optimize contrast visualization of vascular structures or before/after the injection, depending on the type of CT study being performed.

Safety in operation is very important with automatic injectors. As we discussed earlier, flow rate is dependent on several variables. Even so, during the course of the CT study, unexpected problems with the IV catheter, the injector itself, or the patient can arise. Therefore, injectors have a built-in, pressure-limiting device so that the injector will not exceed a preset maximum allowable pressure level, measured in pounds per square inch (psi). You should be completely familiar with the operating instructions and safety features of your automatic injector unit before attempting to use it.

3C Patient Preparation and Radiation Safety

Fortunately, patient preparation and radiation safety practices in CT are similar to conventional radiography. To set you up for success, there are certain aspects you should consider when preparing a patient for a CT examination. In addition, as you have learned previously in this course, radiation safety and exposure-dose control are important considerations that should never be overlooked. To start the CT examination off on the correct path, patients must be prepared for their exam.

3.7 Patient preparation

When patients present themselves to DI with an order for a CT study, there are certain things that take place to prepare the patient for his or her exam appropriately. No CT exam can be performed without a radiologist (or physician at some facilities) protocoling the study. A protocol is simply a standard set of parameters used to image a certain body part. Protocols are necessary to ensure consistency from exam to exam. Included with the exam protocol are designations for you to use or not use contrast-media agents. Before oral or IV contrast are administered, certain aspects of the patient's history and condition must be considered to prepare him or her properly for the CT exam.

Preparation determining factors

In most departments, your first contact with the patient occurs when he or she arrives at the front desk of your department to schedule an appointment for a CT exam that his or her primary care manager (PCM) has ordered. At this point, you are able to give the patient a brief explanation of the exam and state what preparation steps the patient must follow before arriving on the day of his or her CT procedure. Patient preparation for CT examinations that do not require IV contrast is minimal. In fact, many CT exams are performed without any preparation on the part of the patient at all. The following is a short list of CT exams (when performed without IV contrast media) that do not require any patient preparation:

- Head, orbits, facial bones, and temporal-bone studies.
- All spine imaging.
- Bony pelvis and hip imaging.
- All upper- and lower-extremity imaging.

Exam protocols

Exam protocols are a standard set of instructions to be followed for various CT examinations. Radiologists in your department determine CT exam protocols. It is your job to follow them as closely as possible, informing the radiologist whenever you must deviate from the standard. Protocols cover a wide variety of information you need to complete the exam, including the type and amount of contrast media to use; patient positioning; the thickness, location, and number of slices to be taken; image reconstruction (if necessary); and so forth.

Each department has its own procedures for protocoling CT exams; make sure to learn the procedures practiced at your facility. Most times, though, CT orders are printed and then taken to a radiologist for him or her to protocol. The PCM provides the patient's narrative history to the radiologist to reads, who then annotates what type of CT study is necessary (with or without the necessity of IV, oral, and rectal contrast) to help diagnose the patient's condition.

Contrast media

In general, contrast-media agents are used to enhance specific areas (whether vascular or part of the alimentary tract) and differentiate tissue structures to help your radiologist distinguish between normal anatomy and pathologic tissues. Because CT uses radiation to image the body, the contrast media used for CT is similar to that used for radiography.

CT studies can be performed totally non-contrast, with or without IV contrast injected, with or without oral contrast, with or without rectal contrast, or a combination thereof. Common letter symbols are used to denote "with" and "without" a type of contrast. The letter "c" designates "with" a particular contrast, and the letter "s" designates "without". These letters can be used with all three types of contrast administered in CT. For example, if a radiologist wants IV, oral, and rectal contrast used for a particular abdomen and pelvis CT scan, he or she may write the protocol as CT abdomen and pelvis c/c/c. Another example is when a radiologist wants a CT of the kidneys performed without and with IV contrast; he or she would likely write the protocol as CT kidney s/c/ IV contrast.

When a CT order states *with (or without) contrast* (e.g., CT Abdomen w/), it is referring to with (or without) IV contrast media. IV contrast media used in CT is the same used for IV urograms in radiography. Oral/rectal contrast-media agents used are similar to those used for fluoroscopic procedures but are significantly more diluted (approximately 10 percent of the normal strength). Either a barium solution or a water-soluble oral (i.e. Gastroview or Gastrografin) may be used.

Certain CT studies of the abdomen and pelvis regions may require patients to fast from eating (typically 4, 6, or up to 12 hours depending upon your department's policies) and drink a variety of oral contrast agents prior to their exam. Oral contrast is designed to travel through the alimentary tract to help distinguish the structures of the stomach, small bowel, and large bowel from surrounding tissue and other pathology. Patients should be given an instruction sheet clearly outlining how much oral contrast to take and when to take it (e.g., drink one 16-ounce dose 1½ hours prior, drink another 16-ounce dose 1 hour prior, and drink a final 16-ounce dose 30 minutes prior to the start of the CT study).

NOTE: All oral contrast times are based upon when the CT study is scheduled to take place.

When the head, neck, chest, abdomen, or pelvis studies use IV contrast for enhancement, most departments require the patient have nothing passed orally or nothing passed by mouth (NPO) for anywhere from 2–4 hours prior to the injection. This precaution is taken to reduce the risk of vomiting and aspiration when IV contrast is administered. For abdominal and pelvic studies, if the patient has had any barium GI study done in the last day or so, a standard bowel preparation may be needed to help remove any residual barium that could cause artifacts.

Prescreening questions

Whenever IV contrast use is indicated for a CT study, you must prescreen the patient for contraindications to the iodinated contrast material before starting the injection. Each radiology department develops its own protocol of questions that must be asked to every patient before IV contrast media is administered. Below are some standard questions most often asked to patients to evaluate them for a potential reaction to contrast media. Routine screening of your patients prior to IV contrast-media administration is a must to effectively reduce the possibility of an adverse reaction, and, if a reaction occurs, it also helps in the emergency management of a reaction.

NOTE: Always follow your department protocol for screening patients prior to injecting IV contrast media.

1. *Have you ever been injected with IV contrast media (X-ray dye) before*? If a patient has received IV contrast media before, ask if there were any adverse reactions. Patients who have had previous allergic reactions to contrast media may need to be premedicated prior to any subsequent contrast-media injections. (**NOTE:** Remember that a patient who had contrast media injected and did not experience a negative reaction can have a reaction without any prior issues or specific indicators.)
2. *Do you have kidney problems*? The kidneys eliminate contrast agents from the body. A patient with renal insufficiency may require the radiologist to change the type of contrast media to an isosmolar agent, like Visipaque, and/or reduce the quantity administered.
3. *Are you a diabetic?* Diabetic patients sometimes take medications such as Glucophage,

Glucovance, Metaglip, or Avandamet. Each of those four medications contain metformin hydrochloride, which, when mixed with the contrast media, can cause kidney damage or, in worse case scenarios, acute kidney failure. Metformin products should be stopped the day the contrast media is given and for 48 hours after the contrast media is injected. In addition, patients are typically instructed to contact their physician prior to resuming their metformin therapy regimen.

4. *Do you have heart disease or have you previous experienced heart failure?* Pulmonary function affects the timing of the contrast injection; therefore, this factor should be considered during the setup of the scanning parameters. In addition, if an emergency arises, this information is good for the radiologist to know.
5. *Do you have asthma? Do you have any food or drug allergies?* Patients with asthma and/or certain food or drug allergies may have an increased chance of having a contrast-media reaction.
6. *What other medical conditions do you have?* Information on the patient's medical history is good to know ahead of time in case an emergency presents itself.
7. *What medications and doses are you currently taking?* Knowing what medications the patient is taking is important for physicians to know, especially if an emergency presents itself.

If a patient answers yes to any of the above conditions, alert the radiologist prior to administering IV contrast media.

Lab test for kidney function evaluation

Many departments require a blood chemistry test on patients of a certain age (typically somewhere between 40 and 50 years of age and older) with certain specific medical conditions (like renal insufficiency or history of renal failure) or other qualifying factors prior to the administration of IV contrast media. There are three common blood tests used to measure how well the kidneys are functioning. They are serum creatinine, blood urea nitrogen (BUN), and glomerular filtration rate (GFR). Your radiologist determines the type of lab test used to check renal function before injecting IV contrast; therefore, make sure to follow your department's specific policies. No matter the test, if the lab result is outside of the normal range, notify the radiologist prior to contrast-media administration. The normal adult range for the three types of renal function lab tests discussed are as follows:

- Serum creatinine is 0.6–1.5 milligrams per deciliter (mg/dL).
- BUN is 6–20 mg/dL.
- GFR is 90–120 milliliters per minute (ml/min).

It is typical for your radiologist to set a more strict acceptable range for both types of blood tests. For example, the acceptable range for a BUN test may be 6–15 mg/dL, and for a serum creatinine, the acceptable range may be 0.6–1.3 mg/dL. The keys to remember are to get a lab test for everyone who meets your department's prequalifying factors, and notify the radiologist of any result not within the acceptable range ***prior*** to an injection.

Pre-medications for patients with prior contrast reaction

Sometimes a contrast-enhanced study is necessary, even though the patient has experienced a prior contrast-induced allergic reaction. In situations like this, the patient's requesting physician prescribes a prophylaxis treatment (premedication), and then the patient picks up the medications from the pharmacy. For routine contrast-media studies, the prophylaxis treatment is a 13-hour preparation. A prescribed medication (normally methylprednisolone/prednisone) is taken three times by the patient; once 13 hours before the expected injection, again 7 hours before the expected injection, and finally, 1 hour before the expected injection. Also, the patient takes a dose of diphenhydramine (Benadryl) an hour before the expected injection. When a patient is pre-medicated, it is important that his or her exam and injection is performed at the scheduled time for the prophylaxis treatment to be most effective.

Patient positioning

The most common patient position for CT examinations is supine. The supine position is used for nearly all routine head, neck, chest, abdomen, and pelvis CT examinations. However, from time to time, you may also perform scans in the prone or lateral recumbent positions. For instance, a CT- guided

biopsy of the lung may require the prone position if the mass being examined is in the posterior lung tissue.

Another common patient position used to acquire direct coronal images of the face or sinuses is lying prone on the CT table. The prone position requires the patient to lie prone on the table with the patient's neck fully extended. The patient's chin is rested in the head-cradle–couch attachment; the gantry is then angled to bring the scan plane as close to perpendicular to the orbital meatal line (OML) as possible (normally the gantry maximum of 30°). In this position, direct coronal images are acquired that provide more detail than coronal images that have been reconstructed from axial images.

Once it's determined whether the patient should be in the supine or prone position, the technologist instructs the patient to lie with his or her feet towards the gantry (feet first) or with his or her head towards the gantry (headfirst). For any position, the technologist should pay attention to make sure the patient (body part) is not rotated or positioned at an angle to the long axis of the CT couch. Though most CT exams are completed in a short amount of time, any patient movement during the exam will lead to a loss of diagnostic information and may require repeating the images. The following are two ways to reduce patient motion during a CT scan:

1. Provide a pillow to place under the patient's head (when diagnostically possible), making sure he or she is comfortable by giving a place to rest his or her arms when raised above his or her head (as is the case for most all thoracic and abdominal studies). Also, place a positioning sponge (or pillow/blanket) under his or her knees to alleviate low back discomfort. Figure 3–39 shows a patient comfortably positioned feet first with support under his or her knees, a pillow, and with arms raised above his or her head.

2. Use immobilization techniques (Velcro straps) to eliminate unwanted movement.

   NOTE: When immobilizing a patient (or body part), ***always*** explain to the patient what you are doing and why you are doing it. Figure 3–40 shows a CT patient positioned headfirst with Velcro immobilization straps applied across the patient's chin and forehead areas.

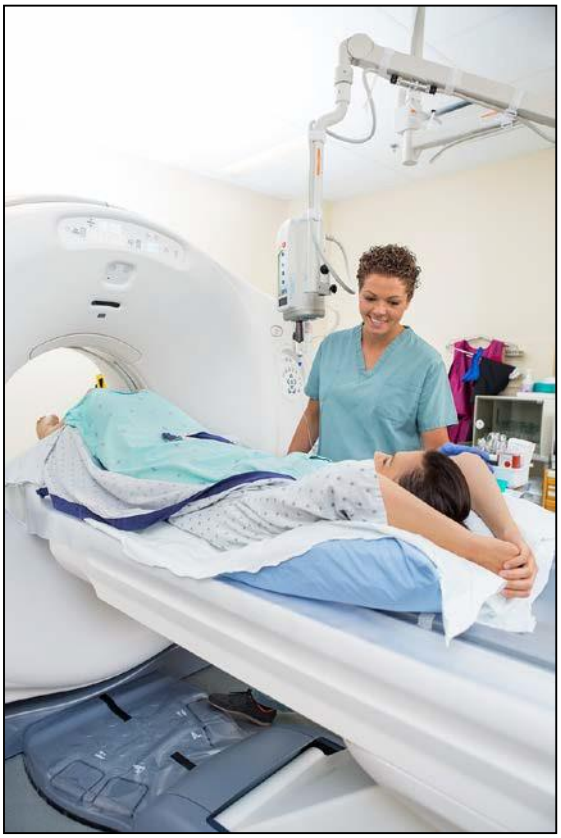


Figure 3–39. CT patient positioned comfortably feet first.

Figure 3–40. CT patient positioned headfirst with Velcro immobilization straps applied.

3.8 Radiation safety in computed tomography

As discussed previously in this course, there are three basic principles when it comes to radiation safety in DI: (1) a decrease in your exposure time, (2) an increase in your distance from the source of radiation, and (3) the use of lead shielding. In CT, the X-ray tube (the source) rotates around the patient in a 360° circle; whereas in conventional radiography, the tube is stationary. With this tube- movement principle in mind, radiation exposure doses are greater in CT; therefore, this lesson discusses the risks versus the rewards of CT, exposure-dose metrics and units, CT radiation exposure reduction, and common radiation practices used in CT. We begin with the risk versus reward.

Risk versus reward

You know by now in your DI career the benefits of using ionizing radiation for medical diagnosis are enormous; however, proper attention must be paid to the risks associated with the use of ionizing radiation. As CT has advanced dramatically in capability to provide accurate medical diagnoses, its use has skyrocketed. It is estimated that as many as 72 million CT scans are now performed annually in the United States, with worldwide use approaching 300 million CT scans annually. In the United States, an estimated 7 million CT scans are performed on pediatric patients. This use exposes a significant portion of the world population to increased radiation over naturally occurring radiation exposures. Currently, medical imaging is estimated to account for up to 48 percent of the total radiation exposure to the population, up from 15 percent estimated in 1987. CT alone accounts for 24 percent of the total radiation exposure to the population.

Of particular concern is the increased use of CT scanning in children, pregnant women, and chronically ill patients, especially those of a young age. The potential risks of exposure to ionizing radiation include induction of malignancy, genetic mutations, and congenital malformations.

It is estimated that for a one-year-old who undergoes an abdominal CT, there is a 0.18 percent increased risk of developing cancer in his or her lifetime. When a head CT is performed on that same one-year old, there is a 0.07 percent increased risk of developing cancer in his or her lifetime. It is important to note, though, these risk levels are extremely small when compared to an estimated 23 percent risk an individual has of developing cancer in his or her lifetime from normal means. This very conservative overestimate of risk must be balanced against the benefit of achieving a proper diagnosis with the use of CT. In many instances, the immediate benefit dramatically outweighs the risk. With all this stated though, unfortunately, there is no significant data available that ties the cause of cancer development in adult life to diagnostic radiation exposure versus that which occurs naturally. Additional cancers possibly related to medical radiation exposure may have a latency period of 30–40 years.

CT's cumulative effective dose contribution

Studies have shown 10 percent of all diagnostic X-ray exams performed are CT. However, studies have also shown that CT accounts for approximately 70 percent of a patient's cumulative effective radiation dose. In other words, CT accounts for 10 percent of all X-ray–based procedures but contributes approximately two-thirds of the total medically related radiation exposures to patients. A CT of the abdomen may have 200–250 times the radiation dose of a chest radiograph. A CT pulmonary angiogram delivers 2.0 radiation absorbed dose (rad) (20 milligray [mGy]) per breast compared to 0.30 rads (3 mGy) per breast for a mammogram.

Children and radiation dose

It is estimated that up to 11 percent of diagnostic exams using ionizing radiation are performed on infants and children who are more susceptible to the adverse effects of radiation. With this knowledge, responsibility primarily falls to the radiologist and the ordering physician to limit CT usage to the following instances:

- Use only when definitive indications are present.
- Provide low dose–efficient CT imaging protocols.

- Offer alternative imaging techniques for young children.
- Educate patients and health care providers on the potential risk of low-dose radiation.

As a CT technologist, you can reduce exposure levels in CT by always using reduced techniques (kVp, mA, and time) that are appropriate for the size (and age) of the pediatric patient you are scanning.

CT and pregnancy

When a woman is pregnant, radiation risk to the fetus is magnified by the small size of the developing human because of rapid growth and extremely active cell division. Potential harmful effects of ionizing radiation to the fetus include prenatal death (especially in very early pregnancy), intrauterine growth retardation, mental retardation, organ malformation, and development of cancer during childhood. Radiation risk to the unborn fetus is highest in the first trimester, diminishes in the second trimester, and is lowest in the third trimester.

If the uterus is outside the field of view of the X-ray beam, the fetus receives only scatter radiation and the radiation dose is minimal. If the fetus is exposed to the direct X-ray beam within the field of view, dosage depends on thickness of the patient, depth of the conceptus from the skin, X-ray technique, and direction of the beam. In the first two weeks of pregnancy, radiation exposure seems to have an all-or-none effect. Radiation may terminate the pregnancy or the embryo may recover completely. At three to eight weeks after conception, organogenesis is at its maximum stage and radiation exposure may cause organ malformation.

The central nervous system is most sensitive from eight to 15 weeks gestation. Significant exposure at this time may cause mental retardation microcephaly. In the third trimester, the fetus is much less radiosensitive and functional impairments and organ malformations are unlikely.

CT examinations that *do not* expose the uterus (fetus) to the *direct* X-ray beam deliver minimal radiation dose to the fetus. When the uterus region is not the primary area of interest during a CT study (e.g., a head, chest, or extremity scan), radiation exposure to the fetus comes from scatter radiation produced from within the patient rather than the primary beam itself. For this reason, shielding the uterus region has minimal protective effect for the fetus. It is important to note that whenever a pregnant patient is CT scanned (no matter the area of interest), the radiologist is the determining authority on whether or not the study is worth the exposure risk to the fetus. Your role is to make certain, prior to commencing the scan, that the radiologist is aware the patient is pregnant.

, The primary purpose of shielding a patient's abdomen (fetus), breasts (females), or thyroidal region during a CT scan is to alleviate the patient's fear related to the risk of being exposed to radiation rather than actual protection for the fetus, breast, or thyroid because of how scatter radiation is produced. Of course, lead shielding cannot be used if the area to be shielded is of primary interest for the CT scan. When shielding is used, wrap a lead gown 360° around the patient since the CT tube rotates and exposes the body part in the full 360° spectrum.

Exposure dose metrics and units

Radiation dose in CT is commonly reported using a *volume CT dose index* ($CTDI_{vol}$), which is given in units of mGy. Another common CT dose metric, the *dose length product* (DLP), is equal to the $CTDI_{vol}$ multiplied by the length of the scan and is given in units of mGy-cm. $CTDI_{vol}$ and DLP represent radiation output from the CT scanner and are measured using a 16-cm acrylic phantom for head exams or a 32-cm acrylic phantom for body exams. $CTDI_{vol}$ and DLP do not directly measure patient dose, as patient size and composition vary widely and are not well represented by these simple phantoms. However, $CTDI_{vol}$ and DLP do provide information on the amount of radiation delivered in a study. This information can be used to compare the amount of radiation delivered across different protocols, scanners, and institutions or to compare against recommended dose levels. In addition, $CTDI_{vol}$ and DLP can be used to estimate patient dose using metrics such as the *size-specific dose estimate* (SSDE), which is calculated from $CTDI_{vol}$ and patient size.

Reference and dose-check levels

In 2010, the National Electrical Manufacturers Association (NEMA) published the technical standard XR–25, mandating that CT scanners implement a dose-check system to monitor for potentially high patient doses. This dose-check system must include both a *notification level* and an *alert level*. A *notification level* is meant to let the technologist know that the chosen scan parameters will produce a higher-than-normal $CTDI_{vol}$ or DLP for that protocol.

The user will then have the option to edit or confirm the settings. Notification levels may be exceeded when appropriate for a specific patient or diagnostic task (e.g., scanning very large patients). *Alert levels* are typically for $CTDI_{vol}$ and DLP values much higher than notification levels, and they apply to the cumulative $CTDI_{vol}$ or DLP across multiple scans of the same patient. Exceeding an alert level requires additional actions by the user to proceed with the exam.

The operator must also enter his or her name and, in some cases, document justification for exceeding the alert level. Currently, selecting the $CTDI_{vol}$ and DLP values for these notification and alert levels is left up to each MTF. Many radiological institutions and professional groups have developed guidelines and recommendations for selecting CT dose-reference levels.

Dose-tracking requirement

As of 9 January 2015, the Joint Commission requires clinics using CT scanners to track doses from patient exams. According to the Joint Commission, "The hospital documents the radiation dose index ($CTDI_{vol}$, DLP, or SSDE) on every study produced during a diagnostic CT examination." Furthermore, "The hospital reviews and analyzes incidents where the radiation dose index ($CTDI_{vol}$, DLP, or SSDE) from diagnostic CT examinations exceeded expected dose index ranges identified in imaging protocols. These incidents are then compared to external benchmarks." Many DI medical equipment and software vendors are now providing products and services to meet these requirements. In addition, national registries now exist to collect CT dose data from participating institutions, allowing for the collection of aggregate data that can help in establishing benchmarks for exam- specific doses.

Radiation exposure reduction

CT has passed conventional radiography as the first option of DI for many physicians. Emergency- room CT orders have skyrocketed and some facilities promote whole-body CT screening to provide early detection of deadly diseases. Unfortunately, the overuse and whole-body screens have only served to increase patients' exposure to ionizing radiation and increase their cumulative effective dose. As a technologist, you are required to look out for the safety and well-being of your patients. At times, it may be necessary to question the validity and necessity of certain CT studies with your radiologist respectfully. You might remember from earlier in this course, principle seven of the American Registry of Radiologic Technologists (ARRT) code of ethics, which states: "The radiologic technologist uses equipment and accessories, employs techniques and procedures, performs services in accordance with an accepted standard of practice, and demonstrates expertise in minimizing radiation exposure to the patient, self, and other members of the health care team."

NOTE: "*Principle seven of the ARRT Standards of Ethics is reprinted by permission of the ARRT. The ARRT Standards of Ethics are copyrighted by the ARRT."*

Ultimately, you (as the CT technologist) are the last line of defense and are directly responsible for protecting patients under your care (and fellow medical staff in the area) from undue or excessive exposure to ionizing radiation in the performance of your duties.

Dose optimization

Dose optimization is a radiation protection concept designed to reduce the dose amounts delivered to patients in CT. It falls in-line with the other prominent radiation protection principle known as

ALARA. Dose optimization aims to reduce the patient's exposure dosage while not affecting image quality. The following strategies can be used to reduce the dose a patient receives during a CT scan:

- Use single-slice conventional CT scan mode versus helical mode for head scanning.
- Scan only the area of the patient necessary; do not overscan above and below the area of primary interest.
- Set your scan parameters for the widest CT beam collimation allowed while still achieving the clinical objectives.
- Reduce the kVp, mA, and scan time whenever possible and for younger/smaller patients.
- Use pitch to increase scan-coverage area while decreasing exposure.
- Eliminate multiphased scanning when appropriate.

Factors affecting dose

Various factors directly affect the radiation dose the patient receives. With on-the-job training and experience, the technologist can manipulate the following factors to acquire high quality CT images while also reducing the exposure dose your patient receives. The factors are:

- Technique: kVp, mA, exposure time in seconds.
- Slice thickness (beam collimation): beam collimation in single-detector imaging systems has a small effect on dose; however, this is not true for multi-detector systems that can scan and reconstruct in many different ways.
- Size of the patient/body part.
- Pitch (increased pitch reduces exposure dose).
- Dose reduction practices (like dose optimization).
- Distance from the X-ray tube to the isocenter of the body part (properly centering the body part reduces the aperture/collimation size needed to image the part).

Technologist radiation protection methods

Up to this point, most of the discussion has been directed at reducing the patients' exposure to ionizing radiation. Radiation protection for you and your fellow staff members is equally important. No personnel should be in the CT suite when the scan is taking place unless it is essential and a lead apron must be worn. The best way to protect yourself from radiation exposure in CT is by practicing the radiation protection concepts of time, distance, and shielding. When in the CT exposure suite, limit the amount of *time* spent in the room when the X-ray beam is on.
Stay as far away from the source (gantry and tube) as possible. Remember, dose is inversely proportional to the square of the *distance*.

Shielding is accomplished by wearing a body-length lead apron. Lead aprons protect all the vital organs of the body from the shoulders to the mid-thigh region. Additionally, wear a thyroid shield to reduce the exposure to the neck region appropriately. Though scatter radiation is reduced in CT due to the fine beam used, scatter radiation is still present and the X-ray beam is still highly energized. All walls and doors should be lined with lead to protect the public, other medical staff members, and other radiation workers (fig. 3–41) from unnecessary radiation exposure.

Figure 3–41. Notification of lead lined

Unit 4. Quality Management

4A Quality Assurance.....93
4.1 Quality assurance in diagnostic imaging.....93
4.2 Factors affecting image quality.....95
4.3 Artifacts.....97
4.4 Image quality control and evaluation.....98
4B Quality Control.....104
4.5 Quality control in diagnostic imaging.....102
4.6 Monitoring radiographic system components.....104
4.7 Repeat image analysis.....109

The use of radiation for diagnostic medical purposes has benefited mankind since the early 1900s. The benefits range from identifying small fractures to discovering if a patient has cancer or other deadly diseases; however, the use of radiation has a variety of variables that can lead to a low-quality image. If an image is produced that is not acceptable, the radiologist will not be able to accurately diagnose a condition or might possibly misdiagnose the patient's condition. Additionally images may need to be repeated if the quality is below the minimum standards. Repeating images causes more radiation dose exposure to patients. Quality management (QM) is ultimately a business application focusing on the customer. Customers are the patients and our goal should be to provide them with excellent patient care practices, ensure the images taken are of high quality, and ensure the radiologist interpretation matches the eventual patient condition. In this unit we will discuss how quality assurance (QA) and quality control (QC) programs help to make sure DI departments provide the best patient care while consistently producing high-quality images repeatedly.

4A Quality Assurance

QA programs include all the behind-the-scenes decisions, initiatives, and policies put in place to make the patient's experience in DI as smooth, complete, and comfortable as possible. QA exists to continuously improve and enhance how patient care is delivered through the collection and evaluation of various data points. Some of the areas monitored by a typical QA program are patient scheduling, wait times, review of operating instructions, staff competency through continued education, and repeat image analysis.

4.1 Quality assurance in diagnostic imaging

Since the standard of quality is always changing, QA deals with people and every aspect of the department affecting the quality of medical care. People are the main focus of a QA program. QA is a program assuring patients, insurance companies, and The Joint Commission (TJC) that patient care will be the highest quality.

Reasons for quality assurance programs

In the 1970s, TJC started to mandate QM programs within hospitals before they would accredit them. Although no law requires a hospital be accredited by TJC, it will not be reimbursed by insurance companies, be able to hold medical licenses, receive malpractice insurance, or host a residency program for physicians if not accredited by TJC. It is because of TJC that DI departments have an extensive QM program seeing that high-quality care will be received. TJC has set standards for hospitals requiring well-planned, process oriented, and career field–wide approaches for monitoring QM and the methods of improving deficiencies to provide patient care.

The many benefits patients receive from DI departments are only beneficial if the quality of the patient's total care experience is high. This experience includes everything from scheduling to levels of patient exposure to radiation, all to produce a quality image for a radiologist to interpret. Years ago the concept of As Low As Reasonably Achievable (ALARA) was coined as it was determined that due to the dangerous effects of excessive exposure to ionizing radiation, only the lowest amount of radiation necessary to produce a quality radiograph should be used. Unfortunately many factors can contribute to radiation overexposure, and this has caused entities like the American College of Radiology, the American Association of Physicists in Medicine, TJC, and the federal government to regulate further the use of diagnostic radiation.

X-rays must be completed with incredible quality, without repeats, for the radiologist to appropriately diagnose any medical condition that the patient may have. The *goal* of every DI department is that the radiologist's diagnosis is ultimately in agreement with the patient's disease. This concept is known as the *outcome analysis.* To make certain that healthcare organizations are fully committed to providing the highest quality care, TJC encourages organizations to adopt TJC's 10–step QA program that helps DI leaders achieve a QA program that gives timely imaging services and great patient care with the correct outcome analysis. One QA area of concern in every DI department is the amount of radiation the patient receives.

Patient dose concerns

With conventional film-screen radiography, it could be determined quite easily if the image and patient was under or overexposed to radiation based on how light or dark the radiographic film turned out; however, computed radiography (CR) and direct radiography (DR) systems create unique challenges in this area due to the way these systems use computer algorithms to convert data into shades of gray (density) on a monitor while at the same time allowing latitude for doctors and techs to make adjustments to the displayed image (darker or lighter).

When using CR and DR systems, the image acquisition can correct a gross overexposure, up to 500 percent, without negatively affecting the overall quality of an image. This correction happens because the analog-to-digital converter (ADC) assigns each pixel on the computer screen with a numerical value that correlates to the strength of the electronic signal read by the ADC. That numerical value relates to a specific shade of gray using complicated math equations. Post-processing then allows the technologist to adjust contrast and density by changing the assigned numerical value; if the numerical value of each pixel is so high that it creates a dark image, the technologist can simply decrease the assigned numerical value to bring the image into a viewable density. This presents a difficult task for the QA program because the latitude that a CR or DR system gives enables radiographers to become careless with the amount of radiation used. A common thought process for unskilled technologists is "when in doubt, burn it out." Unfortunately that philosophy is the exact opposite of what the ALARA principle tries to achieve.

Luckily manufacturers have developed a method to aid QA technologists and physicists in measuring radiation used during the production of digital images. DR systems record the exact amount of kilo–voltage peak (kVp) and milliamperage and time (mAs) as data under the patient's information for each image taken. CR systems provide digital measurements identifying the amount of radiation received by the imaging plate. The basis is that a numerical value is assigned to show the *sensitivity* of a digital imaging system to the amount of radiation the imaging plate received. This sensitivity is shown differently by manufacturer; therefore, the three most commonly used systems are discussed.

Agfa-Gevaert

The Agfa-Gevaert (Agfa) system establishes a numerical baseline value of, as an example, 10 millirad (mR) and attaches it to a numerical value known as the log median exposure (LgM). If the department's baseline was 10 mR, the LgM would be zero. Since the system is based on the log median system, every time the mR is doubled in exposure dose, the LgM increases by 0.3. The system would then assign a range of acceptable LgM to exams taken in the table-bucky and a range

for tabletop exams. As an example when using an Agfa system and the baseline for an image is 10 mR at 0 LgM, an increase in LgM to 0.3 would mean that the exposure doubled to 20 mR. This would continue after each increase of 0.3, meaning a new LgM of 0.6 will show that the imaging plate received 40 mR. Since Agfa has varying speeds of CR imaging plates, like 200 and 400, it is pertinent to know that changing the plate speed will alter the LgM baseline and how it is measured. For this reason it is important that the LgM chart matches the speed class of the imaging plates you intend to use.

Fuji

Fuji systems measure the amount of amplification needed by the photomultiplier tube when processing the CR imaging plate. As the imaging plate is processed, a red laser scans across it and blue light is released, which is equivalent to the radiation absorbed during exposure. The photomultiplier tube receives this radiation and amplifies it to be read by the ADC. The amount of amplification is assigned a numerical value known as a sensitivity-number (S-number). The S-number is inversely related to exposure in mR, so a large S-number shows that the patient received a lower amount of radiation, while a small S-number shows an increased radiation dose to the patient. For example if an exposure of 1 mR has an S-number of 200, as the S-number decreases closer to zero, the mR increases. Instead of memorizing a rate at which the mR changes based off the S-number, most systems will have a chart displaying acceptable S-number values for nongrid and gridded exams (i.e., grid exams should have an S-number between 100 and 400 with 200 being optimal).

Kodak

Kodak's CR indicator system reads radiation that is absorbed in the imaging plate at a directly proportional rate and is termed the *exposure index*. As an example an exposure of 0.1 mR will have an exposure index of 1,000. When 1 mR is reached, the index will jump to 2,000. Furthermore, the index will jump to 3,000 when the dose reaches 10 mR. The majority of properly exposed images in Kodak systems have an index value between 1,800 and 2,000.

The software of digital imaging post-processing systems adjusts for a wide latitude of exposure technique errors; however, as the under- or overexposure exceeds the limitations of the post-processing software, detail and image quality diminish. Additionally with the increased sensitivity of digital IRs to scatter and background radiation, image fog is more of a concern on the finished image. To reduce scatter and the negative effects of fog on a non-gridded image, you should limit the kVp setting to 80 or less.

Benefits of quality assurance

QA seeks to improve the care that a customer receives. In DI, we consistently strive to produce high- quality images while using the lowest amount of ionizing radiation possible (ALARA). To achieve this, QA programs should incorporate TJC's 10-step process to identify problems, monitor problems, and then resolve the problems with corrective measures. The critical aspect of QA is that the patient benefits whenever problems are identified and resolved. The most obvious benefits of a QA program *are* time saved, improved customer service, reduced patient dose, and increased image quality.

4.2 Factors affecting image quality

Producing a high-quality radiographic image for a radiologist to read and interpret should be the goal for every DI technologist. Various geometric factors like magnification and distortion as well as subject (patient) factors like part size and tissue composition influence how each image turns out.
Though geometric factors will be discussed again later in this course, it is important to understand some basic concepts on how magnification, distortion, and focal-spot blur affect radiographic image quality.

Geometric factors affecting radiographic quality

In its most basic form, radiographs are created when a radiosensitive material (an IR) captures the radiation energy in the form of a latent image that can be viewed after some sort of processing. Once produced, X-ray photons travel in a straight line; they cannot be made to turn but can only be directed towards the area of interest. This is an important characteristic to keep in mind when attempting to control the negative effects of geometric factors.

To understand how the path the X-ray photons travel affects the finished radiograph, a simple comparison is that to a shadowgraph. For example if you hold your hand in front of a light source with the shadow projected on a wall, you have created an image or shadowgraph. Three different things will happen to the image when changing either the position of your hand or the light source. If you bring your hand farther away from the wall, your hand will get larger, and the sharpness of the shadowgraph is diminished. The opposite is then true if you move your hand closer to the wall; the sharpness of the shadowgraph improves. Additionally if you leave your hand at a certain distance from the wall and increase the distance of the light source from the wall, you will see an increase in the detail of your hand on the shadowgraph. In turn, moving the light closer to the wall without moving your hand will reduce the detail of your hand. These geometric conditions also affect the creation of a radiographic image and the quality seen on the finished image. Understanding them will enable you to reduce poor-quality exams and aid the radiologist in providing an accurate diagnosis. The three principal geometric factors that affect radiographic quality are magnification, distortion, and focal-spot blur.

Magnification

Referencing the shadowgraph exercise performed with your hand and a light source, we can now attach terminology that ties to radiology. The distance between your hand and the wall will be the object-to-image distance (OID), while the distance between the light source and the wall will be the source-to-image distance (SID). Additionally the wall is metaphorically the IR, while the light source is our X-ray tube.

Magnification is defined as the enlargement of a radiographic image in relationship to its true size. To improve image quality, you must reduce OID and increase SID to control the magnification of the body part. Doing so will make sure the body part is projected on a radiograph as close to its actual size as possible.

Distortion

A body part is considered distorted when it is not projected on the radiograph in its true shape and size. There are two types of distortion: size distortion (magnification) and shape distortion. Referring to our current shadowgraph example, leave the flashlight at a perpendicular angle to the wall, but angle your hand to the projection of the light; you will notice that your hand appears shorter (foreshortened) than its true length. Additionally if you leave your hand parallel to the wall and angle the flashlight (similar to the sun casting your shadow across the ground), your hand will appear much longer than normal (elongated). Like magnification you can keep distortion to a minimum by keeping the X-ray source perpendicular to the body part and IR. On occasion though images are taken with purposeful distortion like in the case of an anterior-posterior (AP) axial (Towne) projection of the skull.

Focal-spot blur

The third factor in radiographic quality is defined by the focal-spot size. The angle of the focal spot, because of its rectangular shape, creates a divergent (spreading out) effect on the X-ray beam. Using as small a focal spot as possible reduces the amount of beam divergence that is generated; this, in turn, improves image quality and detail. Divergence causes blurring of information around the edges of a body part known as *penumbra*.

There is much more to be said about magnification, distortion, and focal-spot blur that will be covered later in this course; however, to limit the effects of each factor on the finished radiograph and improve radiographic quality, it is best to keep the anatomical part parallel to the IR, direct the central ray perpendicular to the IR, keep OID to a minimum, use the maximum amount of SID, and use the smallest possible focal-spot. Doing so will decrease penumbra (blur), thereby increasing the sharpness of structural lines on a finished radiographic image.

Subject factors

Subject (or patient) factors affecting image quality are primarily associated with characteristics such as part size, tissue composition, and shape of the anatomical part being imaged. Various body parts selectively absorbed of X-ray photons directly affect image contrast and density. When an X-ray beam is directed toward a body region, such as the chest, some parts of the region absorb more X-ray photons than others. For example the heart absorbs more photons than lung tissue. Consequently the portion of the IR beneath the lung tissue receives more photons and, when processed, appears darker than the portion of the image beneath the heart. As you can see, selective absorption results in different densities, or contrast, on a radiograph. The *factors* that affect selective absorption and subject matter contrast on a finished radiograph are part thickness, atomic number, tissue density, and the kVp setting.

4.3 Artifacts

Another aspect of image evaluation is identifying unwanted items on a radiograph, or an artifact. Artifacts can be caused by different means when comparing conventional film-screen radiography and digital systems like CR and DR. Understanding what these artifacts look like, what causes them, and how to fix them is very important to a QA program because artifacts cause repeated and increased radiation exposure to the patients. We begin with conventional film-screen artifacts.

Digital radiography artifacts

Conventional film-screen and wet-processing systems are not the only systems that have to deal with artifacts. Unfortunately CR and DR systems are also prone to the occurrence of artifacts. Once again you must be attentive enough to recognize the artifact exists on an image and then be intelligent enough about the process/system to research why it is appearing to correct the issue.

Image plate defects

As the imaging plate ages, it becomes prone to cracks that appear as areas of lucency on the image. Other defects are scuff marks and scratches; all of these defects can misrepresent fractures or other conditions that can lead to a misdiagnosis. Image plates should be routinely inspected for issues and, if any are found, removed from use.

Foreign objects

Foreign objects, like dirt, dust, or hair, at some point always seem to find their way into a processing system. These artifacts appear as light lucency marks on your finished image because foreign objects act as a barrier and block the data underneath from being read by the processor. If foreign object artifacts are noted, have the processing unit serviced for cleaning.

Heat blur

If the imaging plate is exposed to intense heat, the phosphor layer may be permanently damaged. Heat damage causes a blurring effect and a decrease of density due to decreased data storage in the area affected. When this problem is identified, remove and replace the imaging plate so future occurrences of the artifact are prevented.

Image brightness errors

Image brightness errors are typically caused by the *wrong* histogram being selected when processing the latent image. When processing a digital image, you must select the proper histogram (a preprocessing imaging protocol) to tell the system how to interpret the pixel's stored energy. For example selecting a knee histogram preprocessing protocol for an adult chest image would cause the CR system to interpret the pixels incorrectly, causing the wrong image brightness (density and contrast) to be displayed. Another issue causing problems with how image brightness is displayed is nonparallel collimation. For CR histograms to correctly read the edges of the exposure field, the collimated borders should be parallel with the edges of the imaging plate.

Scanner malfunctions

Malfunctions occurring with the laser that scans the imaging plate within the CR reader can cause the laser to skip lines, misread pixels or not read them at all, and distort images. Memory problems, digitization issues, and circuit communication errors typically cause scanner malfunctions. Though the life expectancy is long for the internal components of a CR reader, it is possible for the laser or any of the other electronic parts to malfunction or stop functioning. In this case have the unit serviced for diagnosis and repair.

Printer errors

CR and DR systems utilize laser printers that, when requested, produces hard copy of images. If not properly calibrated and maintained, the printer can cause a number of image quality issues: incorrect density calibration, light leaks, transportation problems, and laser misalignment. These artifacts lead to shaded areas that produce darkness on the image.

Scatter radiation

Digital systems are *more* sensitive to scatter radiation than conventional radiography due to the phosphors containing lower K-shell values. As you have already learned in your technical and clinical training time, scatter radiation decreases image contrast, and with regards to digital systems, the

Post-processing software algorithms may not be able to appropriately correct and clean up the finished image.

Double exposure artifacts

Double exposure artifacts are often caused by the technologist's negligence. It occurs when an imaging plate is exposed and then mistakenly exposed again without being switched out for a new, clean IR. Paying attention to detail will prevent this form of double exposure. Another situation is when CR plates are found in an X-ray suite, leftover from a previous study. In this case make sure to have these leftover IRs thoroughly erased both using them on the next patient.

Phantom or ghost images

Sometimes during the processing of the imaging plate, not all of the latent image data is cleared from the imaging plate during the erasure phase of processing. Whether this is caused by imaging plate age or an excessive amount of radiation used, it causes a previous exposure to appear superimposed with the current exposure. If a double exposure is visualized, check if the imaging plate is thoroughly erased and repeat the exposure again.

4.4 Image quality control and evaluation

Image quality is determined by what we can see on the finished radiograph. As DI technologists we visually evaluate the level of density (amount of blackening), scale of contrast (shades of gray), if the body part looks the appropriate size (magnification/distortion), and if there is anything on the image that shouldn't be there (artifacts) to determine the quality of an image. It is inevitable that we will encounter occasional problems when trying to produce quality X-ray images because of all the factors, both controlled and uncontrolled, that go into creating a high-quality finished radiograph.
Image quality control begins with the analytical process.

The analytical process

Image evaluation is performed every time you make an X-ray and process it, whether conventional or digital. This is the point where you find out whether or not you're positioning efforts, technique selection, and patient instructions worked. When considering if your image is high-quality or not, you must consider a wide spectrum of factors to decide if your image should be repeated or not. This skill takes time, clinical experience, and requires seeing hundreds (or thousands) of poor and high quality images to understand what is good and what is not. By this point in your career as a DI technologist, you have surely evaluated image quality on all of your own images and many of your colleagues. You have learned how to visualize the correct positioning of various body parts, how to identify anatomy and pathology, and how to recognize what is a good density or contrast level for a particular exam.
Image evaluation may very well be the most often performed task throughout your imaging career. The process of analyzing the finished radiographs might be difficult at first, but with information provided here and more experience in the field, you will no doubt become better at identifying the good versus not-so-good images you produce. When you analyze an image, you must review and compare it to similar views you have seen in the past. This is your book of knowledge that can be applied to determine whether or not your image is good.

Critiquing the image

After processing your image, all sorts of questions will likely go through your mind as you view your image on the computer monitor. There are nine basic questions to ask yourself when critiquing an image:

1. Is the correct name on the image?
2. Can you see the lead anatomical marker, and was the correct marker used?
3. Was the correct body part imaged? This is based off what was requested by the physician.

4. Is the body part positioned correctly? For example in the case of an AP knee, is the width of the femorotibial joint space equal on both sides?
5. Are all of the anatomical structures shown on the image as they should be? For example, are the costophrenic angles visualized or clipped off on a posterior-anterior (PA) chestimage?
6. Is the body part represented as close to its true size and shape aspossible?
7. Is the scale of contrast appropriate? Short for bony/orthopedic images and longer for soft-tissue (chest/abdominal) images.
8. If looking for specific pathology like a fracture or dislocation, do you see it?
9. Is there anything on the image that should not be there? For example a ghost image because the IR plate wasn't totally erased from the previous exam, a wedding ring when performing PA hand, or other pathology indicating disease.

Whenever an artifact, error, or problem is identified in an image, you must begin digging deeper to fully capture if the image is acceptable, what caused the problem, and how to possibly correct or prevent the problem in the future. This thought process is critical to reducing repeat rates and improving the quality of patient care you provide.

Acceptable versus unacceptable images

When critiquing an image, you must evaluate it to determine if it is within the diagnostic limits your department uses to deem an image acceptable or not. It is unacceptable to "pass" an image to your radiologist that is clearly rotated or has anatomy clipped off. When you or your QA/QC tech approves the image as a quality radiograph, it means the radiologist will be able to use it to interpret what is going on for the patient. If the radiologist cannot use the image for interpretation, then a repeat image might be necessary. Most USAF facilities utilize a senior technologist as the QA/QC tech to review and "approve" all images before sending the images off to the radiologist. You should always critique your image first and then listen to the QA/QC tech for what they see. Did you see the same things?

Here are some reasons why an image may *need* to be repeated:

- Technique too much or not enough; check the S-number for proof of a proper exposure.
- Positioning errors; rotation, over or under-extension, incorrect angle of obliquity, etc.
- Wrong patient identification is on the image.
- No lead anatomical marker or the wrong one was used.
- Anatomy is superimposed, clipped, or missing.
- An artifact is in the anatomy of the image.

Make sure you follow your department policies regarding passing or repeating images. Some senior, seasoned technologists may have the liberty to decide when an image needs to be repeated without consulting the QA/QC tech; however, that typically only applies to a select few. Use the QA/QC technologist; evaluating images for quality is his or her job, and remember they are there to help you learn! Repeating an image or two may seem like *no big deal*; however, it is a big deal because repeat images mean more patient exposure to ionizing radiation and, as you should know, radiation dose is cumulative.

Determining the cause of the problem

When an image quality problem is identified, you must find the root cause, so the chances of the problem happening again are reduced. If the cause is a positioning error, that is on you to learn and understand what you did wrong to cause the error so you don't do it again. Some errors though have several causes requiring thorough analysis before truly understanding what went wrong. The majority

of image quality problems fit into one of *three* categories: technical factor problems, procedural problems, or equipment malfunction problems.

Technical problems

Problems associated with technical factors create an issue with visibility of optical density and subject contrast. If an image is too dark, it is easy to determine too much technique (kVp and mAs) was used. With digital radiography you might be able to adjust the image to look visually "acceptable", but again, what is the S-number for the exposure? Though current digital systems correct for many technique errors, if an S-number is out of the acceptable range approved by the manufacturer or your radiologist, then the quality of the image is not good enough and should be repeated. The reason for repeating an image because the S-number is out of range is because of an effect called *quantum mottling.* Quantum mottle is caused when there is a disturbance in the recorded detail of a radiographic image. Quantum mottle causes variations in optical density, which degrades image quality, causing the image to appear blurry or fuzzy. When the digital system/processor has to correct beyond what it is capable of, quantum mottling occurs to some degree on the finished radiograph.

As discussed previously geometric factors degrade image quality. The focal-spot size, SID, and OID can be manipulated to decrease magnification and distortion, while increasing image quality. Controlling geometric exposure factors will increase your ability to produce high-quality images and, in turn, reduce the radiation exposure your patients receive.

Procedural problems

Patient positioning and patient preparation for radiographic exams are procedural factors that can lead to problems, if not performed correctly. To prevent procedural problems, follow your department's standard operating procedures (SOP) to properly position the patient, correctly direct the central ray at the area of interest, and use the appropriate SID for performance of radiographic exams. Common errors falling under this area are tube-part–IR misalignment and body part positioning errors. Patient preparation involves, among many things, removing radiopaque objects from the anatomical part being imaged, clearly stated pre and post-exposure instructions; and for gastrointestinal studies, ensuring the patient has a clean bowel tract. Paying attention to detail and exercising clear communication skills will correct patient preparation issues.

Equipment problems

As it will be discussed more later-on in this unit, equipment is the primary area of concern within a QC program. Monitoring the performance of the equipment you use, making sure that preventive maintenance is performed on schedule, and utilizing machines for their intended purpose all contribute to the production of quality images. If the X-ray imaging systems, processors, and display monitors are not properly cared for, artifacts can appear or, worse yet, system failures may happen. When critiquing your images and you find an unexplained artifact are on the image, this could mean a problem with the IR or processing unit. It is important to pay attention to the performance of your equipment, and when problems are encountered, notify your noncommissioned officer in charge (NCOIC) or a biomedical equipment repair technician (BMET) so the issue can get fixed.

Corrective action

Once a problem is identified as to why an image turned out poorly, it's time to take action to fix the issue so it doesn't continue to happen to yourself and others. Correcting a problem may mean studying your positioning guide a bit more, reevaluating the accuracy of a technique chart, or scheduling a piece of equipment for maintenance. No matter what the problem is or how long it may take to correct, don't be afraid to include others (like your supervisor, QA/QC tech, or a more senior technologist) to increase your knowledge and level of skill to produce high-quality images.

4B Quality Control

In this section we examine QC within radiography. QC is the aspect of the QA program that monitors the equipment used to produce quality images. The concept of QC is rooted in the need to stabilize the various equipment components of the radiographic imaging chain. The QC program is important because technical expertise will not guarantee success in radiography unless the equipment is consistently performing in a reliable manner. Additionally TJC verifies that organizations have programs in place to monitor the effective performance of radiation-producing equipment.

We explore the needs and benefits of a QC program and explore what is necessary to make a program successful. Keep in mind that this is only a brief introduction into quality control for it is not possible in this course to detail procedures for all the numerous tests performed on radiographic equipment to assure proper function. Some QC techniques are discussed more thoroughly in later lessons in this course.

4.5 Quality control in diagnostic imaging

QC consists of planned and systematic actions giving adequate confidence that radiologic equipment will produce consistently high-quality images with minimum exposure to patients and medical personnel. Imagine all of the radiographers in a department were of the highest caliber in expertise and training, but the department still had a high repeat rate due to equipment failure. The facility producing the images makes a determination of what constitutes high quality. A medical physicist usually establishes quality guidelines for equipment, while the chief radiologist determines the standard for quality exams. Many of the requirements to run the QC program are assigned as an additional duty to a competent noncommissioned officer (NCO) or a designated QC technologist within the department.

Quality control program

A QC program is an organized, systematic approach designed to monitor and control the quality of operation for key equipment components in a DI department. The nature and extent of the program will vary with the size and type of facility, type of equipment used, available personnel, and resources. QC tests should be routinely performed on X-ray system components, such as the collimator, generator, focal spots, display monitors, and PACS. At larger facilities a medical physicist performs these tests, whereas at smaller facilities, you could perform them at some point. QC tests are specific, documented procedures used to monitor or test the operation and effectiveness of the components of a radiographic system. Thus QC tests are concerned *directly* with the equipment, *not* personnel or processes.

Quality control documentation

Individuals in charge of QC programs are entrusted to check QC monitoring tests are properly performed and evaluated and that necessary corrective measures are taken in response to test results. Administrative procedures set the organizational framework for a QC program. Administrative procedures include documenting QC test results and maintaining a QC manual. Documenting the results of QC tests, problems discovered, corrective measures taken, and the effectiveness of those measures is critical to the QC process. Proper documentation is critical because it creates a method of spotting trends and establishing baselines, or benchmarks, for test results. Forms used for this purpose may be developed locally to fit your specific needs. Record-keeping is as important as the QC checks themselves.

Quality control manual

Each radiology department should have a QC manual. The contents are determined by each facility based on local needs, but the items as follows may be included:

1. List of those responsible for monitoring and maintaining equipment.
2. List of the parameters to be monitored and the frequency of monitoring.
3. Description of the standards, established quality criteria, or limits of acceptability (a range of normal values).
4. Brief description of the procedures to be used for monitoring each parameter.
5. Description of procedures for notifying appropriate personnel of any detected problems.

6. List of publications where detailed instructions for monitoring and maintenance procedures can be found.
7. List of records the department has decided to keep and the length of time these records should be retained before disposing.
8. Copy of each set of purchase specifications developed for new equipment and the results of the acceptance testing for the equipment.

Need for quality control

Many radiology departments that don't have an active QC program experience a high percentage of rejected or repeated radiographs. More often than not, an analysis of substandard images indicates poor equipment performance as a significant cause of repeated images. Problems may arise in any part of a radiographic system.

A QC program should eliminate many of the problems causing poor quality images and detect subtle changes in equipment operation so that problems can be corrected before they affect the quality of the radiographs produced. A QC program does not consist of only making measurements, recording the data, and filing the results. If the results are not periodically evaluated and corrective action taken when unacceptable areas are found, then all the efforts expended have been wasted.

Aside from the obvious benefits to patient care, a QC program serves several other important functions. For example accurate QC records are often required to defend against lawsuits involving medical imaging. Also some insurance companies only pay for services from radiology departments with approved QC programs. In addition TJC requires facilities to have an ongoing QC program for accreditation.

The Department of the Air Force (DAF) has also recognized the importance of a radiology QC program. Directives from DAF Headquarters offer guidelines for QC, and Air Force policy states that all medical and dental treatment facilities must develop and maintain a QC program.

Benefits of quality control

It usually doesn't take long after establishing a QC program before you begin to see its benefits. The impact of a properly executed QC program is usually expressed in terms of a *reduction* in the repeat rate. Reducing the repeat rate is a direct indication that unnecessary radiation exposure and operating costs have been reduced. Such reductions also indirectly indicate an overall improvement in image quality. Additionally evidence shows a properly working QC system will reduce equipment downtime, which can decrease the wait time a patient incurs.

Responsibilities for quality control

The concepts of QM contain many responsibilities held by every member of a radiology department. Some people have varying levels of responsibility but everyone is important in checking the quality of care that the patient receives remains as high as possible while the radiation dose remains as low as possible. A clear assignment of responsibility with the authority to carry out the responsibility is essential to the success of a QC program.

Radiologist

The radiologist has the primary responsibility for quality administration; however, responsibility for managing the QC program is usually delegated to the superintendent or NCOIC.

Medical physicist

The medical or radiation physicist focuses on training, research, equipment, and radiation safety within a department. The physicist performs QC testing twice a year or annually and has the following obligations:

- Performs acceptance testing on new equipment and reviews departmental images to establish baseline value.
- Checks exposure indicator's accuracy with calibrated ion chambers.
- Determines exposure trends.

- Analyzes repeat rates.
- Reviews QC records.
- Analyzes service history for routine maintenance and repairs on equipment.

Superintendent/NCOIC

Superintendents and NCOICs verify the QC program is carried out as directed by Air Force policy. Additionally it is typical to assign a NCO the responsibility to see that QC documentation is being properly recorded and maintained, to report equipment malfunctions to the MERC or other authorized equipment maintenance personnel, and to work closely with equipment maintenance personnel to develop new equipment requirements as needed.

Technologist

The technologist plays the largest role in the actual execution of the QC program. The most important role of the technologist is to visually inspect and recognize potential problems as they happen and then bring the problems to the attention of his or her NCOIC or MERC. Many problems can be spotted through periodic equipment inspections; however, most issues are identified throughout daily operations.

Periodic *visual* inspection of equipment is an inherent responsibility of *every* staff technologist. It must be performed on a regular basis to help prevent equipment breakdowns. Visual inspection of the mechanical and electrical characteristics of the X-ray system includes:

- Checking the condition of cables.
- Assuring cleanliness of the X-ray room.
- Listening for unusual noises in the moving parts of the system.
- Visually inspecting image receptors every time they are used.
- Checking that digital processing systems maintain their connection to PACS.

Service personnel

MERC and outside professional service technicians perform routine preventive maintenance (PM) according to the manufacturer's recommended schedule. Routine PM includes calibration, cleaning and maintaining internal components, and regular inspection and replacement of any parts that routinely wear out or fail.

4.6 Monitoring radiographic system components

A radiographic system is an assemblage of components for the controlled production of diagnostic images with X-rays. It includes, at a *minimum*, a high-voltage generator, X-ray control console, tube/housing assembly, beam-limiting devices, and the necessary supporting structure. Ancillary components, such as image receptors, image processors, and image display workstations, are also part of the system.

Types of testing

There are three areas on which QC tests are performed: acceptance testing, routine maintenance, and error maintenance.

Acceptance testing

Acceptance testing is performed on new equipment before the DI department (or MERC) accepts the piece of equipment. The tests performed are designed to ensure the equipment item is and will perform according the manufacturer's specifications. A medical physicist, BMET, or service professional employed by the facility normally performs acceptance testing.

Routine maintenance

A BMET or other service professional performs periodic routine maintenance, sometimes quarterly but at least annually. This is most times referred to as preventive maintenance and its purpose is to verify the piece of equipment continues to perform up to specifications over the

lifetime it is in service. It is typical that during PM, problems are identified and able to be corrected, preventing a catastrophic equipment failure.

Error maintenance

When equipment errors occur, the piece of equipment may slow down, perform inadequately, or fail to function altogether. If error codes are displayed on the piece of equipment, make sure to write them down and pass them onto the BMET or service professional.

Monitoring equipment performance

A routine QC program using state-of-the-art procedures should be established and conducted on a regular schedule. The purpose of monitoring equipment is to evaluate the performance of a facility's X-ray systems in terms of image quality standards established by the radiologist in charge and compliance with applicable regulatory requirements described by the physicist.

Each facility determines the specific parameters based on an analysis of expected costs and benefits. Factors, such as the size of the facility, available resources, types of equipment used, and a comparison of QC problems that have occurred in similar facilities, should be taken into account when creating a QC program. The monitoring frequency should be based on need and will vary for different parameters. When a problem is identified with an X-ray system component, *increase* the monitoring frequency for that parameter temporarily to confirm the corrective measures taken were effective.

It is not within the scope of this course to list or describe step-by-step procedures for every type of QC test. The monitoring tests for the components of an X-ray system are too numerous and differ widely according to the type of equipment used. Therefore, refer to the manufacturer's publications for each item of equipment used in your DI department, as well as publications providing general guidelines for radiographic QC techniques. The National Technical Information Service (NTIS), a division of the US Department of Commerce, has publications that may be requested pertaining to radiographic equipment QC procedures. Visit the NTIS website at http://www.ntis.gov for more information and methods of contacting them.

Areas to monitor within a digital imaging system

Many additional sources offer guidelines for performing monitoring tests. Regardless of which references you use, consider these five areas to monitor within a digital imaging system: (1) monitor quality, (2) speed tests, (3) digital data integrity, (4) image receptors, and (5) basic performance characteristics of a radiographic unit.

Monitor quality

Monitors are used to view every digital image of every exam for every patient. Just like in digital cameras, the greater the megapixel value the better the resolution of the pictures you take. In essence the same theory is true with monitors. Radiologists' reading stations typically have the highest resolution monitors ranging from 3–5 megapixels (MP); however, it still depends on what kinds of studies are being read. For example many medical facilities and governing entities state a *minimum* of 5MP monitors for interpreting digital mammography and pediatric radiographic images. For general viewing of radiographic images though, it is not yet cost effective to have the highest resolution monitors (greater than or equal to 5MP) everywhere in the medical facility. Monitor QC tests are recommended to verify the clarity of the image and that the monitor is performing up to its capabilities. Outlined are two types of QC tests routinely performed on radiographic viewing monitors.

NOTE: Reference the operator's manual and/or contact the specific manufacturer before performing QC tests on monitors in your department. The steps outlined in this section are general in nature due to the many different types of monitors used throughout the Air Force.

Daily quality control tests

To perform a typical daily QC test on monitor, do the following:

1. Power on the monitor and allow it to warm up.
2. Clean the monitor's screen of dust, finger prints, and smudges, while also making sure the ventilation areas on the sides/back are cleaned.

3. Using the monitor's owner's manual, follow the instructions to display a Society of Motion Pictures and Television Engineers (SMPTE) test pattern. The test pattern display is a series of approximately one-inch by one-inch squares, varying in color from white, gray, to black. Other squares have lines of varying widths.
4. View the test pattern looking for abnormalities and inconsistency in the transitions from black-to-white and vice-versa. Look for artifacts and that the vertical/horizontal lines on the pattern look uninterrupted. This step is for visualization of normal image quality and appearance.
5. Evaluate for distortion within the display. Check that the edges of the SMPTE pattern and lines within the squares are all clear and straight.
6. Visualize the 16 luminance patches for clarity. A photometer can be used with this step to measure the luminescence of the *monitor*. This step evaluates clarity, reflection, and noise.
7. To evaluate resolution, look at the pattern displayed on the SMPTE image in the center and at each corner; you should be able to clearly visualize all aspects of the pattern in these areas.
8. Record all results and compare them to the manufacturer's specifications.

Monthly quality control tests

To perform a typical monthly QC test on a monitor, do the following:

1. Power on the monitor and allow it to warm up.
2. Clean the monitor's screen of dust, fingerprints, and smudges, while also making sure the ventilation areas on the sides/back are cleaned.
3. Display the SMPTE test pattern on the screen.
4. Evaluate for geometric distortion by visualizing the test pattern from a typical viewing distance. From side-to-side and at the edges, the pattern should appear linear.
5. Visually check for reflection of other light sources within the parameters of the display. If a mirroring effect of other light sources is visualized, then dim, redirect, or turn off other lights in the room.
6. Use a photometer and check the luminescence reading for each pattern at the center of the monitor. Do the same with the monitor powered off; record both values. Liquid crystal displays (LCDs) should have a value of greater than 170 candelas per square meter (cd/m^2).
7. Check the resolution by using the magnifying glass within the PACS software. You visually evaluate the line patterns for clarity and brightness. Pay attention for any visual anomalies within the line patterns.
8. Record all results and compare them to the manufacturer's specifications.

For both tests, discuss the findings with a medical physicist for evaluation of results and/or further testing.

Speed tests

The speed at which you are able to perform your job is always evaluated. This includes the digital equipment used to perform your everyday tasks. As a part of the QC program, the workstation's processing speed and image retrieval/transfer rate should be evaluated *monthly* to identify negative trends. The following outlines a 4-step process for evaluating your workstations' processing speed:

1. Choose a patient study with multiple images in the folder.

   NOTE: Use the same study each time this test is performed.

2. Use a stopwatch, open the study, and record the time it takes to display the first image. Next scroll through the images one by one; again use the stopwatch to time how long it takes each image to be displayed.
3. Choose a function of the processing software like stitching or edge-enhancement. Perform the function and time how long it takes the software to complete the task.
4. Open a second study from the same patient; note the time it takes for this new study to load.

Record all findings in a notebook or an electronic spreadsheet. Input the results each month and compare to previous months. Look for longer load times and/or indications of processor lag. Report your findings to the PACS administrator for possibly further testing, evaluation, and resolution when necessary.

Performing the second speed test is related to the speed at which an image will transfer from a modality to PACS and from archival back to the workstation. These steps can be used to evaluate transfer speeds:

1. Choose a patient study with multiple images in the folder.

   NOTE: Use the same study each time you perform this test, and perform the test on the same day of the month and roughly the same time of the day to keep network variables the same.
2. Using a stopwatch, time how long it takes to retrieve a study from an archived state to the active files on the workstation for viewing.
3. Transfer speed evaluation. Have each modality in the department send images to archival. Note the time it takes to transfer the studies with a stopwatch. To ensure consistency month after month, send the same set of images each month when transfer speed is tested.

Again record all findings in a notebook or electronic spreadsheet. Compare the recorded transfer times from month to month to identify inconsistencies in the network related to transfer speed. Report your findings to the PACS administrator for possibly further testing, evaluation, and resolution when necessary.

Digital data integrity

Data integrity QC testing makes sure all the digital images acquired at each modality actually make it to PACS. Most leaders around the Air Force require that this task be completed daily to ensure no image is lost. To complete this QC test, use the Composite Health Care System (CHCS) to retrieve a list of all exams performed for the day and then compare the list of exams to what is on PACS. Make sure you pay attention to the file size and number of images in the study. One problem sometimes noted is the patient's folder will be on PACS, but no images will be in the folder. If this is the case, resend the images from the QC workstation to PACS. If again no images appear, notify your PACS administrator for assistance, and let the radiologist know the issue is being worked on.

Image receptors

A category accounting for many artifacts and problems with producing quality images is attached to the care and condition of IRs. CR uses cassettes with image plates inside, similar to conventional cassettes with film inside. DR, on the other hand, has advanced DI so the IR is actually part of the X-ray imaging system in the form of a table- or wall-bucky. Each of these systems requires routine inspection and cleaning of the IRs to make certain your department consistently produces high-quality exams.

Computed radiography image receptors

For a CR X-ray imaging system, the following QC schedules are recommended:

Daily	Weekly
Inspect all aspects of the cassette housing to include hinges and latches for properly function.	Inspect and clean each image receptor (imaging plate) for damage and foreign objects.
Clean all cassettes with an approved cleansing agent/disinfectant.	Clean the CR reader air intake vents to prevent dust particles from getting in the processor.
Perform the erase feature on all imaging plates to remove any remnant or scatter radiation.	Wipe the monitor, keyboard, and mouse for all stations.

During the daily inspection of the IR cassette housing, you double-check the imaging plate barcode is adequately displayed through the window in the cassette housing, test that there is enough tension in the open/close mechanism spring to properly secure the cassette door, and inspect the cassette door hinges so the door opens freely and allows smooth removal of the imaging plate when in the reader. Each CR cassette should be wiped clean at least daily and whenever the cassette comes in contact with a patient during an exam. For example if barium or IV contrast media is on the exposure side of the cassette, these substances will absorb photons and cause reduced image quality. Each morning at the start of your department's day shift, each cassette should be run through the CR reader to have the imaging plate appropriately erased of any remnant or scatter radiation that may be present on any of IR in your holding bin. Performing daily QC on the CR cassettes will make sure the IRs are in good working order and clean of debris to produce high-quality radiographic images.

On a weekly basis, once completing your visual and functional inspection of the cassettes, proceed to inspect the imaging plates. Inspect the imaging plates for cracks, other damage, or foreign objects like dust, dirt, or hair, all of which can degrade quality on your finished image.

To clean the imaging plate, you must do the following:

1. Remove it from the cassette, and place it on a soft, lint-free surface. You will need to handle the imaging plate by the edges and refrain from touching the white phosphor side of the imaging plate. Do not bend, squeeze, or drop the imaging plate.
2. For periodic routine cleaning, use a lint-free cloth or camelhair brush to wipe all dust and debris off the imaging plate's phosphor side. If dust or dirt is not removed easily, then do not force it.
3. Apply the manufacturer's recommended cleaning solution to a lint-free cloth, and softly wipe the dirt off the white phosphor side of the imaging plate. Do not scrub in a back-and-forth motion; instead, clean the imaging plate starting in one corner and wiping laterally to the other side. Continue to wipe laterally from top to bottom on the imaging plate.
4. After wiping the entire imaging plate, make sure you use a dry, lint-free cloth to wipe and absorb any excessive cleaning solution.
5. Allow the image plate to air dry before placing it back in the cassette housing.
6. Run the cassette through the CR reader to erase the imaging plate before using with a patient's exam. Other weekly tasks to be done in conjunction with the QC program include cleaning the air intact vents on the CR reader/processor. This will reduce the amount of dust and dirt particles induced into the processor, which could potentially cause an artifact. In addition wipe the viewing monitors, keyboards, and computer mouse at each processing and viewing workstation.

Direct radiography image receptors

DR X-ray systems include an IR array system that is built into the table- or wall-bucky. For this reason DR is known as cassette-less radiography. Some DR systems are closed systems; therefore, access to the IR is restricted to authorized service personnel only. Other DR systems use an IR that

can be positioned in the table- or wall-bucky, depending on the exam you are performing. For this type of DR X-ray system, daily QC inspection and cleaning of the IR is necessary for proper function, cleanliness, and safety. When cleaning a corded DR IR, first inspect it for damage. Next inspect the cord for kinks, cuts, or exposure of any wires. Pay special attention to the ends of the cord where connections are made to the main unit or IR. If damage is found to the IR or the cord, report it to your NCOIC and MERC immediately for repair. Failure to report any damage to the IR assembly could result in electrical shock, electrical current shorts, or image noise.

It is best to make a habit of cleaning and inspecting DR IRs at the beginning of your duty day before starting patient care. Throughout the day it may be necessary to clean the IR in between patients due to maintain a clean environment..

Cleaning a DR IR is not complicated. Use the approved disinfectant wipe for your facility to clean the outside surfaces of the DR IR. Wipe the cord as well, if applicable. Keeping your equipment clean increases image quality and presents a positive environment that helps set your patients mind at ease when entering the X-ray suite. No patient feels comfortable entering a dirty or unorganized X-ray suite.

Basic performance characteristics of an X-ray unit

Monitoring tests for radiographic units are numerous, and the types of procedures to be performed depend on the type of radiographic unit you are testing. In other words there are different QC techniques for fluoroscopic units, mammographic units, computed tomography units, and regular radiographic units; however, at a *minimum*, these tests should be performed:

QC Tests for X-ray Units	
Type of Test	**Recommended Minimum Frequency**
Reproducibility of X-ray output (exposure)	Annually
Linearity of mA stations	Annually
Accuracy of exposure timer	Annually
Calibration of kVp stations	Annually
Accuracy of collimator	Twice annually
Focal-spot size	Annually
Beam quality	Annually

Most of the QC tests performed on X-ray imaging systems are performed by qualified BMETs, a medical physicist, or equipment service personnel. When the opportunity presents itself, ask your NCOIC and the person doing the specific QC test if you can help do the tests with them so you can learn more about the various QC tests completed to produce high-quality images.

4.7 Repeat image analysis

A repeated image analysis is a study determining the quantity and reasons for repeated images. A repeated image, often termed a “repeat,” “reject,” or a “retake,” is considered any radiograph that was performed a second (or more) time due to some error, breakdown, or degradation in the radiographic process that affected the finished product being deemed a less than quality image. Repeat analysis studies are an integral part of any properly run QM program. Information from the analysis can help you determine what areas of your QM program deserve more attention to improve efficiency within a DI department. In digital radiography the primary benefits that come from a repeat image analysis are increased department productivity, increased customer satisfaction, and decreased patient radiation exposure doses.

Benefits

Whenever repeat rates are low, it decreases the time needed to complete the patient's exam. Decreasing the time needed to complete an exam increases the amount of patients that can be imaged in the same time period, thus increasing department productivity and customer satisfaction. Another benefit of a repeat image analysis is patients getting exposed to less ionizing radiation, which, as previously stated, is a primary goal of any QM program. Reducing the patient's radiation exposure dose is the result of lower repeat rates due to the analysis identifying areas for improvements by means of training and/or equipment maintenance.

Performing a repeat image analysis

Most literature states a repeat image analysis be performed monthly as a part of a well-managed QC program. The *purpose* of performing a repeat analysis is to analyze if any QC problem areas exist or are developing in your department. A repeat analysis collects data regarding the specific image repeat reason, amount of repeats, and the imaging tech accountable for the repeated image(s). A repeat image analysis is *not* used to specifically single out and discipline poor performing techs. The following are normal areas used to categorized rejected/repeated images: positioning errors, overexposure or underexposure (use the S-number for determining this), patient motion, artifacts, processing errors, and mechanical issues.

Gathering the data

Performing a repeat image analysis with a digital imaging system is normally a matter of gathering data from the software. Most manufacturers have mechanisms built-in to their software in which QC techs can mark images as rejected (less than quality) for a specific reason (like mentioned above). In addition the radiologist can also mark images they receive with quality improvement flags. QC personnel can then retrieve and review these mark images later. This step, involving QC techs and radiologists marking images, is important in identifying training needs for future in-service briefings designed to improve image quality and reducing the amount of radiation exposure the patient receives.

Calculating repeat rate percentage

Repeat rates can be determined for the department as a whole and individually. Within digital systems your PACS administrator should be able to provide you with a count of total images conducted by the department as a whole or individually within a period of time, as well as how many images were rejected. Plug the numbers into the following formula to obtain the department or individual repeat rate.

$$\text{Repeat Rate (percent)} = \frac{\text{Number of repeats}}{\text{Number of images completed}} \text{ X } 100$$

The percentage of repeated images, or repeat rate, can be determined for any period (week, month, or year) by dividing the number of repeated images by the total number of images completed and then multiplying it by 100 to end up at a percentage. For example suppose your department completed 5,700 radiographic images and had 515 repeats during that time. The repeat rate would be calculated this way:

$$\text{Repeat Rate} = \frac{515}{5{,}700}$$

Repeat Rate = 9 percent (rounded)

Analyzing results

The most important data gained from the reject analysis is the distribution of reasons for rejecting images. It is *very* common in digital departments to find that *positioning errors* are the *number one*

cause of rejected images. No matter what though, any large deviation of rejected images in a specific category (body part, reason for rejection, exposure room, or technologist) should be looked at closely to see if a problem exists.

Based off the data acquired, the following needs may be identified:

- Individualized on-the-job training for certain technologists.
- Review of specific body part position for high-repeated exams.
- Topics for continued education or in-service briefings.
- Maintenance for low performing pieces of equipment.

Unit 5. Principles of Image Quality

5A Radiographic Density.....112
5.1 Defining radiographic density.....112
5.2 Controlling radiographic density.....113
5B Radiographic Contrast.....114
5.3 Defining radiographic contrast.....115
5.4 Understanding the factors that affect contrast.....116
5C Controlling the Useful Beam.....118
5.5 Controlling scatter radiation.....118
5.6 Beam restricting devices.....119
5.7 Characteristics and functions of grids.....121
5.8 Problems and selection considerations associated with grids.....128
5D The Effect of Geometric Factors on the Image.....130
5.9 Radiographic detail and its relation to focal spot size.....130
5.10 How geometric factors affect magnification and shape distortion.....132

As radiologic technologists, we strive to produce radiographic images that present maximum diagnostic information to the radiologist with the least amount of ionizing radiation exposure to the patient. There are multitudes of variables that affect the radiographic image. While we can control many of these variables directly, there are others for which we can only compensate. First, however, we must be able to recognize optimal image quality in a radiograph. A radiologic technologist who cannot recognize quality, or lack thereof, in a radiograph will not be able to make the appropriate technical adjustments necessary to correct an imaging problem.

In this unit, we examine principles and methods that impact image quality including density and contrast, remnant beam management, geometric factors, and exposure techniques. We begin with density.

5A Radiographic Density

Each radiograph you produce must have a certain technical balance to be diagnostically useful. One parameter we strive for is a proper optical density. A radiograph is diagnostically useless if it has too much or too little density. Let's look more closely at what affects radiographic density.

5.1 Defining radiographic density

The degree of blackening of a radiograph after exposure and processing is called "radiographic density." Radiographic density (also known as optical density) is similar to photographic density; however, the density we are referring to in this discussion cannot be confused with the density of a structure (referring to atomic tissue mass density).

The relationship of transmitted light on density

The spectrum of OD can vary on an image (or film) from totally black, where no light passes through the film, to totally clear, where most all light is allowed to pass through the film. Images that are overexposed (having a high OD) come out too black which means too many X-ray photons made it to the image receptor (IR). In contrary, an image that is underexposed (having a low OD) comes out too light because not enough X-rays made it to the IR.

5.2 Controlling radiographic density

From the previous lesson we learned that radiographic density is a measure of the quantity of radiation energy absorbed by the IR.So, if we can control certain factors that determine the quantity of radiation, then we should be able to control the resultant OD. There are four prime exposure factors: milliamperage (mA), exposure time (s), kilovoltage peak (kVp), and source-to-image distance (SID). **NOTE**: Combining "mA" and "s" will be referred to as "mAs." The most effective way to control OD is by adjusting mAs and SID.

Milliampere-time and density relationship

As discussed, mAs has a direct, proportional effect on the quantity of radiation produced. For this reason, we can also state that mAs has a direct and proportional effect on density. Exactly how much of mAs is necessary for adequate density is dependent on many factors including type of exam and amount of kVp used. However, we can say that good background density generally indicates the sufficient amount of mAs was used. Should you need to alter an image's density because an original radiograph is either too light (underexposed) or too dark (overexposed) due to an incorrect amount of mAs, then keep in mind that it takes at least a 30-percent change in mAs to produce a discernible change in OD. As a standard of practice, if only mAs is adjusted to alter the density of an image, then either double or halve the initial mAs value.

Kilovoltage peak and density relationship

In some instances, you may determine that a radiograph has an appropriate background density, but the body part is either over- or under-penetrated. In a case like this, kVp can be used to adjust OD. When changing kVp, remember, this value affects the penetrability of the beam, scatter radiation, dose to the patient, and especially the scale of contrast. For these reasons, kVp is ***not*** the prime exposure factor of choice used to affect a change in OD. In order to visualize a discernible change in OD using kVp, the kVp setting must be adjusted by approximately 4 percent. Since the relationship between kVp and density is nonlinear, we reference the 15 percent rule whenever kVp is used to affect a change in OD. The 15-percent rule states:

- An increase in kVp by 15 percent will approximately double the OD.
- A decrease in kVp by 15 percent will approximately halve the OD.

Source-to-image and density relationship

Understanding the SID-to-OD relationship is not difficult if we first review the inverse square law: the intensity of a beam of radiation is inversely proportional to the square of the distance from its source.

We can clearly state the relationship between SID and OD in the following manner:

- As SID increases, density decreases.
- As SID decreases, density increases.

While SID should never be adjusted for the sole purpose of controlling density, there are instances in which SID must be altered for other reasons. To maintain the desired density in these instances, the quantity of radiation *produced* can be manipulated to compensate for changes in SID. Since mAs controls the total quantity of X-rays produced, appropriate changes in this factor can be made to maintain image density and compensate for changes in SID.

NOTE: An exception to this rule occurs when only a small change in SID takes place. In this case, the compensation can be made by adding or subtracting 1 kVp for each inch of a like change of SID up to six (6) inches.

Taking into account the directly proportional relationship between mAs and OD and the inversely proportional relationship between distance and OD, we are able to develop an equation to maintain density by compensating mAs for a change in distance. The equation is known as the *mAs-distance*

$$\frac{mAs_1}{mAs_2} = \left(\frac{SID_1}{SID_2}\right)^2$$

formula or in some cases the *new-mAs formula*, and it looks like this:

To give a practical application of this formula, suppose that a technique chart specifies 10 mAs using a 72-inch SID for imaging a given body part. Due to equipment limitations and the patient's condition, you are only able to use a 36-inch SID. What new mAs setting is required to maintain the original image's OD? Let's substitute the known technique values into the formula:

$$\frac{mAs_1}{mAs_2} = \left(\frac{SID_1}{SID_2}\right)^2$$

$$\frac{10}{mAs_2} = \left(\frac{72"}{36"}\right)^2$$

$$mAs_2 \times (72")^2 = 10 \times (36")^2$$

$$mAs_2 \times 5184" = 10 \times 1296"$$

$$mAs_2 \times 5184" = 12960"$$

$$mAs_2 = \frac{12960"}{5184"}$$

$$mAs_2 = 2.5$$

Therefore, your new mAs value is 2.5.The above example provides us with an interesting observation. Notice that the square of the new SID (1296) is one-fourth of the square of the original SID (5184). Also, note that the new mAs (2.5) is one-fourth of the original mAs (10). Thus, concerning the mAs-SID formula, we can make this assumption: When compensating for a change in SID, the new mAs needed to maintain density is directly proportional to the original mAs in the same manner as is the relationship between the squares of the SIDs. In other words, the squares of the SIDs increase or decrease, so too must the mAs if density is to remain constant. We can see this when using the mAs-distance formula (short method).

To calculate new mAs when compensating for a change in SID, we can use the mAs-distance formula (short method) by following these steps:

1. Divide the new distance by the original distance.
2. Square this answer.
3. Multiply the square answer by the original mAs (this gives the new mAs to use at the new distance).

Let's solve a couple of mAs-distance problems by using the short method. Suppose you want to find the new mAs to use at a 36-inch SID from an original technique of 10 mAs at 72 inches. Follow each step to solve the problem:

Step 1: 36" (new distance) ÷ 72" (original distance) = 0.5"

Step 2: $(0.5)^2 = .25$

Step 3: $.25 \times 10$ (original mAs) $= 2.5$ (new mAs)

The new mAs at 36 inches is 2.5.

When you don't have time to do the calculations to make precise mAs changes required because of a change in SID, you can get close by using the following general rule-of-thumb. When the SID is doubled, use four times the original mAs to maintain OD. On the other hand, when the SID is halved, use one-fourth the original mAs to maintain OD. Additionally, if the SID is increased by 50 percent, use twice the original mAs.

5B Radiographic Contrast

Along with density, each radiograph must have a balance of contrast. Our discussion of contrast

includes a definition of contrast, a description of the types of contrast, a listing of factors affecting it, and finally, an explanation of how it is controlled.

5.3 Defining radiographic contrast

The job of radiographic contrast is to make anatomy easier to visualize on an image. Therefore, contrast is one of the most important prime exposure factors affecting the quality of a radiograph.

Types of radiographic contrast

Radiographic contrast, commonly called *subject contrast*, is defined as the visible difference in density between two areas or structures within the radiographic image. In other words, contrast is the result of how the X-ray beam is absorbed as it passes through the different tissues of the body.

Contrast is measured by referencing a gray scale. A *gray scale of contrast* is basically the range of changes from the whitest to the blackest areas on an exposed image. Contrast on an image is typically classified as either short-scale or long-scale.

Short-scale contrast

A *short scale of contrast* has relatively few shades of gray with greater differences in density between each shade. This can be visualized by referring to image "B" in figure 4–1. Notice that the number of useful densities represents only a short portion of the scale. Short scale is also referred to as high contrast or more contrast because there is greater difference in densities between adjacent structures on the image.

Long-scale contrast

A *long scale of contrast* has many shades of gray with little noticeable difference in density between each shade. Notice that in image "A" of figure 4–1, the number of useful densities comprises a much larger portion of the scale. This type of contrast is also referred to as low contrast or less contrast because there is very little difference between adjacent shades of gray.

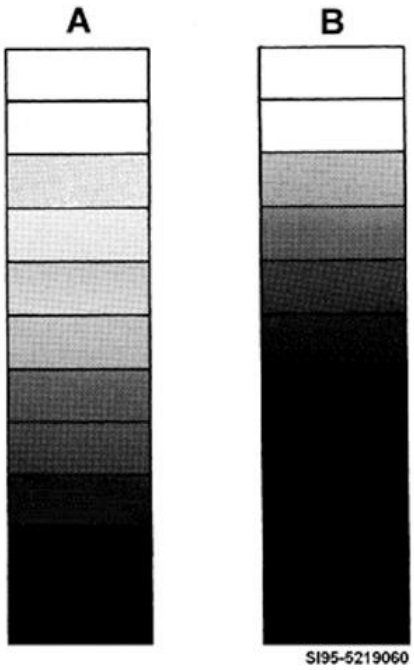


Figure 5–1. Scales of contrast.

An acronym to remember the relationship between a short and long scale of contrast versus high or low contrast is S.H.A.L.L. (**S**hort is **H**igh **A**nd **L**ong is **L**ow).

Relative properties of contrast

You should realize by now that there is no definite line separating the two types of contrast.

Contrast is a *relative* measure of the difference between densities on a radiograph.A particular radiograph may exhibit short-scale contrast when compared to another radiograph, but its scale of contrast may be long when compared to a third radiograph. For instance, when comparing a hand radiograph taken at 60 kVp to a chest radiograph taken at 120 kVp, we would say that the hand has a relatively short scale of contrast. However, if we were to compare the same hand radiograph to a mammogram taken at 25 kVp, we would say the hand has a relatively long scale.

5.4 Understanding the factors that affect contrast

Various parameters affect the differing degrees of grayness (contrast) and allow us to "see" the information in a radiographic image. Here we will discuss the subject contrast parameters that affect the degree of grayness on an image and how to alter the subject contrast levels using the 50/15 rule.

Subject contrast

Subject contrast depends upon the selective absorption of X-ray photons by the various body parts being irradiated. When a beam of x-radiation is directed toward a body region, such as the chest, some parts of the region absorb more X-ray photons than do others. For example, the heart absorbs more photons than lung tissue. Consequently, the portion of the IR beneath the lung tissue receives more photons and, when processed, appears darker than that portion of the image beneath the heart. As you can see, selective absorption results in different densities, or contrast, on a radiograph. Since subject contrast depends on selective absorption, we need to know and understand the factors that affect selective absorption. They are: part thickness, atomic number, tissue density, and kVp.

Part thickness

If an X-ray beam is directed at two different thicknesses of the same material, the number of photons transmitted through the thick part is less than the number of photons transmitted through the thin part. Stated another way, thicker parts absorb more photons than do thinner parts, and thinner parts allow more photons to pass through them than do thicker parts. Figure 4–2 shows how part thickness affects photon absorption.

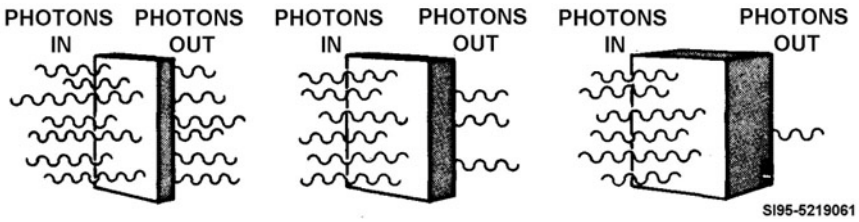


Figure 5–2. Absorber thickness affects photon absorption.

An example of this is an AP radiograph of the leg. The fibula, which is thinner than the tibia, absorbs fewer photons than does the tibia. Consequently, the fibula appears a little darker on the radiograph. The greater the difference in part thickness, the greater the difference in the densities appearing on the radiograph, or the higher the contrast.

Atomic number

The atomic numbers (Z number) of the various structures (or tissues) also affect the selective absorption of photons. The greater the difference between the atomic numbers in adjacent tissues, the greater the absorption differences in those tissues and, consequently, the higher the contrast between those tissues on the radiograph. The reason for the difference in absorption is that materials with higher atomic numbers have an increased incidence of photoelectric effects.

Recall for a moment the two radioactive interactions that are predominant in diagnostic radiography: photoelectric effect (PE) and Compton effect. Compton effect is independent of the atomic number (photon energy directly affects the probability of Compton interaction). However, atomic number does directly affect the probability of PE ionization. The greater the Z number, the greater the probability of a PE will happen. When a photon is fully absorbed during a PE interaction, the photon is absent from the exiting remnant beam. Thus, the intensity of that portion of the remnant beam is somewhat decreased and the radiographic density of tissues beneath that part would also be

decreased.

The atomic numbers for bone, muscle, and adipose (fat) are approximately 12, 7.5, and 6, respectively. When comparing bone and muscle or bone and adipose, because of the atomic numbers, there is more contrast (a shorter scale or high contrast) between the different types of tissue. When comparing muscle and adipose, the atomic numbers are very close to each other therefore low contrast (a longer scale or low contrast) is displayed. Of the three tissues given, bone to adipose would have the highest subject contrast because the difference in atomic density is greatest between them, which results in the greatest difference in selective absorption between these two types of tissues.

Tissue density

The difference between the structural densities of absorbers is another factor that affects the selective absorption of photons. By "density" we mean the number of atoms per unit area. The higher the density of an irradiated tissue means the greater the attenuation of the useful beam. In-turn, the greater the difference between the densities then would mean the greater the difference in absorption—consequently, the higher the subject contrast.

Kilovoltage peak

Remember, when we speak of the quality of the useful beam, we actually mean the ability of the beam to penetrate matter or, more specifically, human tissue. The ability of an X-ray photon to penetrate tissue depends on its energy, which is controlled by kVp. High-kVp X-rays have greater energy and therefore greater penetrating ability when compared to low-kVp photons. As the penetrating ability of the useful beam increases, it means more photons will reach the IR and produce more shades of gray.

Wavelength is another term associated with beam quality—the shorter the wavelength of the X-ray photons, the greater the penetrating power. Since the *energy* of a photon is directly related to its wavelength, energy is yet another term closely associated with beam quality. Keep in mind that although we may speak of the energy or wavelength of a single X-ray photon, there are actually millions of photons in a useful beam of X-radiation all with different wavelengths and energy levels. It is the *average* energy level (or wavelength) of the beam, which can be controlled by the DI technologist, that determines beam quality. The technologist has direct control of the useful beam's ability to penetrate, its wavelength, and its energy level when adjusting kVp on the control panel.

To summarize, beam quality affects subject contrast in that a higher kVp setting produces a long-scale of contrast (low contrast) because more photons reach the IR allowing for more shades of gray on the processed image. On the other hand, lower kVp settings produce photons that are more readily absorbed by the thicker body parts, resulting in fewer photons reaching the IR. This results in fewer shades of gray or a short-scale of contrast (high contrast).

Using the 50/15 rule to alter subject contrast

With digital imaging, the scale of contrast can easily be changed with a click and slide of the computer mouse. However, it is important for you to understand how to change the scale of contrast of an already properly exposed image quickly and easily. Many times, the scale of contrast is changed to help the radiologist better visualize and diagnosis certain pathology. The purpose of the 50/15 rule is to give the technologist a mechanism for changing the scale of contrast without negatively affecting the background density of the original diagnostic image.

We know from our prior discussions that while mAs is directly proportional to density, kVp does not follow a linear scale in relationship to density. Therefore, proportional adjustments must be made to both mAs and kVp in order to lengthen or shorten the scale of contrast while maintaining the background density of the original image. By following the 50/15 rule as stated below, the technologist will make the proper proportional adjustments to mAs and kVp:

- **To lengthen the scale of contrast and produce low contrast**, halve the mAs setting and increase the kVp by 15 percent.

- **To shorten the scale of contrast and produce high contrast**, double the mAs setting and decrease the kVp by 15 percent.

5C Controlling the Useful Beam

Early in the history of radiography, pioneers in the field became aware of a serious problem affecting image quality. The problem was image fog due to scatter radiation. To overcome this condition, certain devices were developed to control the amount of scatter radiation that reached the film (or image receptor). In this section, we discuss beam restricting devices and grids as they relate to the control of scatter radiation and the subsequent improvement of image quality. We begin this section with a closer look at scatter radiation.

5.5 Controlling scatter radiation

Three types of radiation comprise the remnant beam (that part of the beam that exits the patient): primary, secondary, and scatter. Photons that pass through a body part without interacting with the body part remain a part of the useful beam and are instrumental in forming the image. Secondary radiation is low-energy radiation produced when photons interact with atoms in the body. Since these photons are produced by a chain of ionizing events in the atoms of the tissue that is being irradiated, they represent characteristic radiation of extremely low energy and are usually quickly absorbed by the body part. Relatively few secondary radiation photons ever reach the IR. Scatter radiation (SR), on the other hand, comprises a large part of the remnant beam and has a major effect on radiographic image quality.

Scatter radiation

Scatter radiation results whenever primary photons have undergone a change of direction after interacting with atoms. This change in direction can cause the photon to deposit its information on a different part of the image causing fog or image noise. Most SR in the diagnostic energy levels are a result from the Compton effect which was discussed in unit one of this volume.

Factors affecting scatter radiation production

There are three factors that influence the production of SR: patient thickness, field size of the X-ray beam, and kVp.

Patient thickness

The amount of SR varies directly with the thickness of the body part being irradiated. Thicker body parts emit more SR than do thinner ones. You can readily see this if you compare the detail and contrast of an abdomen radiograph (taken without a grid) with that of a hand. The radiograph of the hand appears much sharper because of reduced SR. The radiograph of the abdomen will most likely look dull and foggy, with some structures blurred. This is because the photons experience multiple scattering in thicker body structures.

Of the three factors that influence the amount of SR produced, patient thickness is the only one you cannot control. However, you can minimize its effects by using grids and beam restricting devices which will be further described in subsequent lessons in this unit.

Field size of the X-ray beam

The amount of SR produced by an X-ray beam is relative to the field size of the X-ray beam. In other words, increasing the field size of the useful beam will increase SR and a decrease in field size will decrease SR.See figure 4–3 as it illustrates the same body part projected by both a large and a small X-ray field. For a part of this size, a relatively small image area is needed. If the field

size of the useful beam is restricted to only the portion of the IR that is needed, as in drawing A, there is a relatively small amount of scatter radiation reaching the IR. If the field size of the beam is enlarged so that it covers a larger area, as in drawing B, then the result of the larger field size is an increase in the scatter radiation reaching the IR.

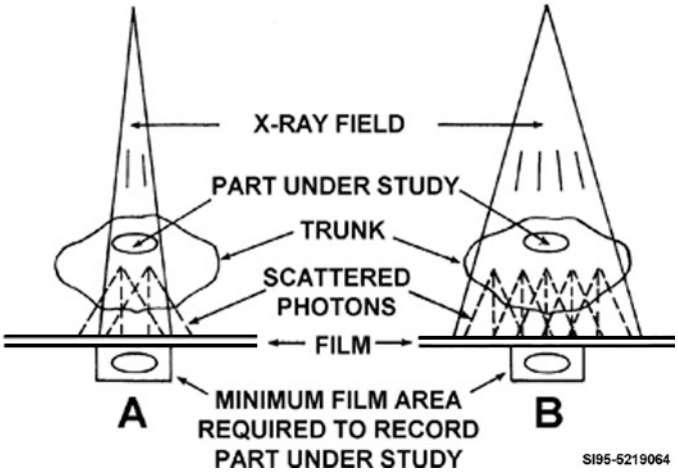


Figure 5–3. The effect of field size on scatter radiation.

Notice the increase in scatter reaching the IR not only occurs in the areas of the IR that do not record the image, but also occurs directly over the image itself. This is because scatter radiation has "ricocheted" from a different body part to strike an area of the IR not directly beneath that body part. For the purposes of increasing radiation protection and decreasing SR production, you should always collimate so that only the anatomy of interest is exposed to the useful X-ray beam.

Kilovoltage peak

At higher diagnostic energies (above 60 kVp), Compton scatter is the most common interaction between X-rays and body tissues. Since almost all SR is Compton scatter, the amount of SR produced is directly affected by kVp settings. You can therefore conclude that higher kVp techniques produce more SR that, in turn, causes more fogging of the image, decreased contrast, and decreased detail. As kVp increases, the incidence of Compton effect increases and the resultant SR produced has a higher energy level, which makes it more likely to reach the IR.

Since low kVp techniques do minimize some of the negative image quality effects found when high-kVp techniques are used, it might seem logical to conclude you should always use the lowest kVp possible to improve image quality. Unfortunately, using low kVp techniques are not always feasible because they typically cannot produce the desired scale of contrast and it also increases the exposure dose to the patient. No matter what though, both high and low-kVp techniques do have their place in radiography.

5.6 Beam restricting devices

Various types of beam restrictors are used in radiography: diaphragms, cones, cylinders, and variable-aperture collimators. When used, these simple beam restrictors are very effective in restricting the size and shape of the useful beam while also improving the overall quality of the beam. Diaphragms, cones, and cylinders are very simple beam restrictors that have been widely employed since the early days of radiography. We begin with the purpose and benefits of beam restricting devices.

Purpose and benefits of beam restricting devices

The purpose in using any beam restricting device is to restrict (or limit) the field size of the useful beam. The useful beam should be confined to a size and shape that just covers the area of diagnostic interest. Two major benefits immediately arise whenever the useful beam is restricted. The first and most important benefit is that the radiation exposure to the patient is reduced. Secondly, image quality is improved because there is a reduction in the amount of SR produced.

By limiting the size and divergence of the useful beam to only the area of interest, beam-restricting devices reduce patient radiation exposure, which should always be an important concern to any technologist. Image quality is improved because of a sequence of events: the size of the useful beam is limited, which causes a reduction in the area of irradiated tissue, which causes a reduction in the amount of SR that is produced, which results in a reduction in image fog. Additionally, when image fogging (due to SR) decreases, then image quality is enhanced because density decreases, contrast increases (more short-scale contrast because fewer gray tones), and detail improves. Conversely, this sequence of results reverses if the size of the useful beam is enlarged.

Collimators

The variable aperture collimator (or *collimator* for short) is the most commonly used beam-restricting device because of its versatility and ease of use. When a collimator is used to adjust the field size of the useful beam, this action is commonly called *collimation*. The main parts of a collimator are the first-stage entrance shutters, the mirror, the second-stage long shutters, and the second-stage cross shutters. On the outside of the collimator are adjustment knobs used to adjust the second-stage long shutters and second-stage cross shutters into either a square or rectangular field. **NOTE:** Both sets of second-stage shutters work in pairs. The shutters, or leaves, are typically made of lead of at least 3 mm in thickness. The mirror and a small lamp inside the collimator housing provide the light-localization that all technologist and patients "see" when setting up for an X-ray image.

Most collimators made today come with an option known as positive beam limitation (PBL). When this feature is utilized, the collimator automatically adjusts the shutters to the size of the IR or cassette that is placed in the bucky. Some PBL units will operate at virtually any SID while others require the tube to be placed at specific SIDs, such as 40 or 72 inches. This option is obviously of great benefit, because it ensures that parts of the body outside the area of interest will not be exposed. When the area of interest is smaller than the automatic collimation size, you must still consider whether to override the automatic collimation and reduce the field size even further.

Depending upon tube capacity, additional filtration may be required in order to consistently produce the best quality radiographic images. Most collimator housings are designed for the insertion of added filtration in levels up to 3 mm aluminum equivalency. The added filtration is typically included during system installation and calibration by a qualified service technician.

Collimator requirements

Multipurpose X-ray units are required to be equipped with an adjustable rectangular collimator containing a light localizer that defines the entire X-ray field.

In addition, periodic checks must be performed to ensure "light localizer" is properly aligned with the "actual" X-ray field to within two (2) percent of the SID. This requirement is based upon a CR perpendicular to the plane of the IR. For example, if the lighted field measures 8 by 10 inches at a distance of 40 inches, the short side of the X-ray field must measure between 7.2 and 8.8 inches (2 percent of 40 is 0.8), and the long side must measure between 9.2 and 10.8 inches.

To check the X-ray field against the lighted field, place a cassette on the table and turn on the collimator light. Adjust the collimator until the lighted field is at least 2 or 3 inches smaller than the IR. Place four small pieces of wire, each bent to form a 90° angle, so that the angles correspond to the corners of the lighted field. Measure the borders of the lighted field and record the information. Place some sort of orientation marker on the IR so that you can identify the sides of the collimator out of adjustment. Make one exposure; then open the collimator to cover the entire IR and make another exposure. After processing, measure the sides of the first exposure and compare them to the measurements of the lighted field. If any side of the X-ray field deviates by more than 2 percent of the SID, contact a BMET and report that the collimator must be adjusted.

Figure 4–4 is a drawing of a test radiograph. This drawing shows one side of the collimator, AB, to be out of adjustment. Sides AC and BD of the X-ray field are shorter than the corresponding light field sides. Whether the collimator meets the required standards depends upon whether sides AC and BD are off by more than 2 percent of the SID. Also, notice that the "wires" near corners A and B would not have been on the radiograph if the second exposure had not been made.

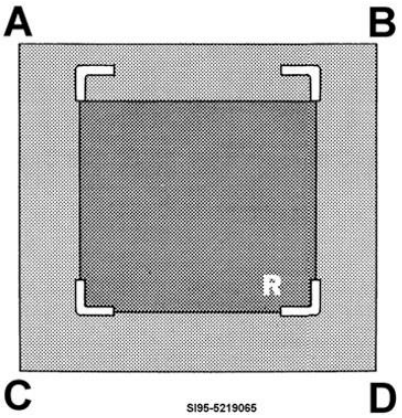


Figure 5–4. Collimator accuracy test.

Technique compensations

A final fact to remember about beam restrictors is that their use affects radiographic density because a smaller X-ray field produces less SR. For this reason, fewer photons reach the IR, thereby decreasing density. As a result, some compensation in radiographic technique may be needed to keep image density constant whenever you collimate.

The compensation is always an increase in either kVp or mAs. The exact amount of increase varies and is dependent upon such factors as the thickness of the body part, the amount of collimation, the types of film and screens used, etc. Therefore, we cannot state an exact technique compensation to use in all situations. Through experience, you learn to make these technique compensations.

5.7 Characteristics and functions of grids

While the use of a collimator contributes substantially to the reduction of image fog caused by SR, collimation by no means solves the problem completely. Considerable image fog can still occur unless an additional device is used between the patient and the IR; this device is called a *grid.*

Function and operation of grids

Grids are made of very small strips of lead placed side by side and held in place by plastic or some other radiolucent material. Between each radiopaque lead strip is a radiolucent, interspace material that is either aluminum or fiber. The purpose of a grid is to absorb SR, thus improving image quality by reducing the amount of SR that reaches the IR. A grid is placed between the patient and the IR. SR is emitted from many points and in many directions from the patient (and the radiographic table top, too). Because the greatest portion of the scattered rays strike the grid at an angle, most of them are absorbed. Most of the primary remnant beam, on the other hand, passes through the grid because the useful beam strikes the grid at the appropriate angle. Figure 4–5 shows the relationships between the angles of the lead strips and the direction from which primary and scatter radiation approach the lead strips. Since some body parts do not emit enough scatter radiation to significantly fog a radiograph, these do not require the use of a grid. As a rule, body parts that measure 10 cm and larger should be radiographed with a grid.

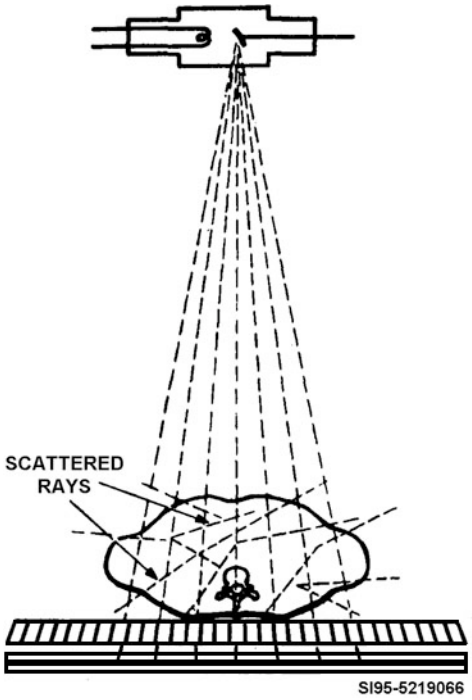


Figure 5–5. Grid function.

Grid design characteristics

There are many different grids on the market today. Each is designed to be used under specific conditions. In order for you to use the grid that best fits your particular needs, you need to be aware of the elements of grid design.

Grid ratio

The height of a lead strip in relation to the width of the space between two strips is called the *grid ratio* (fig. 4–6). The grid ratio is not directly related to the thickness of the grid or to the number of lines (lead strips) per inch. Consequently, a thin and a thick grid can have the same ratio and an 80-line grid can have the same ratio as a 100-line grid. Each grid has a specified ratio, and it can usually be found on the tube side of the grid. Common grid ratios are 5:1, 8:1, 12:1, and 16:1. The higher the grid ratio means it is more effective at cleaning up the SR. In fact, a 16:1 grid can get rid of as much as 97 percent of the SR whereas a 5:1 grid may clean up around 85 percent of the SR.

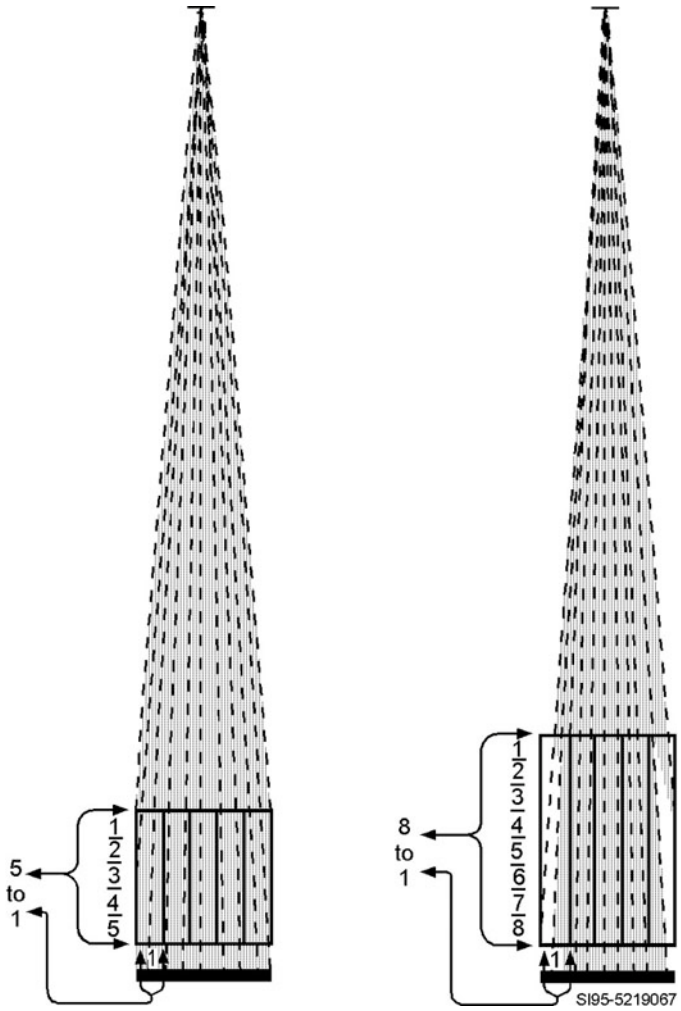


Figure 5–6. Grid ratio.

Grid efficiency refers to the amount of SR absorbed compared to the amount of primary radiation absorbed. Ideally, a grid would absorb all the SR while allowing all the primary photons to pass through to the IR. However, due to the lead content in a grid, there is always a small portion of the primary (useful) beam inadvertently absorbed. Consequently, grids are not 100 percent efficient.

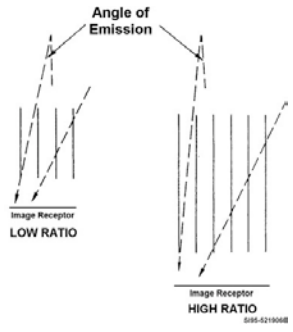


Figure 4–7. The effect of grid ratio on efficiency.

Figure 4–7 illustrates how a grid with a higher grid ratio is more efficient. This figure shows lead strips from two grids with different ratios. Notice that the angle of emission, by which scattered photons can reach the IR between the lead strips, is larger with the low ratio grid. Consequently, the smaller ratio grid absorbs fewer photons. In addition, notice a scattered photon must penetrate more lead strips to reach the IR through the high ratio grid; as a result, the photon has a better chance of being absorbed.

Unfocused versus focused grids

An *unfocused* grid is designed with lead strips that are positioned perpendicular to the plane of the grid and run parallel to each other. In a *focused* grid, the lead strips are angled towards the center progressively more as you move away from the center of the grid

to coincide with the divergence of the beam. in figure 4–08 image “A” represents an unfocused grid, while image “B” represents a focused grid. The inherent problem with an unfocused grid is that X-ray photons do not travel in parallel lines; rather, they diverge from a central point. Therefore, unfocused grids tend to absorb a progressively larger portion of the useful beam as you move from the center to the outside edges of the grid. For this reason, angling the lead strips in a focused grid is designed to coincide with the divergence of the useful beam (again, see figure 4–08 image “B”).

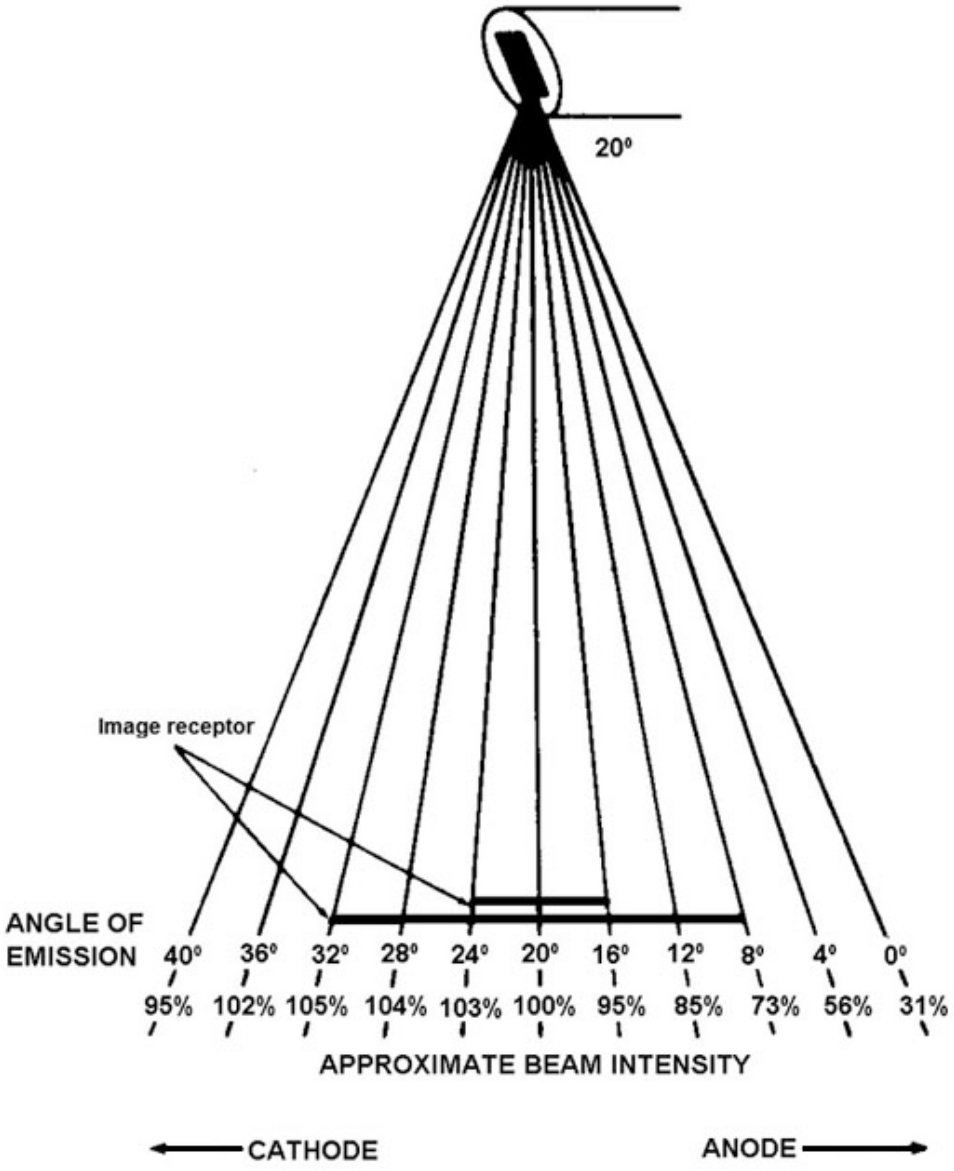


Figure 5–7. Unfocused and focused grids.

Because the lead strips are angled toward the center of the focused grid, focused grids have a *grid radius* (or a focal distance) which correlates to the distance (SID) at which a focused grid is supposed to be used. To visualize the grid radius, imagine if the angled lead strips are all extended upward to a point in which all the lines eventually meet. The grid radius is that point where the lines all meet. Figure 4–09 shows the lines extended from the angled lead strips up to the grid radius. Focused grids are all marked with their grid radius and with which side is supposed to face upward towards the tube.

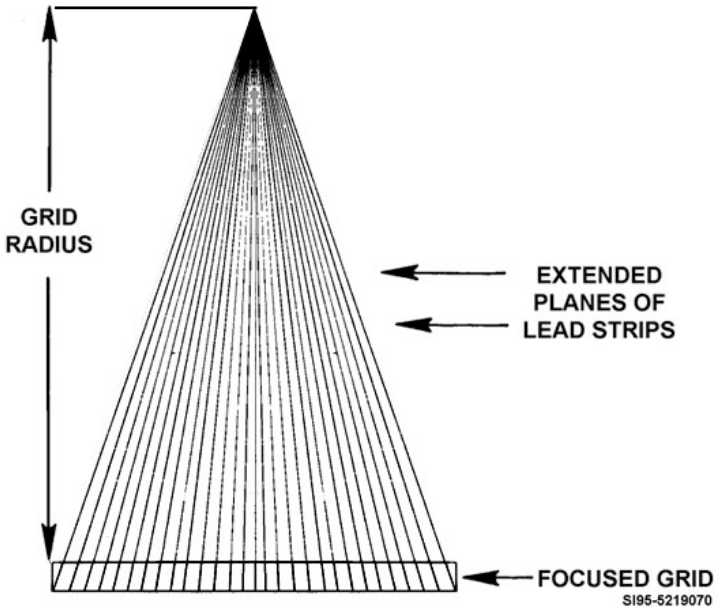


Figure 5–8. Grid radius.

Grid frequency

Grid frequency is the number of leaded strips per inch. A high frequency grid has more lines per inch, while a low frequency grid has fewer lines per inch. For example, a 12:1 grid may have either 80 or 100 lines per inch. The greatest advantage of using a high frequency grid (one with many lines per inch) is that the lead strips are less visible on the radiograph because they are thinner and therefore, interfere less with interpretation. This reduced thickness of the lead strips also reduces the total lead content of the grid. When a grid with many lines per inch is used with high-kVp, the energy level of the scattered radiation may be high enough to penetrate the lead strips and fog the image.

Consequently, at high-kVp ranges, a grid with many lines per inch is less effective than one with fewer lines per inch.

Arrangement of lead strips

Grids are made with the lead strips in either a linear or a crossed pattern. A linear grid is one with lead strips running in one direction only, lengthwise (or longitudinal). Linear grids may be either focused or unfocused. Most grids in X-ray tables are linear, focused grids. Linear grids are also available in gridded cassettes and as regular portable grids. The direction of the lead strips with respect to the longitudinal axis of the X-ray table, grid cassette, and portable grid are shown in figure 4–10.

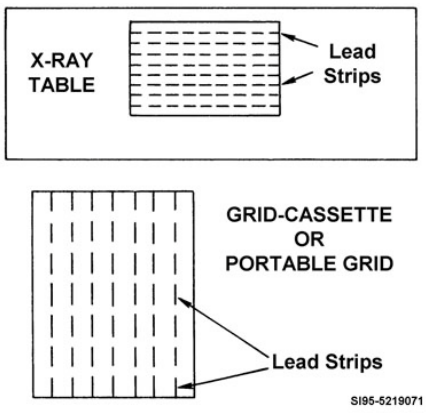


Figure 4–10. Examples of linear grids.

A crossed grid (sometimes called cross-hatched) consists of two sets of lead strips arranged as shown in figure 4–11. Crossed grids are designed for use during procedures that produce unusually high amounts of scatter radiation (e.g., biplane angiography). They are not found in X-ray tables used for general radiographic work.

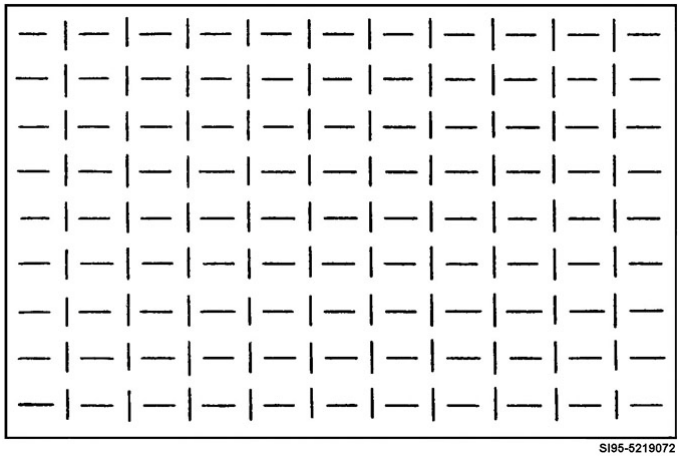


Figure 5–10. A crossed grid pattern.

There are advantages and disadvantages to using both linear and crossed grids. A linear grid permits photons from the useful beam to pass between the strips when tube angulation is in a direction parallel to the length of the strips (see fig. 4–12 image A). Angulation perpendicular to the strips of the linear grid results in virtually all of the photons of the useful beam being absorbed by the lead strips (see fig. 4–12 image B). This undesired absorption of photons making up the useful beam is referred to as "grid cutoff" and will be explained in greater detail in the next lesson. Crossed grids are generally used in special procedures using biplane techniques. Since a crossed grid is actually made up of two superimposed linear grids, its effective ratio is about twice its nominal ratio. For example, an 8:1 crossed grid has an effective ratio of about 16:1. The inherent problem with crossed grids is that virtually *any* tube angulation results in grid cutoff.

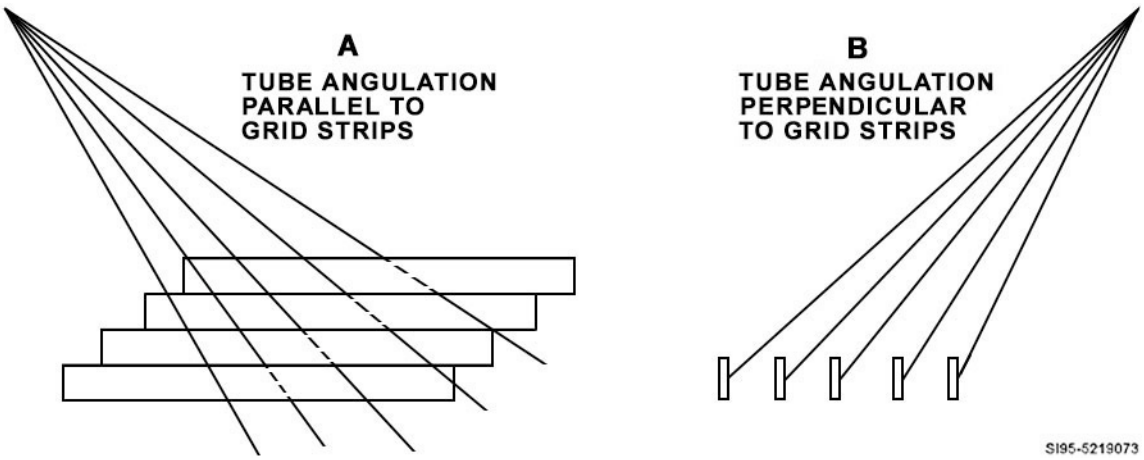


Figure 5–11. Tube angulation for linear grids.

Moving grids

To this point in the discussion about grids, we have been referring to stationary grids. One of the disadvantages of any stationary grid is that they can show the grid lines on the image. Grid lines show up on the radiographic image when too many of the useful X-rays are absorbed by the lead strips of the grid itself. Currently, the Potter-bucky diaphragm or simply, the "bucky" is the standard moving grid device in most fixed imaging systems. There are two types of moving grid apparatuses in use currently; they are the reciprocating grid and the oscillating grid.

The *reciprocating* grid is motor-driven and it moves back and forth throughout the exposure

moving approximately two (2) cm. The *oscillating* grid has spring-like devices on each corner that keeps the grid centered within the bucky. With 2 to 3 cm of space around each edge of the grid, an electromagnet is used to pull the grid in one direction as the rotor is activated and then the grid is released when the exposure is taken. The result is the grid moves in a circular motion within the frame of the bucky because of the springs at each corner.

Though the motion induced by moving grids can cause an increase in image blur, the benefits of moving grids clearly out-weigh any disadvantages.

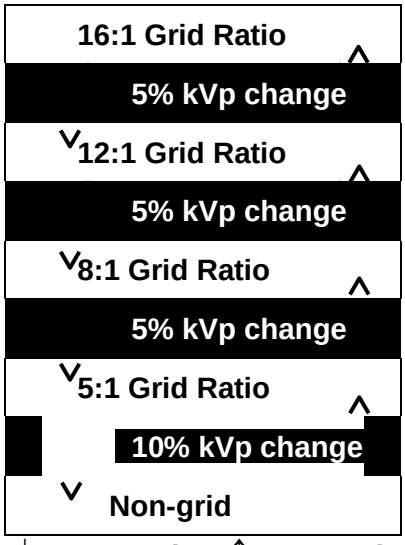
Exposure compensation

Grids absorb a significant portion of the useful (remnant) beam before it reaches the film. For this reason, you must adjust your technique (increase kVp and/or mAs) when switching from a nongrid to a grid procedure, and when changing grid ratios to maintain density. This increase in exposure technique, and subsequent increase in patient dose, is the primary disadvantage of using grids. In most instances though, the increased image quality derived from using a grid is well worth the moderate increase in patient exposure.

Various radiologic references offer different suggestions concerning technique compensations. It's impossible to state absolutely that this amount of mAs or that amount of kVp is the right amount of compensation for all cases. However, we can suggest a rule of thumb that works well in most cases: Add or subtract 5 percent of the applied kVp per ratio change. Thus, when you change to a higher grid ratio, increase the kVp, and vice versa. An additional 5 percent of the applied kVp is needed when you change from a nongrid technique to a grid technique. Although it is possible to compensate for grids using mAs, increasing the kVp is preferred because this causes a smaller increase in radiation exposure to the patient. (Remember, increasing kVp increases beam quality.)

The table below shows kVp technique compensations you can use when changing grid ratios. Remember that these are only starting points—the exact compensation depends on kVp range, number of lines per inch, type of interspace material, and whether you're using film or a digital IR.

Table 5–1. Technique compensation for grid changes.



↓= Decrease kVp ↑= Increase kVp

5.8 Problems and selection considerations associated with grids

The primary problem associated with the use of grids is improper positioning of the tube and/or grid which causes grid cutoff.

Grid cutoff

Improper placement of a grid is likely to result in *grid cutoff.* Grid cutoff is the undesirable absorption of useful (image-producing) radiation by a grid that results in a loss of radiographic density and detail.

Grid cutoff can result from a variety of problems including: focused grids used upside down, distance decentering, lateral decentering, combined lateral and distance decentering, and off-angle alignment.

Upside down focused grid

Since the lead strips in a focused grid are angled, all focused grids have a tube side identified that must face the tube in order to line up correctly with the divergent X-ray beam. When a focused grid is used upside down, remnant radiation can only pass through the middle section of the grid while the two lateral borders of the upside down focused grid will absorb the useful beam causing severe peripheral cutoff. The result is only a wide band of density down the middle of the radiographic image. The corrective action for this problem, of course, is to turn it over so the “tube side” of the grid faces the tube.

Distance decentering

Also called *off-focus* or *off-distance* cutoff, distance decentering refers to the use of a SID that is more or less than the specified grid radius. The result on the radiograph is similar to upside down focused grid cutoff with a reduction in density over both lateral borders of the image. However, in distance decentering, the effect is not quite as pronounced. The specific loss in density over the lateral borders is dependent upon the amount of decentering, the grid ratio, and the direction (near or far) of the decentered tube. There is a certain amount of tolerance for this type of decentering built in to most focused grids. The tolerance depends partly upon the grid ratio. A grid with a high ratio will not tolerate as much distance decentering as will a grid with a low ratio. Most focused grids give a range of SIDs that may be employed with that particular grid (e.g., 36 to 44 inches). Exposures may be made at any distance within the range without very much appreciable cutoff.

Lateral decentering

Lateral decentering, also called *off-center* cutoff, is a problem frequently encountered in using a portable grid, because there is no mechanical means of centering the tube to the IR. Lateral decentering causes an even loss of density over the entire image. As the amount of decentering increases, so does the undesired absorption of the useful beam.

Transmission of primary radiation begins to decrease with any amount of lateral decentering; however, lower grid ratios are more tolerant for lateral decentering than higher grid ratios. For this reason, you should select the lowest practical grid ratio for portable exams.

Lateral decentering plus distance decentering

When lateral and distance decentering occur together, they are unique in that they produce a radiograph with a loss of density on only one lateral margin of the image. If the X-ray tube is misaligned in both directions and the focus-grid distance is greater than the grid radius (fig 4–13 image A), the lateral margin of the image beneath the tube will be underexposed. If the focus-grid distance is less than the grid radius (fig. 4–13 image B), the lateral margin of the image most remote from the tube is underexposed.

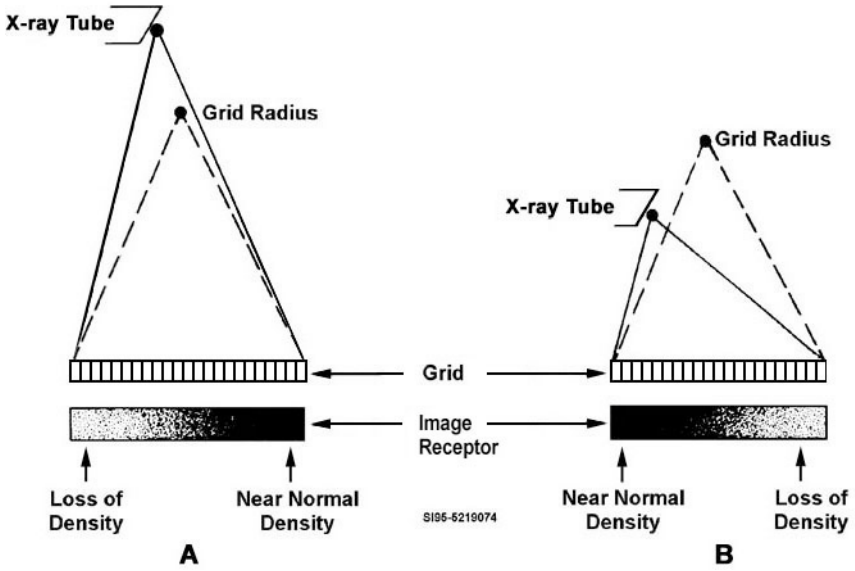


Figure 5–12. Effect of lateral decentering plus distance decentering on image density.

Off-angle alignment

If the X-ray tube is excessively angled across the lead strips, or if the grid is angled in respect to the useful beam, there is an even loss of density over the entire image. The amount of loss depends upon the degree of the angle and grid ratio.

Factors to consider when selecting a grid

Selecting a proper grid requires an understanding of some interrelated factors and is usually a compromise of sorts. The first of these factors to discuss is kVp. Generally, you should select a high- ratio grid when using high-kVp techniques. Keep in mind though, with higher grid ratios, the patient dose increases because of the need for increased exposure techniques. For this reason, use the lowest practical grid ratio for the examination.

When using higher kVp techniques, you must also consider grid frequency and how it affects the grid's efficiency. Remember, earlier we determined that at higher kVp levels, such as above 120 kVp, the SR produced is at an energy level that is sufficient enough to still penetrate the thinner lead strips found in grids with high-grid frequencies (above 100 lines per inch). Therefore, when using high-kVp techniques, the grid characteristics of choice are high ratio (12:1 to 16:1) with low frequency (60–80 lines per inch).

The trade-off of increased cleanup with a high-ratio grid is that the patient exposure dose increases considerably and tube alignment becomes more critical. You also have to weigh the value of a better quality radiograph against your obligation to minimize patient exposure. Therefore, use the following general guidelines when selecting grids:

- When the applied kVp is below 90, grid ratios up to 8:1 are satisfactory.
- When the applied kVp is above 90, grid ratios above 8:1 are acceptable.
- When the applied kVp is above 120, grids with high ratios (12:1 to 16:1) and low frequencies (60–80 lines per inch) should be used.
- When the thickness of the selected body part to be X-rayed is at least 10 cm, a grid should be employed.
- During portable radiography, a 16:1 grid ratio should ***not*** be used because it will not tolerate very much lateral decentering.

5D The Effect of Geometric Factors on the Image

In our high school days, we may have learned that geometry is a branch of mathematics that deals with measurements and relationships of lines, points, and angles. In radiography, we are concerned with certain other geometric factors that affect image formation. In this section, we address three of these specific geometric factors—focal spot size, SID, and object-to-image distance (OID)—and we'll discuss how each affects detail, magnification, and distortion.

5.9 Radiographic detail and its relation to focal spot size

Producing a sharp image is important in the diagnosis of your patient's condition. It is important for you to understand what affects image detail and how the focal spot size helps produce a high-quality crisp image. We begin by defining detail.

Radiographic detail

Recall for a moment what comprises good radiographic quality. In your earlier radiologic education, you learned that radiographic quality is a composite of parameters affecting the visibility and sharpness of the image. Density and contrast are the parameters most affecting the visibility of structures, whereas, distortion and recorded detail make up the sharpness of structures. We define *detail* as it applies to a radiographic image as the visual demonstration of the structural lines and contours of an image. There are other terms used when referring to detail; for example, you could say an image with good detail has a high degree of sharpness, or good *definition.*

The opposite of sharpness is unsharpness or *blur*. It is normal when an image is blurry to assume some kind of part movement took place during the exposure. Another type of blur that takes place on nearly every radiograph exposure to some degree is *focal-spot blur*. Focal-spot blur occurs because our source of radiation—the target—is more of a rectangular area rather than a single point. "Penumbra" was the term used to describe this phenomenon in the past, but since this is a term borrowed from astronomy, the term "focal-spot blur" is now commonly used to describe this effect unique to radiographic imagery.

Although many things influence detail, we generally consider focal-spot blur to be most affected by the following three factors: OID, SID, and focal-spot size. A high degree of blurring is caused by: a large focal-spot size, a short SID, and a long OID. By contrast, image sharpness results from—among other things—a combination of a small focal-spot size, a long SID, and a short OID.

Focal spot size and detail

No doubt, you have been told many times to use the smallest focal spot possible. Note the use of the word "possible." It is not always possible (or practical) to use a small focal spot when imaging larger body parts because a small focal spot cannot produce the higher mAs techniques that are typically required.

So why does a small focal spot produce better detail than a larger one? To answer that question, refer to figure 4-14. Notice we have drawings of three focal spots projecting an image. Image A shows the focal spot as a point source of the X-ray photons. Image B represents a small focal spot and image C represents a large focal spot. Notice that we did not refer to the "point source" in image A as a small focal spot; this is because we have no focal spots that are actually small enough to be considered "point sources" in radiology. They usually range from 0.3 to 2.0 mm. We show the point source in image A merely to illustrate the difference in the projection of the image.

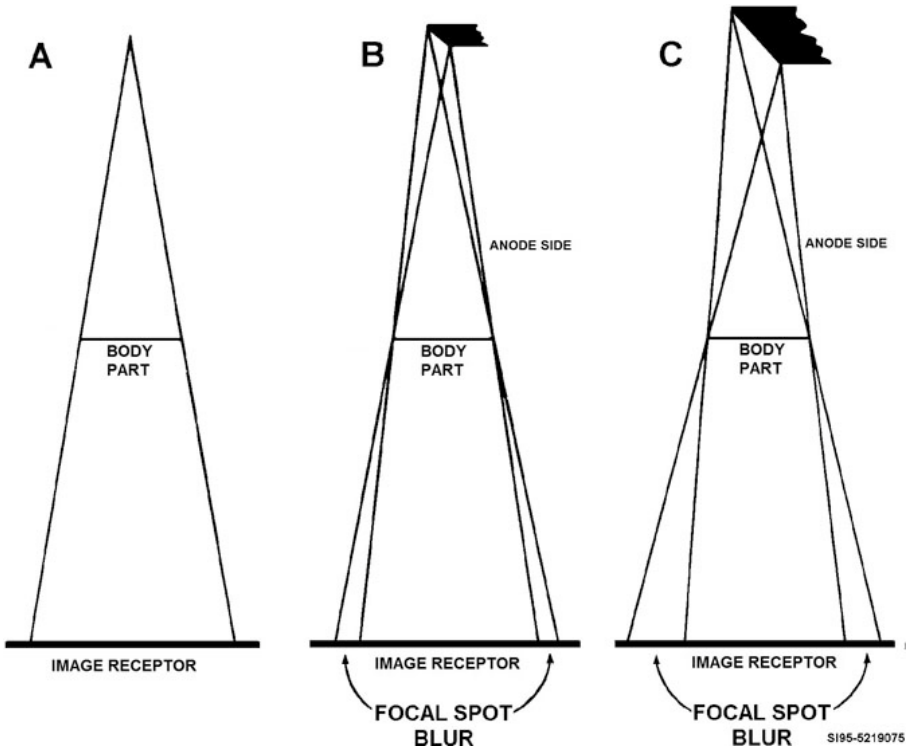


Figure 5–13. The effect of focal spot size on image blur.

Notice that all edges of the part in image A, figure 4–14, are projected to one spot on the IR, while in images B and C each edge is projected to a different spot. The reason that each edge is projected to a different spot is that the edge is projected by photons from many points within the target. For simplicity, we have shown only the photons from each side of the target in images B and C of figure 4–14, which determine the maximum area of blurring. When the border of the body part is projected in this manner, it is called focal-spot blur and the image will have a “fuzzy” or “unsharp” appearance.

As you can see, there is less blurring present on the image of the part projected by the smaller focal spot. A smaller focal spot causes less blurring because the edges are projected by photons from fewer point sources that are closer together.

Refer to figure 4–14 B and C once again. Did you notice the difference between the amounts of focal-spot blur from the anode side of the tube to the cathode side? As you can see, the amount of focal- spot blur produced is greater on the cathode side of the tube. What does this difference mean? It means that the edge of the part on the anode side is being radiographed with a smaller effective focal spot than the edge on the cathode side. Of course, the important aspect to note is that radiographs have better detail on the anode side. Figure 4–15 gives you an idea of the relative focal spot sizes in the center and at both edges of the beam. The one in the center represents the size listed on your tube- rating chart.

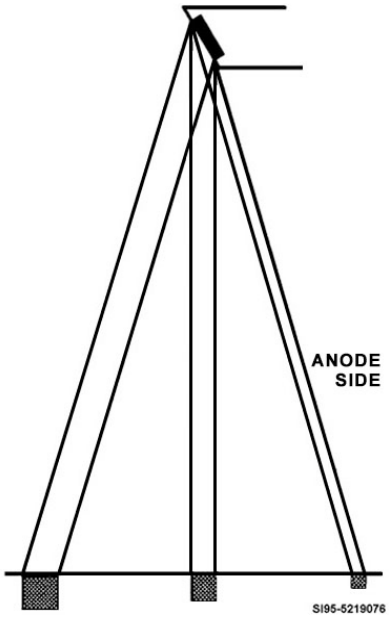


Figure 5–14. Focal spot sizes as seen from different parts of the X-ray field.

5.10 How geometric factors affect magnification and shape distortion

How you position the body part, where in relationship to the IR the part is positioned (OID), and the SID all contribute to the amount of magnification and/or distortion. As a technologists, it is important for proper radiologist interpretation to project the body part correctly on the finished image. So what is magnification?

Magnification

As it pertains to a radiographic image, *magnification* is defined as a form of size distortion causing enlargement of a body part on the image relative to its true size. We can determine the amount of magnification with this formula:

$$\text{Magnification} = \frac{Size\text{-}of\text{-}the\text{-}image}{Size\text{-}of\text{-}the\text{-}object} = \frac{Size\text{-}of\text{-}the\text{-}image}{Size\text{-}of\text{-}the\text{-}object}$$

For example, suppose the actual size of an object you X-rayed is 8 cm but the projected image size is 10 cm. How much magnification occurred? We can solve this problem by substituting the known values into our magnification formula:

$$\text{Magnification} = \frac{10}{8}$$

$$\text{Magnification} = 1.25$$

In this example, the image size is 1.25 times larger than the actual size of the part. Thus, some magnification has occurred.

Magnification should normally be kept to a minimum so that the part is projected as near as possible to its actual size. Increased magnification increases the effect of focal-spot blur on a radiograph, which causes lower clarity on the image. In addition, enlargement of some body parts is a sign of disease. If the part is magnified because of the projection, the radiologist may have a difficult time making a diagnosis. The best way to image a part as near as possible to its actual size is to use OID and SID properly.

Factors affecting magnification

Basically, two factors affect magnification: SID and OID. If you make two radiographs of a particular body part using the same OID but different SIDs, then the radiograph with the longer SID will show less magnification. To illustrate how SID affects magnification, refer to figure 4–16,

where we have illustrated the same size part projected by three different SIDs. Notice that a more divergent beam projects the part on the IR at the short SID. It is this greater divergence that increases the magnification.

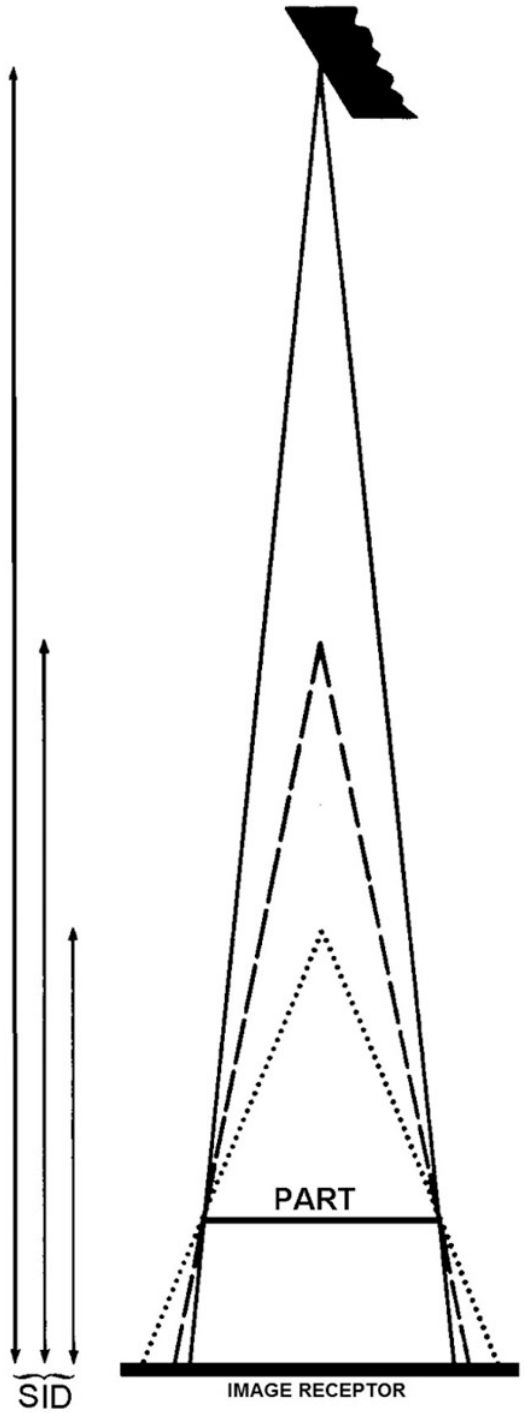


Figure 5–15. How SID affects magnification.

The OID (object-to-IR distance) also has a pronounced effect on magnification when the SID remains constant. Notice in figure 4–17, three different equal sized parts are projected by the same SID. The only difference is in the OID. Part A, which is farthest from the IR, is magnified most, while parts B and C, which are nearer the IR, are magnified progressively less. Magnification due to an increase in OID occurs for the same basic reason as magnification from decreased SID—that is, the part is projected by a more divergent beam.

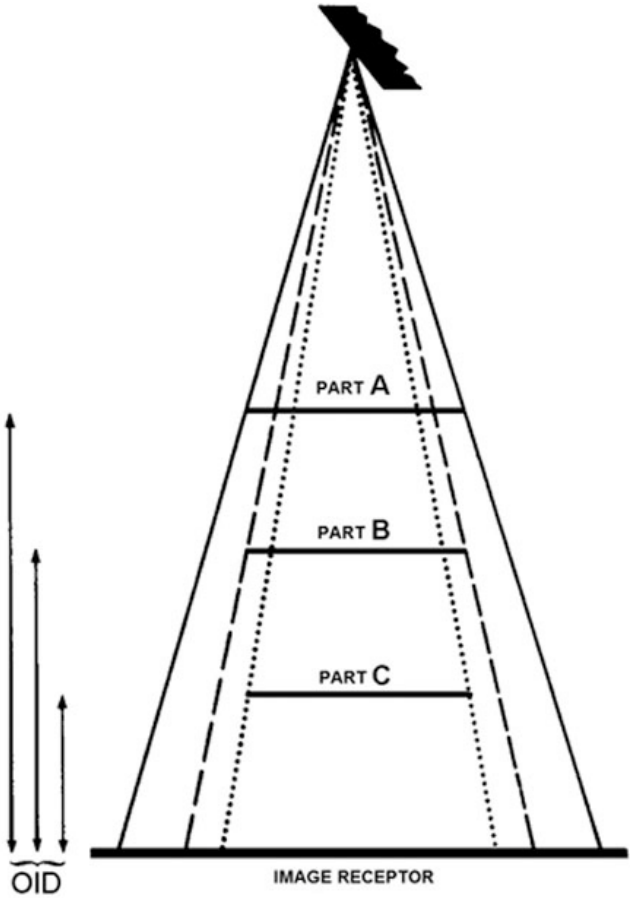


Figure 5–16. The effect of OID on magnification.

In summary, to reduce magnification of a structure as much as possible, you should use a long SID and a short OID.

Shape distortion

We say a body part is distorted when the body part is not projected on the image in its true shape and size. From that definition we can say that there are two types of distortion: size distortion (magnification) and shape distortion. Since we've already discussed magnification, we will cover only shape distortion. For clarification purposes, when you see the term *distortion* used alone, it is most commonly referring to shape distortion.

There are two types of shape distortion: elongation and foreshortening. Elongation is created when the tube or IR are angled to the body part while foreshortenting occurs when the tube and IR remain perpendicular to each other with the body part angled. Normally, you should try to keep elongation and foreshortening to a minimum on your radiographs so that the part appears in its normal shape in order for the radiologist to recognize an abnormality easier. In some instances, we use distortion to free a part from superimposition over another part. An example of acceptable distortion is the inferosuperior, or axial, projection of the clavicle. Distortion is necessary in this case to demonstrate the clavicle free from superimposition of the ribs. Other examples of acceptable distortion include the PA Caldwell projection of the sinuses and the AP axial (Towne) projection of the skull. Each of these projections intentionally introduces distortion into the radiographic image to better demonstrate specific anatomy.

Tube-part-image receptor (film) relationships

The relationships between the tube (the CR), the plane of the body part, and the plane of the IR affect distortion. In fact, we can state that the controlling factor for shape distortion is tube-part-film (IR) alignment. Specifically, the plane of the part and the plane of the IR must be parallel, and the CR should be perpendicular to the part and IR (film) to minimize distortion.

Unit 6. Ionizing Radiation Protection

6A Roles and Responsibilities.....137
6.1 Oversight of the radiation safety program.....137
6.2 Training for radiation workers….....138
6B Radiation Protection…….....140
6.3 Dose limits for radiation exposure….....140

Having a working knowledge of radiobiology and radiation protection procedures is one of the most important aspects of our profession. The information covered in this unit could quite possibly save lives. Excessive exposure to ionizing radiation has been linked to everything from cancer to cataracts to shortened life spans and birth defects. You can realize just how important it is for you to understand how radiation affects the body and what measures you can take to minimize its effects on you, your patients, and fellow hospital staff members.

In this unit, we examine the roles and responsibilities different staff members of the hospital have to oversee the radiation protection program. We then identify different training and qualification requirements needed to perform our jobs as imaging professionals. Finally, we will reference radiation protection practices for both occupational purposes and the general public.

6A Roles and Responsibilities

The Air Force supplies its people with the best quality equipment, supplies, and weapons systems needed to accomplish the mission. However, these are all useless without people to maintain and operate them. Since people are our most important resource, it is imperative that we keep them healthy, injury free, and able to perform their assigned duties.

As future supervisors and NCOICs in diagnostic imaging, you should be familiar with the various instructions that pertain to radiology safety. All guidance pertaining to ionizing radiation protection can be found in AFMAN 48-148.

6.1 Oversight of the radiation safety program

The Assistant Surgeon General, Medical Operations, oversees the use of sources of radiation to ensure compliance with all Federal, DoD, and AF regulations and requirements. They also establish the Air Force Radiation Safety Committee (AF-RSC) to serve as the focal point for all ionizing radiation issues and medical non-ionizing radiation issues, such as Magnetic Resonance Imaging (MRI) and medical lasers.

The Air Force Radiation Safety Committee (AF-RSC)

The Air Force Radiation Safety Committee provides direction on uses of radiation and serves as the primary Air Force point of contact for communications with federal, state, and host nation regulatory authorities regarding radiation issues. This committee also recommends policies to the AF/SG for keeping radiation exposure as low as reasonably achievable (ALARA).

The RSC will meet as often as necessary, but not less than two times per year. A total of at least 50% of the appointed representatives is required to be present for each meeting and the minutes are published and provided to all members. The RSC will conduct visits, as necessary, to respond to incidents and mishaps within the scope of AFMAN 48-148, and accompany the Air Force Inspection Agency during inspections where special emphasis investigations are being addressed.

The Unit Radiation Safety Officer (URSO)

The Unit Radiation Safety Officer (URSO) provides technical support to organization or unit commanders on radiation protection issues and inform unit commanders and the installation RSO about radiation health and safety issues. The URSO manages the organization or unit radiation safety program and ensures

radiation workers are properly trained on the risks of radiation methods to minimize exposure, and the ALARA principle. They also are responsible for forwarding Diagnostic Imaging personnel's off-duty or moonlighting radiation dose records to the installation URSO for inclusion into the master radiation exposure registry (MRER)

Workplace Supervisors

Workplace supervisors ensure adherence to AFMAN 48-148 for all Diagnostic Imaging personnel to protect Airmen and Air Force civilians from occupational exposures. As a supervisor, it is also your responsibility to ensure the protection of the public from workplace practices and that personnel are trained on radiation hazards in the workplace and appropriate protection requirements.

Supervisors in the Diagnostic Imaging department will notify the URSO, as soon as practicable after identification, of changes in practices or procedures involving radiation, unsafe work practices involving radiation, or accidents or incidents involving radiation. Supervisors are also responsible for ensuring subordinates are properly trained on the risks of radiation, methods to minimize exposure, and the ALARA principle.

Radiation Workers

It is imperative that all Diagnostic Imaging professional follow all applicable rules, and receive information, instruction, and training for radiation protection and safety specified by organizational management and AFMAN 48-148. Radiation workers must use dosimeters and personal protective equipment correctly when issued.

All Diagnostic Imaging personnel will provide the URSO information on past and current work relevant to ensure comprehensive effective protection and safety for themselves and others, to include any moonlighting dosimetry data to the URSO. They must also notify supervisors of any changes to procedures or operations that could affect exposure, unsafe practices involving radiation, or accidents or incidents involving radiation.

An active duty pregnant female shall, on becoming aware she is pregnant, notify her workplace supervisor or primary care manager. A non-military or civilian member is encouraged to notify her workplace supervisor or Public Health office of her pregnancy, but it is not mandatory. It is important to remember that it is the decision of a civilian woman whether or not she declares her pregnancy. This applies to female radiation workers and not all females.

6.2 Training for radiation workers

All radiation workers have training requirements as outlined on Table 7-1. Initial and annual training is provided by the URSO or permit RSOs depending on the scope of training. Training for radiation workers includes all personnel (military, civilians and in-house contractors) who have the potential to be occupationally exposed to 1 mSv (100 mrem) in a year. These workers will receive initial and annual training, and their records will be maintained for a period of no less than three (3) years.

See Table 6-1 on next page.

Table 6-1. Training for DI workers

Topic	Diagnostic Imaging Workers
Radioactivity, radioactive decay, and radiation production devices (x-rays, neutrons)	As Applicable
Radiation vs. contamination	X
Internal vs. external exposure and dose	X
Biological effects of radiation	X
Types and hazards associated with Radioactive material or devices	X
ALARA concept	X
Training in the principles of time, distance, and shielding	X
Radiation detection and measurement	As Applicable
Personnel dosimetry	X
Applicable regulations and reporting requirements	X
Locations of use and storage of radioactive material	As Applicable
Material control and accountability	As Applicable
Annual audit of radiation safety program	As Applicable
Transfer and disposal	As Applicable
Record Keeping	X
Managing incidents and mishaps	X
Recognition and assurance of radiation warning signs; visibility and legibility	X
Employee protection	X
Deliberate misconduct	X
Emergency response procedures	X
Bioassay techniques	As Applicable

6B Radiation Protection

Besides having some knowledge of the biological effects of ionizing radiation, you must practice positive, protective measures in the exposure room. Furthermore, it is not enough to limit the protection to yourself; you must give your patients equal consideration to keep their exposures at a minimum.

The final responsibility for protecting both you and your patient from needless exposure to radiation rests with you. Health physicists, radiologists, supervisors, and other personnel are responsible for establishing and maintaining radiation protection programs within the radiology department. Effective radiation protection from ionizing radiation will not exist without your constant efforts to reduce exposure whenever possible.

This section explains dose limits, how you can minimize exposures to yourself, to patients, and to others who must be present in the exposure room.

6.3 Dose limits for radiation exposure

Dose limits are an important aspect of radiation protection. Establishing these limits is one of the primary functions of radiobiologists. *Occupational exposure* dose limits are set to restrict the total amount of radiation a person may receive while doing their medical diagnostic radiology job. Occupational exposure dose limits are carefully determined to minimize the risk of radiation induced somatic and genetic effects and are based on a linear, nonthreshold dose-response relationship. Please note that these limits only apply to occupational exposure, not exposure received as part of medical treatment.

Dose limit standards

The Since the 1950's, a maximum permissible dose (MPD) was established for radiation workers. The MPD was used to describe the dose of radiation that occupational workers could receive and yet expect to produce no significant effects from the radiation exposure. This concept of MPD is no longer recognized in our profession and has been replaced by the concept of simply, dose limits (DLs). (Older MPD standards gave a false impression that a threshold for radiation exposure existed.)

In 1987, the National Council on Radiation Protection and Measurement (NCRP) established new recommendations for dose equivalent limits. They based these standards on the newer SI system of radiation measurement (gray and sievert) while incorporating philosophies aligned with the ALARA concept and the nonthreshold dose-response relationship. In essence, DLs are set knowing that we assume *all* radiation exposure is harmful; therefore, *all* unnecessary radiation exposure should be avoided.

Annual occupational dose limits

The accepted *annual whole body occupational DL for radiation workers* is 50 mSv per year (5000 mrem/yr). The annual whole-body DL is considered an effective dose limit which includes things like averaged exposures to different tissues and/or organs of the body based upon their RBE value. For particular parts of the human body, the NCRP also states the following DLs:

- *Skin, thyroid,* and *extremities* is 500 mSv per year (50 rem/yr)
- *Lens* of the eye is 150 mSv per year (15 rem/yr)

With good individual radiation protection habits, it is expected that actual occupational exposure readings need not exceed even 1/10 of the annual DL.

For *pregnant occupational radiation workers*, their DLs are set at 5 mSv (500 mrem) for the entire gestation with the stipulation that no monthly exposure can be greater than 0.5 mSv (50 mrem).
Another group of radiation workers to consider are young adults in school to learn our profession. Students must be 18 years old or be within a few months of their 18th birthday to enter into any diagnostic imaging course. Exposure levels for *students under the age of 18 years old* should be

closely monitored and never exceed 1 mSv per year (100 mrem/yr) because their cells are considered more radiosensitive.

Cumulative occupational dose limits

To this point in the discussion about DLs the focus has been on annual DLs. Going back to what was discussed in the previous lesson, we know that repeated small exposures accumulate and must be a concern. Therefore, in addition to the annual DL for occupational radiation workers, the cumulative whole-body DL is calculated by multiplying 10 mSv (1000 mrem) and the radiation workers age (in years). The table below shows how the old formula (5 times (N–18)) and the current formula (10 times N) differ in calculating cumulative DLs for occupational workers. **NOTE:** "N" represents the age of the individual).

Age of Radiation Worker	Old Formula 5(N–18)rem	Current Formula 10 mSv/yr
20 yrs	5(20–18)rem = 5 × 2 rem = 10 rem	10 mSv × 20 = 200 mSv (20,000 mrem) = 20 rem
30 yrs	5(30–18)rem = 5 × 12 rem = 60 rem	10 mSv × 30 = 300 mSv (30,000 mrem) = 30 rem
40 yrs	5(40–18)rem = 5 × 22 rem = 110 rem	10 mSv × 40 = 400 mSv (40,000 mrem) = 40 rem

Dose limit rational for radiation workers

Dose equivalent limits for radiation workers are significantly higher than those established for the general population for various reasons. First, a person becomes a radiation worker by choice, which therefore, implies an accepted risk to exposure. In other words, you are willing to accept a small degree of risk to benefit from this chosen occupation. Second, not everyone can receive occupational exposure; some segments of the population are excluded. People under 18 years of age and those with abnormal blood cell patterns are excluded. Another reason why radiation workers have higher dose limit levels is that radiation workers constitute only a small part of the total population. Therefore, from the viewpoint of the overall population's gene pool, it is acceptable for the small population group to receive greater exposure than the bulk of the general population.

Dose limits for the general public

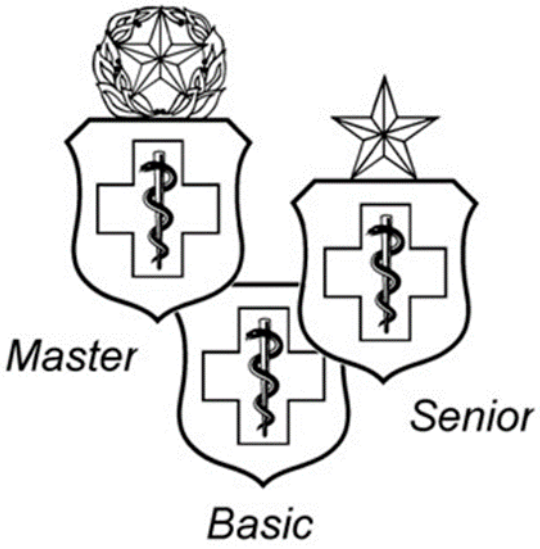
Everyone receives natural background radiation from a variety of sources including the Sun, the stars, and the Earth itself. The human race has managed to survive in spite of any adverse effects from this radiation. Still, it's prudent and reasonable to establish guidelines to protect the public from excessive occupational exposure. We use dose levels to derive working standards, such as radiation facilities and barriers (shields) to protect those who don't work with radiation. This includes medical professionals and office workers in and around radiation facilities.

The DLs for nonradiation workers are much lower than that for radiation workers to minimize possible adverse genetic effects for the population as a whole. The DL for the general population receiving occupational radiation exposure is set at 1 mSv per year (100 mrem/yr). Medical physicists use this amount to figure the thickness of a barrier and the amount of lead needed in the walls to protect people in adjacent areas around a radiology exposure room. If a room adjacent to an exposure room is occupied by non radiology workers, then the shielding must be good enough to limit the exposure to these people to less than 1 mSv per year. If that same adjacent room is occupied by radiation workers, then the shielding is designed to ensure an annual exposure of less than 10 mSv per year (1000 mrem/yr).

IF STUDYING FOR E5 STOP HERE!

IF STUDYING FOR PROMOTION TO E6 CONTINUE TO NEXT PORTION!

Diagnostic Imaging Testing For TSgt



Testing for TSgt

Page

Unit 7. Professionalism, Legal, and Ethical Aspects of Radiology.....147
7A Professionalism and Protection of Patient Information..... 147
7B Legal and Ethical Aspects of Diagnostic Imaging.....155
Unit 8. Joint Review Committee on Education in Radiologic Technology..... 163
8A Standards for an Accredited Educational Program in Radiography..... 163
Unit 9. Diagnostic Imaging Regulating Authorities..... 166
9A U.S. Nuclear Regulatory Commission.....166
9B Food and Drug Administration..... 168
Unit 10. Nuclear Medicine..... 170
10A Federal Regulations and Radiation Protection.....170
10B Generators and Radiopharmaceutical Shielding.....172
10C Patient Examinations.....173
Unit 11. Diagnostic Medical Sonography..... 178
11A Patient Examinations..... 178
11B Cidex/Trophon..... 182
Unit 12. Magnetic Resonance Imaging (MRI).....183
12A Equipment Safety Zones..... 183
12B Patient Examinations..... 187
Unit 13. Mammography.....190
13A Mammography.....190

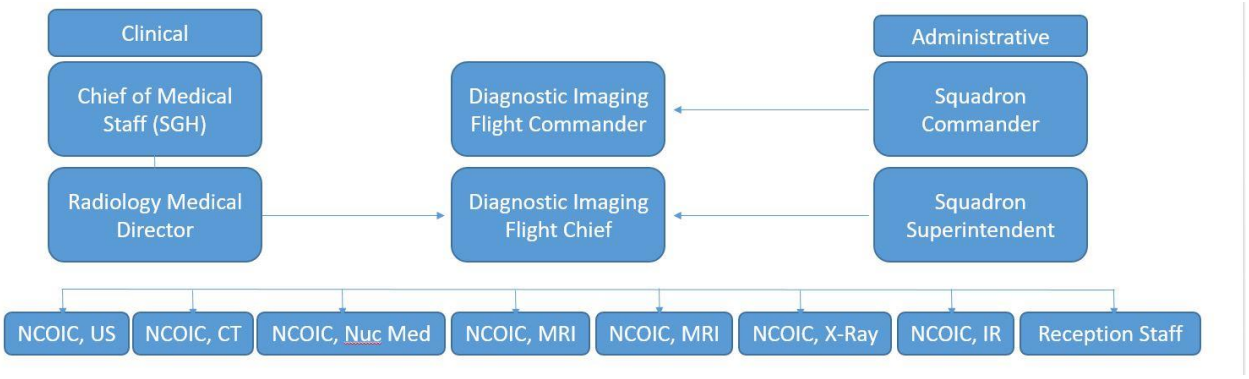
Unit 7. Professionalism, Legal, and Ethical Aspects of Radiology

7A Professionalism and Protection of Patient Information 147
7.1 Professional interaction considerations……147
7.2 Patient information and privacy……...…153
7B Legal and Ethical Aspects of Diagnostic Imaging 155
7.3 Ethical considerations in Diagnostic Imaging…….……..…155
7.4 Malpractice…….……159

PATIENTS come to Diagnostic Imaging (DI) when they are not feeling their best and, because of their medical issues, they may respond to you in an angered or frustrated manner. Remember in these situations it is how you react to it is what is important. Whether talking about being in the military or working in DI, both are professions and you are expected to always maintain your professionalism (or military bearing). How you interact with patients, fellow DI staff, and other medical staff in your facility is a reflection of you, your imaging department, and of course, the USAF. In section one it discusses professionalism and protection of patient information, while section two lays out some important legal and ethical issues to consider and be aware of in medical imaging.

Radiology Structure

The diagram below outlines the hierarchal structure of a typical Diagnostic Imaging Department. Although actual titles may vary depending on your location, it is important to understand that everyone plays a key role in the direction and management of the department's goals and it's human resources.



You may notice that there are essentially two separate entities that all military imaging departments answer to. Although they are separate in their own right, the Flight Chief's responsibility is to ensure that the needs and desires of both the *clinical* and *administrative* entities are met.

The *clinical* chain of command rests with the medical group's SGH. This person is essentially the head of the medical staff and responsible for proving leadership and guidance to the medical staff and promotes effective communication between the medical staff and the medical group executive staff. This person is also responsible to provide clinical oversite to all of the providers that work in the facility. The Radiology Medical Director is the lead radiologist. This person approves the imaging protocols and liaises between the SGH and the department. All of the imagery is performed to the specifications of the radiologist. Having a good working

relationship with the Radiology Director is essential for the Flight Chief as well as section NCOICs. This is the person that you should call upon to sort out issues with ordering providers

The *administrative* chain of command is funneled through the direct leadership chain of the Squadron Commander to the Flight Commander to the Flight Chief. This chain of command is responsible for the constant day to day management of the department. As the direction is passed down from the Medical Group Commander, this chain of command develops operations and pathways to execute the mission.

Professional Organizations

There are organizations of imaging technologists that serve those with specific professional interests. The oldest and largest national professional association for technologists in the radiologic sciences is the American Society of Radiologic Technologist (ASRT). The ASRT is the only nationally recognized professional society that represents all radiologic technologists in the United States today. It reaches radiographers on the local level through affiliate state societies. The mission of the ASRT is to advance and elevate the medical imaging and radiation therapy profession and to enhance the quality and safety of patient care. The House of Delegates is the legislative body of the organization, with 166 eligible positions, including affiliate delegates elected or appointed by state societies, national chapter delegates elected by the membership at large, and military chapter delegates. Chapter delegates represent the different areas of practice in the radiologic sciences (to include management and education) and imaging and therapeutic professionals in the military. The role of the House of Delegates is to debate and vote on issues that have a major impact on professional practice.

Practice Standards

ASRT has developed a written statement that describes the radiographer's duties and responsibilities. *The Practice Standards for Medical Imaging and Radiation Therapy* defines the clinical practice, technical activities, and professional responsibilities of imaging and therapeutic professionals. Visit the ASRT's website (www.asrt.org) to view the practice standards. These standards outline achievable levels of performance against which a technologist's actual performance can be assessed or measured. It delineates the parameters of practice, identifies the boundaries for practice, and typically can be used by Flight Chiefs to develop an individual's job description. Additionally, in the case of medical malpractice or negligence claims, a lawyer may use this document to determine the acceptable level of care and to show whether the professional standard has been met.

As a supervisor, it is important to have a good understanding of these practice standards to ensure your technologists are working within their scope of practice. Knowing this information also comes in handy while you are being asked by other work centers to modify your daily operations. A common ask of radiology technologists that are outside of our scope of practice, is to remove cervical collars for patients that need to be examined. If you possess a clear understanding of the national practice standards comes in handy during these conversations.

7A Professionalism and Protection of Patient Information

Throughout your daily imaging activities, you interact with patients, fellow medical staff members, and view protected patient information. It is important to always treat people with respect and speak to them in a courteous manner, showing compassion when appropriate. In addition you have access to protected patient information to perform the job competently. Protecting patient information is imperative and understanding privacy rules is required. In this section the discussion will include considerations for professional interaction and protections for safeguarding patient information.

7.1 Professional interaction considerations

Stop and think for a minute, what does "act professional" mean to you? Your answer to that question will quite possibly be based upon your cultural upbringing and life experiences. Cultural differences (diversity) in the workplace definitely affect how professionals act and are received by others.

Therefore, before looking at communication skills, let's look briefly at how cultural diversity affects the professional environment.

Respect for cultural diversity

Depending upon the resource, cultural diversity can be interpreted in many ways. One definition of *culture* states that it is the behaviors and beliefs characteristic of a specific social, ethnic, or age group. *Diversity* is known as the state of difference or variety. Cultural diversity, therefore, is the variety of behaviors and beliefs that exist among people from different social and ethnic backgrounds or age groups. Cultural beliefs affect how people live their lives and, in turn, how people view healthcare and the need for care. If cultural differences are not respected, medical professionals (including you) may find it difficult to communicate and provide care for sick individuals. While cultural diversity may pose some issues in the medical setting, it also creates the potential for more widespread growth and acceptance in providing quality healthcare.

Now let's revisit what it means to "act professional." According to the Merriam-Webster's dictionary, professionalism is "having or showing the skill, good judgment, and polite behavior that are expected from a person who is trained to do a job well." As a DI technologist, you are a professional working in a professional field. It is very important that you conduct yourself in a manner that is viewed as respectful to the various groups of people you interact with. Whether you are interacting with a medical staff member from outside of DI or a patient, you must always actprofessionally.

Showing respect for a person's beliefs and culture will improve relations with them, which will, in turn, increase your ability to provide them the highest quality healthcare while visiting the DI department. You must be attentive to the behaviors of different groups of people and to how they view some basic mannerisms. For example eye contact, how close you stand to another person, the volume of your voice, gestures, and touch are all mannerisms that may potentially have different meanings from culture to culture.

Communication technique considerations

Poor communication is the *most* often filed complaint by a patient or visiting medical staff member (physician, nurse, or medical technician). Communication in its most basic form is the exchange of information from one person to another. Nonverbal and verbal are two forms of communication we need to discuss.

Nonverbal communication

Considering that what you say to a patient is the primary means of communication, it is important that your nonverbal communication behaviors are supporting the words you speak. Nonverbal communication accounts for up to 55 percent of human communication by means of gestures, posture, facial expressions, touching, appearance or eye contact. How you communicate nonverbally is typically a representation of how you were raised culturally. You should be aware of your own nonverbal messages to gain adequate trust and acceptance from your patient when communicating with them.

For example eye contact in the United States is a welcomed, positive behavior, whereas in other cultures, eye contact is simply not acceptable. The same goes for touching; placing your hand on a patient's shoulder may seem okay to you because you may be trying to convey a feeling of reassurance or support. In other cultures, though, it could be interpreted as a form of dominance. If you must touch patients, it is always best to tell them in advance what you are going to do first so not to inadvertently offend them or make them feel uncomfortable.

Verbal communication

Verbal communication uses language to convey your message. When using language to explain a DI exam to a patient, you must use words appropriate to your listener. For example if explaining a radiographic procedure to a retired physician, you could be quite technical and use medical terms in your explanation; if talking to a person that doesn't have medical training, you would probably need to use more basic terms to explain the same procedure. Being a good verbal communicator means you speak clearly and distinctly, while choosing appropriate words your patient will understand. Speak face-to-face so your patient can make eye contact (if they so desire) and see your expressions.

Interacting with people in this way shows them they have your full attention while also allowing you to see any nonverbal messages as you speak to them. Always pay attention to your patient when

communicating with them and be willing to modify your approach if you find your first method doesn't seem well received.

Listening skills

One of the *most* important parts of good communication is effective listening. The skill of listening involves being patient enough to not interrupt a person when he or she is speaking while also giving your full undivided attention. Patients often give subtle messages as to what they are feeling; it is important to pay close attention to what is stated while not rushing to get on to the next question, exam, or patient on the schedule.

Having good listening skills is also important when you are communicating with other healthcare professionals. You should employ the following techniques to ensure that you understand the message that is being delivered to you from the sender. Pay attention to the speaker and acknowledge the message. Use your body language and gestures to show engagement in the conversation. Provide feedback and ask clarifying questions to ensure you understand what is being communicated. This point is hard to do at times, but don't interrupt with counter-arguments. Allow the speaker to finish each point before asking questions. Finally, active listening is designed to encourage respect and understanding. Remember to respond appropriately. You add nothing by attacking the speaker or otherwise putting him or her down.

Patient interaction

All patient interaction should be on the professional level. Patients should consistently be addressed properly by their rank and last name or Mr./Mrs./Ms. and their last name. Common courtesies of "please", "thank you", and "you're welcome" are expected whenever addressing a patient. Patients have a right to privacy and must be offered a gown anytime an exam requires the removal of clothing. If performing an exam on a patient of the opposite sex, which requires private body parts to be uncovered, make sure a chaperone is present during the examination (or anytime at the patient's request). At no time is it appropriate to ask for personal information from the patient who does not pertain to the procedure or reason for his or her visit to the DI department.

A large majority of patient interaction occurs over the telephone. This introduces a different barrier to effective communication because the ability to observe nonverbal gestures is not possible over the telephone. Here are some guidelines for avoiding problems with telephone communications:

- Be familiar with your telephone system to include forwarding and "hold" functions.
- Identify yourself and your department at the beginning of each telephonic conversation.
- Keep paper close by and make notes during the call to avoid losing details.
- Use a pleasant, receptive tone of voice.
- Validate the message BEFORE concluding the call.
- Be sure that messages are relayed promptly to the proper person or department

Medical staff interaction

Other medical staff members bring emergency room and inpatients to DI. These staff members may be under stress just as you may be. Always show respect and patience with fellow medical staff members as they are doing their best to provide the utmost in patient care just as you are. If disagreements or confrontations arise, take the discussion away from the patient if possible or delay the conversation to a later time when the patient is not around. Remember, you are a service-oriented professional; therefore, patients and staff members will come and go—make sure their time in DI is a pleasant experience.

Situations may arise that require you to pass information from DI to the medical staff. In these cases, you must be clear and concise in your communication to ensure that your message reached its intended recipients and that it is well received. Common acronyms utilized by the DI department are SBAR, BLUF, and SWOT.

SBAR stands for Situation, Background, Assessment, and Recommendations. SBAR was originally

developed by the U.S. Navy as a way to communicate information on nuclear submarines. In the 1990s the civilian healthcare system adopted the Navy's platform and now SBAR is used worldwide. According to the Joint Commission, components of SBAR are as follows:

SBAR	
Situation	Clearly and briefly describe the current situation
Background	Provide clear, relevant background information on the patient or issue
Assessment	State your professional conclusion, based on the situation background
Recommendation	Tell the person with whom you're communicating what you need from him or her, in a clear and relevant way

Here is an example of an SBAR that is patient specific that may be sent to a provider or clinic:

- *Situation*: Mrs. Murphy is having increased dizziness following contrast administration during her CT exam.
- *Background*: Mrs. Murphy has been NPO for 4 hours in preparation for her Abdomen/Pelvis CT exam. Once contrast was introduced through her IV, she complained of nausea and dizziness. The exams were completed and she was given water to drink and instructed to lay on the table for an additional 15 minutes.
- Assessment: Mrs. Murphy is now coherent and is ready to be moved to x-ray for her routine imaging post her exam.
- *Recommendation*: I recommend that Ms. Murphy is transported to x-ray in a wheelchair and also that she is not left alone on the x-ray table during routine imaging.

Here is an example of an SBAR that is DI system related that may be sent to the medical staff for their awareness:

- *Situation*: Starting in June, fluoroscopy procedures will only be performed on Fridays. All HSG procedures will be referred off base secondary to time and scheduling constraints. If imaging for Upper GI studies/Esophagrams cannot be performed within 2 weeks, they will also be referred to the network.
- *Background*: Radiologist manning constraints require a decrease in fluoroscopic procedure capabilities.
- Assessment: Musculoskeletal fluoroscopic exams for MRI and joint injections will be prioritized. *Recommendation*: Please defer all HSG exams to the network until further notice. Operations will resume to normal when our radiologist manning has increased to patient capacity. If you have questions, please contact the X-Ray Core at 702-653-2855.

Sometimes, SBAR correspondence is not sufficient and a full e-mail is more appropriate. In these cases develop an eye-catching subject line and insert a BLUF statement at the beginning of your e-mail. Your name and the subject line is the first thing a recipient sees, so it is critical that the subject clearly states the purpose of the e-mail and specifically, what you want them to do with your note. Use keywords that characterize the nature of the e-mail in the subject. Some of these key works include:

ACTION - Compulsory for the recipient to take some sort of action with the information you are sending
SIGN - Requires the recipient to sign what you are sending
INFO - For information purposes only, and there is no response or action needed
DECISION - Requires the recipient to make a decision on what you are presenting
REQUEST - Seeks permission or approval by the recipient
COORD - Coordination by or with the recipient is needed
STATUS UPDATE - used to provide updates to correspondence that was previously disseminated

Bottom Line Up Front (BLUF) statements are desired by most military members due to the large number of e-mails that are received daily. This paired with the correct keywords in the subject line will help the recipient to prioritize the messaged in their e-mail inbox. Leading off with a BLUF statement helps the reader to quickly digest the announcement, decision, and when the new procedures go into effect. In this case, the reader doesn't necessarily want to know all the background information that led to the decision. Essentially, they want to know "how does this e-mail affect me?" See attachment below for a great example of the use of key subject line and BLUF email correspondence. Notice how well the email was written and also how the subject line catches the eye of the recipient and the great use of a BLUF statement to get to the true intent of the correspondence.

SUBJECT: AY20 Defense Advanced Research Project Agency (DARPA) Service Chiefs' Fellows Program (SCFP) Call for Nominations (**Suspense: 30 May 19**)

BLUF: ACC requests NAFs/Directorates nominate a maximum of three (3) active duty officers (Major selects, Majors, Lieutenant Colonel selects, and Lieutenant Colonels) to participate in the AY20 DARPA SCFP program, which is scheduled to begin in September 2019.

1. The DARPA Service Chiefs' Fellows Program exposes rising military officers to a unique organization whose mission is to rapidly develop imaginative, innovative, and often high-risk research ideas, offering significant technological impact that goes well beyond the normal evolutionary approach. Officers nominated for this 90-day program must be highly motivated, Active Duty officers who demonstrate outstanding leadership abilities in operational positions and have a clear potential to move into senior operational leadership commands. Please see the AY20 DARPA Service Chiefs Fellows Program myPers Message (Atch 1) for additional information and program description.

2. ELIGIBILITY CRITERIA:
a. Must be an Active Duty Air Force officer in the rank of Major select, Major, Lieutenant Colonel select, or Lieutenant Colonel
b. Must be considered highly competitive for promotion
c. Must have at least a secret level security clearance

3. NOMINATION PACKAGE REQUIREMENTS: (via e-mail, with a consolidated PDF containing all documents)
a. Cover Page - Include rank, full name, duty title, organization, phone number, e-mail and mailing address where nominee can be contacted.
b. Personal Statement - Indicate how this program would benefit the nominee's career goals. Also, indicate which quarter nominee desires (in order of precedence). Review paragraph 5 Timeline to identify quarter.
c. Résumé (Tongue & Quill or Personalized)
d. Letter of Nomination - Must be on official letterhead from MAJCOM, COCOM, DRU, FOA, or AFDW A1's (Atch 2) or equivalent; letter should highlight nominee's leadership qualities and benefits of program for the Air Force and the officer's career.
e. Letter of Endorsement - Must be on official letterhead from Wing CC/CV or equivalent nominating member for consideration and endorsing applicant's participation; letter must include statement of understanding that member must be available for any of the quarters described.
f. Release Letter from AFPC Assignment Team - Must be an electronically signed e-mail from AFPC's respective officer assignment team lead.

4. SELECTION PROCESS: A senior panel at AFPC will review and select nominees for membership. Selection will be based on strength of application. Letters of nomination and personal statements will be carefully considered in determining acceptance to the program. Officers selected for the program will be announced by message to the field. If for any reason an officer selected for the program becomes unable to attend, the opportunity will be presented to the next alternate on the list, as determined by the selection panel.

5. TIMELINE:

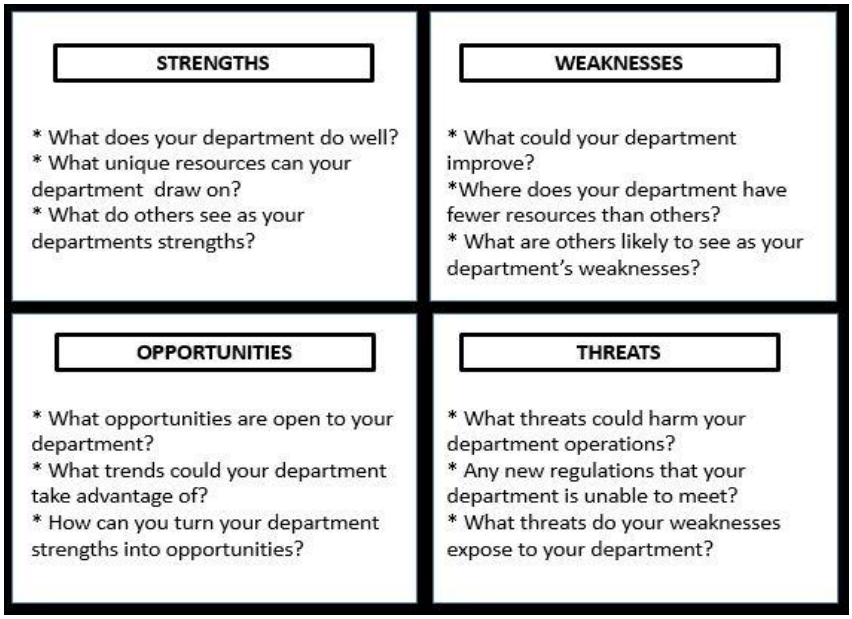
June 2019	Nomination packages due to AFPC NLT 14 June 2019
June 2019	AFPC panel reviews and selects officers for AY20 program
July 2019	AFPC announces AY20 Air Force DARPA SCFP selects
Fall through Summer 2019	DARPA SCFP convenes in four individual 3-month periods. AY20 dates: Fall 2019: 17 September 2019 – 13 December 2019 Winter 2020: 7 January 2020 - 27 March 2020 Spring 2020: 31 March 2020 - 19 June 2020 Summer 2020: 23 June 2020 - 11 September 2020

6. NOMINATION PACKAGE SUSPENSE: Please electronically forward a single PDF endorsed nomination package for each individual via encrypted email to USAFWC/A1 **30 May 19**. Ensure e-mail subject lines mirror the format provided within the call for nominations. Late submissions will NOT be accepted. Negative responses are required.

V/r,

BRITTANY J. BOTSFORD, 1st Lt, USAF
Deputy Director, Manpower & Personnel (A1)
USAF Warfare Center, Nellis AFB, NV
DSN: 682-3890, COMM: (702) 652-3890

The final communication acronym used often by the DI flight is SWOT. SWOT stands for *Strengths*, *Weaknesses*, *Opportunities*, and *Threats* and this analysis is a technique for assessing these four aspects of the imaging department. This tool is most often used as a guide during Distinguished Visitor briefings but may also be tailored to brief squadron leadership and DI staff. Brainstorming techniques are used to build a list of ideas and organize your thoughts about the current status of your department. Once you've developed your SWOT, look for potential connections between the quadrants.



7.2 Patient information and privacy

Medical records, whether electronic or paper, are considered personal identifiable information (PII) and must not be released or shared with unauthorized personnel or entities. Protection of patient's PII is another important task of radiographers. PII is considered any information that can be used to distinguish a person's identity, such as (but not limited to) a person's name, social security number (SSN), date and place of birth, and mother's maiden name. Moreover, medical, educational, financial, and employment information are also considered PII and must be protected.

Medical records

The medical record is the official record of medical diagnosis and treatment for the patient. A properly documented medical record is vital in ensuring continuity of care for the patient. In addition it may be used as a record for legal proceedings. Traditionally, documenting the medical record has been the domain of physicians and nurses; however, in certain situations radiographers are responsible for making entries as well.

The specific requirements for documenting medical imaging procedures will vary from facility to facility, but there are several areas that may be addressed including: appropriate clinical history (reason for the exam), patient vital signs during the procedure, technical aspects of the procedure (exposure technique, number of images, fluoroscopic time, etc.), the amount and type of contrast media administered, and any post-procedural patient instructions. Familiarize yourself with your facility's requirements before attempting to document a patient's medical records.

Whenever making entries in a patient's medical record, only record the pertinent facts. Avoid opinionated statements, such as "the patient was a jerk," in favor of factual statements, such as "the patient appeared

agitated." Using factual, professional language should help avoid a defamation suit.

Privacy Act

The Privacy Act of 1974 was enacted because congressional leaders determined that individual privacy was directly affected by the collection, maintenance, use, and dissemination of personal information by federal

agencies. The Privacy Act is meant to *protect* individuals' right to privacy as it relates to information kept in a system of records by the federal government. Information contained in patient medical records and patient information kept in hospital computer systems are protected under the Privacy Act.

In effect the Privacy Act restricts personnel who maintain a system of records from releasing information contained in those records to unauthorized individuals. Generally hospital personnel are authorized access to patient records but *only* in the performance of their duties. You may not, for instance, pull your neighbor's medical records to find out why he or she was seen in Internal Medicine last week or look up a colleague's lab results. *Disclosure* is the transfer of information from a system of records by any means of communication to organizations or individuals other than the subject or an agent acting for the subject. Those who are responsible for protecting records will not disclose any record to anyone other than to the subject, except when ordered to do so by a court or when authorized under the Freedom of Information Act. For example you may *not* release a husband's record to his wife or an adult child's record to a parent *without* a valid power of attorney authorizing that person access to the record. When in doubt as to whether or not you should release medical records, contact your facility's legal consultant.

As a radiographer, you have a requirement to complete initial and annual privacy act training to ensure you are aware of the rules of behavior for handling PII and consequences when privacy act rules are not followed.

Social media

Social media presents a unique challenge to the radiographer's responsibility to protect patient information. Radiographers often encounter interesting studies that they may be tempted to share on the internet via Facebook, Twitter, or Instagram; however, in doing so, radiographers are violating a patient's right to privacy. Even radiographic images posted on the internet that include no specific patient information (name, date of birth, SSN, etc.) can possibly be linked to a patient and violate privacy rules if the individual sharing the image(s) also shares unique details about the study or states the imaging location.

While social media is a fun and fast way to communicate with friends and colleagues around the globe, you are expected to take the ethical highroad and refrain from posting (sharing) any patient information, radiographic images, or exam videos on social media websites.

Electronic transmission of patient information

There are three things to consider before sending an electronic message (e-mail) with patient information or PII included in the message:

1. Is the PII or private patient information necessary to the message?
2. Does the recipient have a right to know the PII or specific patient information?
3. Do you have permission to release the PII or patient information?

When using e-mail to transmit PII or patient information, you must *encrypt* the message and add the following:

1. In the subject line, add "For Official Use Only" ("FOUO") to the beginning of the entry.
2. Include the following statement at the beginning of the e-mail:

   "This e-mail contains FOR OFFICIAL USE ONLY (FOUO) information which must be protected under the Freedom of Information Act (5 U.S.C 552) and/or the Privacy Act of 1974 (5 U.S.C. 552a). Unauthorized disclosure or misuse of this PERSONAL INFORMATION may result in disciplinary action, criminal and/or civil penalties. Further distribution is prohibited without the approval of the author of this message unless the recipient has a need to know in the performance of official duties. If you have received this message in error, please notify the sender and delete all copies of this message."

Do *not* indiscriminately apply this statement to all e-mails. Use it only in situations when you are actually transmitting protected personal information.

Social security number reduction plan

The purpose of the SSN reduction plan is to reduce or eliminate the use of SSNs in DoD and AF record systems. In reference to this plan, even your military identification card (or common access card) no longer displays your SSN. Instead, a Department of Defense (DoD) identification number is assigned and included on the back of your card. When patients check-in for their imaging procedure, this DoD number is now used to access patients' information in your hospital information system (computerized record and retrieval system). DoD identification numbers should be protected the same as a SSN.

7B Legal and Ethical Aspects of Diagnostic Imaging

Legal issues are an important yet often overlooked aspect of medical imaging, especially in the military; however, litigation involving imaging professionals, including technologists, is on the rise. Many of us tend to feel that we are somehow shielded from litigation because we serve in the Department of Defense. Yet the adage "you can sue anyone for anything" has been put to the test successfully with increasing frequency and fervor in our litigious society. In addition advances in medical science have made once clear ethical boundaries increasingly fuzzy. Almost daily health care professionals are faced with a myriad of ethical dilemmas, and the field of imaging is no exception. For these reasons we have included this section on the legal and ethical aspects of medical imaging to familiarize you with some of the more pertinent issues faced in the day-to-day DI environment.

7.3 Ethical considerations in Diagnostic Imaging

The term *ethics* has a different meaning depending on the field of reference. Perhaps the definition or aspect that is the most appropriate for our discussion is a code of morals of a particular group or profession. Ethics is what we use in our daily activities to help us determine right from wrong in instances when the law does not define the answer clearly. For instance, we use our professional judgment to decide if a radiograph meets acceptable standards of quality or if it should be repeated; however, at 1630, on a Friday afternoon, it often becomes as much an ethical decision as one of professional judgment.

The health care profession is and should always be a patient-centered environment. The decisions we make in the performance of our duties can have significant impact on the quality of life of the individuals for whom we care. With this in mind, the American Registry of Radiologic Technologists (ARRT) has developed the *Code of Ethics for Radiologic Technologists* to guide those working in our profession.

Ethics versus morals

Before diving into the ethical principles for radiologic (or DI) technologists, it is necessary to lay out the subtle differences between ethics and morals. *Morals* describe one's own principles regarding right and wrong. While morals may be influenced by an individual's culture or society, they are personal "rules" created and followed by the individual himself or herself. *Ethics* are external standards created by institutions, organizations, or professions. Ethical standards are a set of rules laid out for a social system or profession regarding what is considered acceptable behavior. Though both terms represent right versus wrong conduct, morals are personal rules versus ethics are rules of a profession.

As a DI technologist, your most important ethical concern is to always protect the rights of your patient. Below is a list of key components used to create most facilities' Patient's Bill of Rights, which ensures patients have the right to:

- Considerate and respectful care—this is self-explanatory.
- Information; yes, the patient has a right to information, but you are not obligated to give information when it is requested. A good example is when your patient asks you what you saw on his or her radiograph; as a DI tech, you are not authorized to give the patient your interpretation of what you see on his or her radiograph. In cases such as this, always instruct the patient to contact the exam's ordering provider to attain their results.
- Privacy and confidentiality; the *right to privacy* means the patient's modesty and dignity will be respected. An example of modesty is ensuring a patient is properly dressed in a gown and/or covered with a sheet or blanket to prevent open body exposure during sensitive examinations. *Confidentiality* means a patient's financial and medical information cannot be released without

his or her written permission.

- Genetic information; patients are given the right to allow or not allow their biological information to be used with the health treatment or anonymous genetic research cases.
- Informed consent; a patient's permission is *required* for any procedure that involves high risk or experimentation. A healthcare provider explains a medical treatment/procedure to a patient and attains the patient's permission BEFORE executing the procedure. This is discussed in more detail later in this unit.
- Refuse treatment (or an examination); straightforward, if patients decides they do not want the treatment or examination to be performed on them, you must comply.
- Dignity when dying; simply stated, the patient has the right to pass away with respect to his or her own wishes/beliefs. This right ventures into the realm of "do not resuscitate/intubate" (DNR/DNI) or "advanced directive" orders.

Ethical principles

The code of ethics for our profession is based on several ethical principles recognized by our society as applying to health care delivery. Among these are the principles of autonomy, nonmaleficence, beneficence, and fidelity.

Autonomy

The principle of *autonomy* means each individual has the right to determine the course of his or her own health care. Closely associated with the principle of autonomy is the basic right of self- determination, which means individuals should be allowed to control what happens to their own bodies.

To place this in concrete terms, we cannot force a person to have a medical procedure he or she does not wish to have. As a technologist, you should always ensure the patient has received enough information about a procedure to permit the patient to make an intelligent decision about having the procedure before proceeding. This can involve answering any questions the patient may have that are within your realm of expertise or informing the physician of the patient's concerns so that the physician may address them. The only time the principle of autonomy should be bypassed is in life- threatening emergencies where the patient is incapacitated and unable to provide consent or in instances where the patient is incapable of providing consent and the parent or legal guardian does so.

Nonmaleficence

The principle of *nonmaleficence* means to do no evil or harm. This principle requires no action to prevent harm; it simply requires that we do nothing that would harm the patient, such as intentionally administering the wrong medication or contrast medium. While at first consideration this concept seems very straightforward, it can lead to ethical dilemmas in situations where doing nothing will actually cause harm to the patient, but the patient adamantly refuses to be treated.

Beneficence

The principle of *beneficence* means to do good and prevent harm. The primary difference between this principle and the principle of nonmaleficence is that beneficence *requires action*. Performing the repeat radiograph at 1630 on Friday afternoon when you would rather be on your way out the door to start your weekend requires a degree of beneficence to do what is good for the patient.

Fidelity

The principle of *fidelity* means to strictly observe duties and meet the reasonable expectations of patients regarding professional service. In other words a person has a right to expect a certain degree of service from any professional (radiographers included) who has a duty to that individual. In health care the legal basis for reasonable expectations is based on the accepted standard of care for the profession. You have a duty to perform your job to the level of competency that is generally possessed by other radiographers.

Code of Ethics

Based on these and other ethical principles, *all* registered radiographers must adhere to the ARRT's *Code of Ethics*. At this point in your career, you may not be registered radiographer; however, since you are

practicing the profession, adherence to the code of ethics is the standard to which you will be measured. If you are called to defend your actions while performing your radiography duties, you will be held responsible under these ethical standards.

Military members may undergo military disciplinary actions for violations of ethical standards. It is important to understand that military registered technologist is also subjected to civilian sanctions by the ARRT Ethics Committee if those actions are presented to them for review. This action is to ensure that our profession maintains a level of professionalism and that members are held accountable for their actions. This sort of action is in line with provider credential sanctions in the event of subpar actions.

Visit www.arrt.org to view the complete list of reportable infractions. In this handbook, we bring your attention to the infractions listed below:

- Dishonest conduct concerning the ARRT examination
- Failure or inability to practice the profession with reasonable skill and safety
- Any professional practice that is illegal, contrary to prevailing standards, or that creates an unnecessary danger to patients
- Delegation, or acceptance of delegation, of professional functions that might create and unnecessary danger to the patient
- Revealing privileged communication except as permitted by law
- Assisting a person to engage in the practice of radiologic technology without current and appropriate credentials
- Practicing outside the scope of practice authorized by one's credentials

Failing to report to ARRT any violation or probably violation of any Rule of Ethics by any registered technologist or applicant for certification by ARRTThe code consists of 11 principles, which are listed in the table below. Read them carefully so that you may comply with the spirit in which the code was written. *"The ARRT Standards of Ethics are reprinted by permission of the ARRT. The ARRT Standards of Ethics are copyrighted by the ARRT."*

Principle		
Number	**Text**	**Discussion**
One	The radiologic technologist acts in a professional manner, responds to patient needs, and supports colleagues and associates in providing quality patient care.	The driving concept behind this first principle is professionalism—in both appearance and attitude. Each of these factors is critical in obtaining confidence and trust from patients and coworkers.
Two	The radiologic technologist acts to advance the principle objective of the profession to provide services to humanity with full respect for the dignity of mankind.	Always remember that your patients are people, not units of work that must be accomplished. Fully address any questions or concerns they may have and always respect their modesty and privacy.
Three	The radiologic technologist delivers patient care and service unrestricted by the concerns of personal attributes or the nature of the disease or illness, and without discrimination on the basis of sex, race, creed, religion, or socio-economic status.	We in the military must perform our duties free from discrimination based on sex, race, creed, religion, or socioeconomic status. However, perhaps less clear is our responsibility to care for patients regardless of the nature of disease or illness. We have all encountered patients whose physical condition was repulsive. It is a natural human reaction to recoil from disease (i.e., AIDS or Ebola), but as health care professionals it is our duty to care for the sick regardless of the nature of their disease. Imagine yourself or a parent in the patient's place and act accordingly.

Four	The radiologic technologist practices technology founded upon theoretical knowledge and concepts, uses equipment and accessories consistent with the purposes for which they were designed, and employs procedures and techniques appropriately.	This principle calls for technologists to obtain and maintain technical competency. Never perform a procedure or operate a piece of equipment for which you have not been fully trained by a competent authority. In addition technologists must strive to keep pace with ever advancing technology and the changes in practice that accompany these advances. Just because you learned to perform a procedure a certain way 5 or 10 years ago while you were in training does not mean that technique necessarily meets the current standard of care.
Five	The radiologic technologist assesses situations; exercises care, discretion and judgment; assumes responsibilities for professional decisions; and acts in the best interest of the patient.	Contrary to popular belief outside our career field, DI technologists are not "button pushers." We are trained professionals who possess a high degree of knowledge and skill in diagnostic medical imaging. As such, we must take responsibility for our behavior and the decisions we make in the course of our duties. Read patient histories, ask for clarification on unclear or seemingly illogical orders, feel free to make recommendations to the physician on the best way to accomplish the goals of the examination based on your personal experience. In short, be a thinker, not just a doer.
Six	The radiologic technologist acts as an agent through observation and communication to obtain pertinent information for the physician to aid in the diagnosis and treatment of the patient and recognizes that interpretation and diagnosis are outside the scope of practice for the profession.	Note and document appropriate information about the patient's behavior and condition when it may be of value to the radiologist in interpreting the examination. When you receive a radiographic consultation request from the emergency room for an ankle series and the only patient history provided is "R/O Fx," expound on that history for the benefit of the radiologist and, ultimately, the patient. Ask the patient how the ankle was injured. Indicate on the form the location and degree of any soft tissue swelling. However, realize that our role as technologists stops short of radiographic interpretation, regardless of how tempted you may be to reveal examination findings to the patient.
Seven	The radiologic technologist uses equipment and accessories, employs techniques and procedures, performs services in accordance with an accepted standard of practice, and demonstrates expertise in minimizing radiation exposure to the patient, self, and other members of the health care team.	Ultimately, the DI technologist is the one directly responsible for protecting all others from undue or excessive exposure to radiation in the performance of his or her duties. Do not allow other hospital personnel to ignore safe radiation practices. In most instances they do not have the requisite knowledge to determine potentially unsafe exposure conditions.
Eight	The radiologic technologist practices ethical conduct appropriate to the profession and protects the patient's right to quality radiologic technology care.	Always act as the patient's advocate and with his or her best interests in mind. The patient is depending on you to provide quality DI technology care—do not let him or her down.
Nine	The radiologic technologist respects confidences entrusted in the course of professional practice, respects the patient's right to privacy, and reveals confidential information only as required by law or to protect the welfare of the individual or the community.	Respect the patient's right to privacy in matters disclosed in the course of treatment unless there is a strong indication the patient intends to harm another person, violate the law, or is being abused. In these instances, notify the proper authorities.

Ten	The radiologic technologist continually strives to improve knowledge and skills by participating in continuing education and professional activities, sharing knowledge with colleagues, and investigating new aspects of professional practice.	Continue to learn throughout your DI career. There is so much to know in our field that you'll never master everything, but each professional article you read and each class you take will make you a more competent technologist who is better able to meet the needs of patients.
Eleven	The radiologic technologist refrains from the use of illegal drugs and/or any legally controlled substances which result in impairment of professional judgment and/or ability to practice radiologic technology with reasonable skill and safety to patients	As our job is to provide the best imaging for providers to ascertain the patients injuries when it comes to care. Having judgement clouded by external substances can lead to negative consequences for both the patient and the technologist.

7.4 Malpractice

In most scenarios the term *malpractice* is not normally used in connection with a DI technologist; however, there have been cases in which malpractice litigation included DI techs due to plaintiffs naming multiple defendants in an attempt to collect the largest amount of damages possible. As a result DI technologists have found themselves defending their actions in courts of law. For this reason we have developed this lesson on malpractice and the elements of a malpractice suit.

Medical malpractice

Medical malpractice is professional negligence by action or omission of a healthcare provider where treatment provided fails to meet the accepted standard of practice within the medical community and causes patient injury or fatality involving a medical error in some form. The term *malpractice* is based on the legal concept of negligence as it applies to professionals (including health care providers). *Negligence* may be defined as the failure to perform any act or service that would normally be performed by a reasonable person in similar circumstances, or the performance of an act or service that would not be performed by a reasonable person in similar circumstances. In short, the concept is based on reasonable conduct. It is a well-established principle that a medical provider has to use reasonable skill and care for the safety of his or her patients. In determining medical negligence, health care professionals are measured against their peers. If a doctor, nurse, or DI technologist does not perform to reasonable standards of competence and proficiency, and a patient is injured as a result, the professional may be found negligent. In other words not knowing your job, not being careful when caring for patients, or just not thinking about what is best for the patient can result in a lawsuit if any of those actions cause injury to the patient. With this in mind, you can minimize the risk of medicolegal problems by remembering and applying the Seven Cs of Malpractice Prevention listed below.

The Seven Cs of Malpractice Prevention	
Competence	Knowing and adhering to professional standards and maintaining professional competence reduced liability exposure.
Compliance	The compliance by health professionals with policies and procedures in the medical office and hospital avoids patient injuries and litigation.
Charting	Charting completely, consistently, and objectively can be the best defense against a malpractice claim.
Communication	Patient injuries resulting from malpractice cases can be avoided by improving communications among health care professionals.
Confidentiality	Protecting the confidentiality of medical information is a legal and ethical responsibility of health professionals.
Courtesy	A courteous attitude and demeanor can improve patient rapport and lessen the likelihood of lawsuits.
Carefulness	Personal injuries can occur unexpectedly on the premises and may lead to lawsuits.

In any medical malpractice suit, four elements must be proven by the party bringing the suit (the plaintiff)—duty, breach, proximate cause, and injury to the patient.

Duty

Every medical professional has a duty to provide *quality care*. The parameters of quality care and the scope of practice are defined by professional ethics, common law, statutes, and regulations. Whatever the accepted practice, it is generally referred to as *the standard of care*. First and foremost, the provider is required to acquire and maintain current diagnostic and technical skills. This means each medical professional must not only learn what is necessary for the basic qualifying certification but should also be aware of modern advancement and research in their field.

The element of duty in a malpractice suit means that the person (or people) being sued must have had a responsibility (duty) to care for the patient. To put it in perspective, if you are performing a radiographic examination of a patient, you have a duty to perform that examination within the accepted standards of practice for our profession. If the patient is injured as a result of your negligence (e.g., the patient falls off the X-ray table), then you may be sued because you had a duty to the patient; however, the technologist working in the next exposure room had no duty to your patient; therefore, he or she could not be sued.

The provider also has a duty to look for all relevant factors that could reasonably affect the general health of the patient. Much litigation focuses on the need for providers to understand how particular diagnostic techniques or treatment will affect the patient's health. Some of the more common concerns in the field of DI are possible allergies to contrast media and the effects of medical imaging on an unborn child.

Breach

The element of breach refers to a breach of duty to the patient. In other words the defendant must have performed his or her duty to the patient in a substandard manner. It is not enough simply to have an unsuccessful result from treatment; medicine, after all, is not an exact science. For a breach to exist, you must have in some way deviated from the accepted standards of care.

Proximate cause

Proximate cause of an injury means (1) the breach of the standard of care must actually cause the injury, and (2) the injury is one that could reasonably be anticipated when that particular breach occurs. For example in one case, the plaintiff's claim that he was left on the table under x-ray for over 3½ hours, although treatment should have lasted only 15 minutes, that he escaped only by rolling off the table onto the floor, and then hurt all over and was nervous and sick thereafter, sufficiently showed *resulting* injuries.

Injury

For malpractice to exist, there must be some element of injury resulting from the breach of duty. If you, for instance, removed a patient's C-spine collar before proper authorization from a physician, that is a breach of duty; however, if the patient received no injury as a result of your breach, there is no case for malpractice. Malpractice is a civil matter (civil liability), rather than a criminal matter. Civil matters involve violations of private rights for which monetary damages are sought as compensation. If there is no injury to the patient, there is no basis for collecting monetary damages.

Civil liability

Civil liability is a concept derived from a portion of law known as torts. Civil liability means everyone is liable for damage caused not only by acts of a person but also by negligence and carelessness. A *tort* is a civil wrongdoing that most times results in injury to a person, his or her property, or reputation in which the injured person has the right to monetary compensation. Civil liability (civil law) comes directly into play when plaintiffs look to be compensated for the act of wrongdoing against them. Many times, DI techs can get pulled into these cases in an attempt for the plaintiff to score a larger settlement as a result of a compensatory judgment.

Vicarious liability

In this concept of malpractice, vicarious liability refers to someone being held liable for negligence they did not directly commit. The most common form of vicarious liability is *respondeat superior*. The literal translation of this principle is "let the master respond." Its legal interpretation is that the supervisor (or employer) may be held responsible for the actions of his or her subordinates.
Supervisors are responsible for properly training their subordinates, establishing rules and guidelines governing subordinates' actions, and ensuring compliance with these rules. Failure to do so may result in the supervisor/employer being named as a codefendant in a civil suit. In the military, this concept generally applies only to the employer—that is, the US government.

Malpractice in the military

Because the United States cannot be sued for negligence, except to the extent that Congress has enacted legislation authorizing suit, the Federal Tort Claims Act (FTCA) is the primary mechanism used by most litigants suing the federal government. The FTCA allows suits for money for injury, property loss, or death caused by the act or failure to act of any government employee performing within the scope of employment.

As military personnel one of the benefits you receive is the relative freedom from being sued personally as a result of job performance; however, the freedom from suit is not absolute. People injured or just plain frustrated by the actions of government employees can and have filed lawsuits against those employees in their individual capacities.

The first issue in any malpractice suit is often to specifically identify the parties. Exactly who is the defendant? Answering that question may not be easy. The fact your name appears in the title of a case does not mean that you have been sued individually. Government employees may be sued in either their official capacity or personal capacity. The distinction is based on whether the plaintiff seeks damages from the government or the individual employee. If the target is the government, then the real defendant is the United States.

Once determined a government employee has been sued personally, a major concern is whether the government will provide legal representation. The short answer is yes, but there are exceptions.
Federal regulations provide that both current and former government employees may request representation by Justice Department attorneys. The employee request, together with an agency recommendation for approval or disapproval, is forwarded to the Justice Department. The request will be approved if the Justice Department determines that (1) the employee was acting within the scope of his or her employment at the time of the acts giving rise to the lawsuit and that (2) representation is considered to be in the best interests of the United States.

In determining "scope of employment," the question is: was the employee conducting government business at the time of the acts that instigated the lawsuit? Because of time constraints often imposed during the early stages of litigation, extensive fact-finding on the subject of scope of employment can be impractical. For that reason doubts are usually resolved in the employee's favor. The second criterion, the "best interests of the United States," is harder to define. As a practical matter, it is almost always in the government's interest to protect morale by defending federal employees who act within the scope of employment. Additionally, a clear interest can frequently be found in defending the process or integrity of the federal program involved. Even though an individual government employee may not have to pay any money as a result of a medical malpractice suit that does not mean there are no ramifications to the individuals involved. Whenever a medical malpractice claim is filed against the government, the medical treatment facility must identify each significantly involved provider. While the case is being reviewed, a standard–of– care determination is made for each provider. An adverse standard–of–care determination is reviewed by the Air Force Surgeon General and may result in a report to licensing or certifying agencies.

Informed consent

Because of the principle of autonomy, every adult patient must give informed consent before undergoing a medical procedure. Two exceptions to this rule include: (1) when a patient is unable to give consent due to a life-threatening emergency, and (2) in situations where the patient is not legally competent to give consent. In the latter case, consent must be provided by a parent or legal guardian. The process of

informed consent involves giving the patient enough information about the benefits and risks of the procedure, as well as alternative procedures, and the risk of refusing treatment altogether. The patient must receive enough information to be able to make an intelligent decision as to the course of his or her own medical treatment. Obviously the information must be provided in a manner that the patient is able to understand, which usually requires the physician to explain the procedure in layman's terms, and in some instances may require an interpreter.

While informed consent is technically required for any medical procedure, it does not always have to involve a signed consent form. Many medical procedures (such as a routine chest X-ray) are so common and benign that the mere fact the patient presents himself or herself in the DI department for the procedure implies consent; this type of consent is called *simple consent*. In these instances all that may be required is a brief description of the examination and a signed pregnancy questionnaire for females of childbearing age.

However, any type of invasive procedure or one that involves potentially serious risks to the patient, no matter how remote, requires formal documented informed consent. The consent process requires that a physician explain the procedure to the patient in the presence of a witness. The role of the witness in the informed consent process is designed to protect patients and their rights. By law a witness must be a minimum 18 years of age and must be of normal mental competency and capacity. The witness may be a stranger, family member, or friend of the patient, but the witness ***cannot*** be a member of the procedure team tasked with performing the DI examination, including the assisting DI technologist. If a member of the procedure team serves as the witness to informed consent, it may cause two undesirable perceptions: (1) a conflict of interest, and (2) a situation where the patient feels pressured to sign the consent form. If witnesses are not appropriate, their credibility may be argued in a court of law.

Legally physicians are the only people authorized to obtain consent from patients for medical procedures. After the procedure has been explained and the physician has answered any questions the patient may have, the physician fills out a consent form including the patient's name, the name of the procedure, a brief description of the procedure, the risks and benefits of the procedure, and the name of the person performing the procedure. The patient or the patient's authorized representative and the witness must sign the form, indicating the date and time that consent was provided.

The form used should be approved by the law consultant for the facility to ensure it meets the legal requirements of the local jurisdiction. As a DI technologist, you are not responsible for obtaining consent for DI procedures; however, *you are responsible* for ensuring informed consent has been *obtained and documented* before performing the exam. At a minimum verify the presence of a signed consent form in the patient's medical chart and ensure all of the patient's questions regarding the procedure have been answered.

Unit 8. Joint Review Committee on Education in Radiologic Technology

8A Standards for an Accredited Educational Program in Radiography..... 163
8.1 Importance of Accreditation.....163
8.2 Radiology Education Program Requirements..... 164

In the accreditation aspect of an educational program there are some standards that must be followed for the program to retain Joint Review Committee on Education in Radiologic Technology or known as JRCERT. Accreditation is a process of validation for all higher education programs ensuring they met the standards set by a peer review board comprised with faculty from various accredited colleges and universities.

8A Standards for an Accredited Educational Program in Radiography

8.1 Importance of Accreditation

Accreditation is important aspect when choosing your education career as colleges that have been through the accreditation process are more likely to offer degrees that employers and recruiters recognize. Companies evaluate a perspective employee by looking at the quality of education that they receive which translates into what you bring to the table. There are two types of educational accreditation, national and regional. National accredited schools are for-profits generally and offer the vocational, career, or technical based programs. Also, these schools focus on career or religious education and as the name states accredits courses throughout the entire country. Regionally accredited programs are mostly academically oriented, not for profit or state-owned institutions that are organized specific to their geographic region of the United States. They accredit post-secondary colleges along with both primary and secondary schools rather than the technical or career-based schools. There are six regional accreditation agencies that operate in the United States.

1. **Middle States Commission on Higher Education**, serving Delaware, the District of Columbia, Maryland, New Jersey, New York, Pennsylvania, Puerto Rico, and the U.S. Virgin Islands.
2. **New England Association of Schools and Colleges**, serving Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.
3. **North Central Association of Colleges and Schools**, serving Arizona, Arkansas, Colorado, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, New Mexico, North Dakota, Ohio, Oklahoma, South Dakota, West Virginia, Wisconsin, and Wyoming.
4. **Northwest Commission on Colleges and Universities**, serving Alaska, Idaho, Montana, Nevada, Oregon, Utah, and Washington.
5. **Southern Association of Colleges and Schools**, serving Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia.
6. **Western Association of Schools and Colleges**, serving California, Hawaii, Guam, and American Samoa.

The accrediting body from the list above that provides both Community College of the Air Force (CCAF) and the College of Allied Health Sciences (CAHS) at the Uniformed School of Health Sciences is the Southern Association of Colleges and Schools.

8.2 Radiology Education Program Requirements

The main accrediting body that is specific to Radiology program is called JRCERT as mentioned above and they have six standards that are designed to promote academic excellence, patient safety, and quality healthcare. These six standards assists the JRCERT in assuring the public that a program meets the specific quality standards to be called an accredited quality program through these assessments. The Six Standards are:

1. **Integrity:** The program demonstrates integrity in the following: representations to communities of interest and the public, pursuit of fair and equitable academic practices, and treatment of, and respect for, students, faculty, and staff.
2. **Resources:** The program has sufficient resources to support the quality and effectiveness of the educational process.
3. **Curriculum and Academic Practices:** The program's curriculum and academic practices prepare students for professional practice.
4. **Health and Safety:** The program's policies and procedures promote the health, safety, and optimal use of radiation for students, patients, and the general public.
5. **Assessment:** The program develops and implements a system of planning and evaluation of student learning and program effectiveness outcomes in support of its mission.
6. **Institutional/Programmatic Data:** The program complies with JRCERT policies, procedures, and STANDARDS to achieve and maintain specialized accreditation.

Once the program meets the above stated standards for the program a package would be submitted for Accreditation by the Chief Executive Officer or an officially designated representative of the sponsoring institution. Once approved and accreditation award for the program, it will be required to maintain the accreditation through below requirements.

a. Submitting the self-study report or a required progress report within a reasonable period of time, as determined by the JRCERT.

b. Agreeing to a reasonable site visit date before the end of the period for which accreditation was awarded.

c. Informing the JRCERT, within a reasonable period of time, of changes in the institutional or program officials, program director, clinical coordinator, full-time didactic faculty, and clinical instructor(s).

d. Paying JRCERT fees within a reasonable period of time.

e. Returning, by the established deadline, a completed Annual Report.

f. Returning, by the established deadline, any other information requested by the JRCERT.

When a program fails to meet the above administrative requirements for maintaining accreditation will lead to being placed on the Administrative Probationary Accreditation and could result in Withdrawal of Accreditation.

Unit 9. Diagnostic Imaging Regulating Authorities

9A U.S. Nuclear Regulatory Commission..... 166
9.1 Medical Uses of Nuclear Materials.....166
9.2 Regulation of Radioactive Materials.....167
9B Food and Drug Administration..... 168
9.3 Diagnostic Imaging Standards..... 168
9.4 Mammography regulations..... 169

AS future leaders within the Diagnostic Imaging Career field it is imperative that you have a general knowledge of the different regulatory authorities that affect different sections within the department. One of the biggest ones that can easily shut down a training or medical clinic is regulated by the Nuclear Regulatory Commission known from here on as NRC. Another one that regulates standards in the Diagnostic imaging sections along with primary focus in Mammography is the Food and Drug Administration or known commonly as the FDA. Lastly, the Joint Commission evaluates and regulates all medical facilities within the United States while ensuring that we are taking the proper safety precautions and utilizing the most up to date empirical data related to the demographics or disease based care.

9A U.S. Nuclear Regulatory Commission

The Nuclear Regulatory Commission's mission is to regulate the United States civilian utilization of the byproduct, source, and special nuclear materials to ensure adequate protection of those in the public with emphasis on the health and safety that it is utilized for while ensuring that the environment and those around it are secure and protected. As a Diagnostic Imaging professional it is important that you have an understanding behind the regulatory requirements for Nuclear Medicine and ensure that sources and radioactive pharmaceuticals are being handled properly and safely.

9.1 Medical Uses of Radioactive Materials

With the exception of the use of 1 microcurie carbon-14 urea radioactive drug capsules for in vivo diagnostic use in humans, all internal or external administrations of byproduct material or the radiation therefrom to human patients or human research subjects must be done in accordance with a medical use license (or authorization) issued pursuant to NRC's regulations in 10 CFR Part 35, "Medical Use." NRC licenses the medical use of byproduct materials in diagnostic devices in the practices of dentistry and podiatry. The medical use of plutonium in nuclear powered pacemakers is licensed pursuant to 10 CFR Part 70.

NRC (or the responsible Agreement State) also regulates the manufacture and distribution of these products (see Medical Products Distribution Licensee Toolkit). The Food and Drug Administration oversees the good practices in the manufacturing of radiopharmaceuticals, medical devices, and radiation-producing x-ray machines and accelerators. The states regulate the practices of medicine and pharmacy and administer programs associated with radiation-producing x-ray machines and accelerators.

NRC oversees medical uses of nuclear material through licensing, inspection, and enforcement programs. NRC issues medical use licenses to medical facilities and authorized physician users, develops guidance and regulations for use by licensees, and maintains a committee of medical experts to obtain advice about the use of byproduct materials in medicine. The Advisory Committee on the Medical Uses of Isotopes (ACMUI), comprised of physicians, scientists, and other health care professionals, meets twice a year to be briefed by, and provide advice to, the NRC staff on current initiatives in the medical uses of radioactive materials.

Types of Medical Use

Diagnostic medical use

Use of nuclear materials in radioactive uptake, dilution, excretion, imaging, or localization diagnostic clinical or research procedures. The metabolic or physiological properties of radiolabeled drugs are used to obtain medical information, and the radiation produced from sealed sources are used in diagnostic devices to image body parts or determine tissue density. Diagnostic medical use includes the use of certain portable imaging devices in dentistry and podiatry, as well as bone mineral analysis devices in podiatry.

Therapeutic medical use

Use of nuclear materials to deliver palliative (pain relieving) or therapeutic doses of radiation to specific tissues or body areas. Although most therapeutic uses of radiation involve the treatment of cancer, therapeutic doses may also be used to treat benign conditions such as the use of intervascular brachytherapy radiation to treat clogged blood vessels (restenosis).

Medical research use

Research involving human subjects using byproduct materials may only be performed if the licensee has a 10 CFR Part 35 medical use authorization. There are a wide variety of research uses of nuclear materials in human subjects. They include the use of nuclear materials in well-established nuclear medicine procedures to monitor a human research subject's response to a nonradioactive drug or device treatment as well as clinical trials to determine the safety or effectiveness of new radioactive drugs and devices. The particular medical research use must conform to requirements in 10 CFR Part 35 and the possession and medical use authorizations in the license.

Certain in vitro diagnostic tests

Some medical facilities or private physicians may only have regulated material in the form of prepackaged in vitro diagnostic test kits. These facilities and physicians do not have "medical use" licenses because these materials are not regulated pursuant to 10 CFR Part 35. The amount of regulated materials used in this form of in vitro diagnostic testing determines whether its use is authorized by a specific license issued pursuant to 10 CFR Part 30 or a general license pursuant to 10 CFR Part 31.11. See the General License Uses page for those materials generally licensed pursuant to 10 CFR 31.11.

9.2 Regulation of Radioactive Materials

The NRC is the Federal agency responsible protecting the health and safety of the public and the environment by licensing and regulating the civilian uses of the following radioactive materials:

1. Source material (uranium and thorium)
2. Special nuclear material (enriched uranium and plutonium)
3. Byproduct material (material that is made radioactive in a reactor, and residue from the milling of uranium and thorium)

The NRC regulates the use of these radioactive materials through Title 10, Part 20, of the *Code of Federal Regulations* (10 CFR Part 20), "Standards for Protection Against Radiation," which spells out the agency's requirements for the following aspects of radiation protection:

- Dose limits for radiation workers and members of the public
- Exposure limits for individual radionuclides
- Monitoring and labeling radioactive materials
- Posting signs in and around radiation areas
- Reporting the theft or loss of radioactive material
- Penalties for not complying with NRC regulations

Of more than 20,000 active source, byproduct, and special nuclear materials licenses in place in the United States, about a quarter are administered by the NRC, while the rest are administered by 37 Agreement States.

9B Food and Drug Administration

The Food and Drug Administration's mission is to protect and promote public health through the control and supervision of food safety, tobacco products, dietary supplements, prescription and over-the-counter pharmaceutical drugs, vaccines, biopharmaceuticals, blood transfusions, medical devices, electromagnetic radiation emitting devices, cosmetics, animal foods & feeds along with veterinary products. The FDA was formed on June 30 1906 with headquarters currently located on the White Oak Campus in Silver Spring Maryland.

9.3 Diagnostic Imaging Standards

FDA enforce the compliance of Title 21 of the Code of Federal Regulations(subchapter J, Radiologic Health) where medical equipment must be safe and evaluated to ensure quality standards and all parts of the radiation emitting device are performing as directed and designed in the submission to the FDA prior to market submission. Patient radiation dose is considered to be optimized when images of adequate quality for the desired clinical task are produced with the lowest amount of radiation considered to be reasonably necessary. A facility can use its quality assurance (QA) program to optimize radiation dose for each kind of X-ray imaging exam, procedure, and medical imaging task it performs. Patient size is an important factor to consider in optimization, as larger patients generally require a higher radiation dose than smaller patients to generate images of the same quality.

Note that there may be a range of optimized exposure settings, depending on the capabilities of the imaging equipment and the image quality requirements of the physician. Radiation exposure may be optimized properly for the same exam and patient size at two facilities (or on two different models of imaging equipment) even though the radiation exposures are not identical. One important aspect of a QA program entails routine and systematic monitoring of radiation dose and implementation of follow-up actions when doses are considered to be anomalously high (or low).

Flouroscopy is also regulated by the FDA as it is using a radiation emitting medical device to assist providers in diagnosis of the patient's disease. Concerns about radiation-related injuries to patients have increased since the mid-1990s due to the increasing complexity and radiation dose of some fluoroscopically-guided interventions. In 2005, the FDA revised the radiation safety performance standard for diagnostic X-ray systems, including fluoroscopy to improve the display of dose information to the physicians (21 CFR 1020.32). The FDA developed Questions and Answers about the Radiation Safety Performance Standard for Diagnostic X-ray Systems. The increase in medical radiation exposure was highlighted by the National Council on Radiation Protection and Measurements (NCRP) Report 160. (2009). In 2010 the FDA Center for Devices and Radiological Health (CDRH) launched an Initiative to Reduce Unnecessary Radiation Exposure from Medical Imaging. As part of this initiative, the FDA held a public meeting on ways to improve devices to reduce unnecessary radiation exposure to help the agency decide on any new targeted requirements for manufacturers of CT and fluoroscopic devices. The new requirements that could be built into fluoroscopy equipment could facilitate implementation of the principles of justification and optimization in the protection of patients undergoing radiological examinations. These principles, implemented through a clinical facility's quality assurance program, are fundamental to radiation protection.

CT imaging systems are regulated by the FDA under two statutes. They are regulated as radiation-emitting electronic products under the Radiation Control for Health and Safety Act and as medical devices under the Medical Device Amendments to the Food, Drug, and Cosmetic Act. The regulations implemented under these laws place controls or requirements on the manufacturers of the CT systems rather than on the users of the CT systems. Through the Medical Device Amendments, FDA is responsible for assuring the safety and effectiveness of medical devices. Medical devices are classified into one of three classes, based on the risk associated with the device and controls needed to assure safety and effectiveness. CT imaging systems are Class II medical devices. This means they are subject to manufacture registration and listing, premarket notification to FDA, quality system regulations along with both general and specific controls.

The use of CT systems for medical purposes is controlled, in the U.S., largely at the State and Local government levels. States control the practice of medicine, license medical practitioners and typically license or register facilities operating medical x-ray systems such as CT systems. Some States have established regulations regarding the operation of screening programs that employ ionizing radiation.

9.4 Mammography regulations

FDA manages the mammography standardization of care throughout the United States via the MQSA or otherwise known as the Mammography Quality Standards Act. MQSA guidance interprets MQSA regulations and addresses compliance issues. It is meant to help facilities comply with MQSA Final Regulations, but it does not have the force of law. If facilities follow the guidance developed for a specific MQSA requirement, they will be considered to have met the requirement. However, as guidance is intended to guide, not mandate, facilities may identify other ways of meeting MQSA requirements.

In contrast, the MQSA final regulations are national quality standards for mammography services. Written by FDA, these regulations are based on MQSA of 1992 and MQSA Reauthorization of 1998. They have the force of law. Words such as "shall," "must," and "require" are used when stating statutory or regulatory requirements.

The MQSA was passed back in 1992 to assure high-quality mammography for early breast cancer detection, which can lead to early treatment, a range of treatment options leading to an increased chance of survival. Congress enacted the MQSA on October 7, 1992. Responsibility for implementing MQSA was delegated to FDA by the Secretary of the U.S. Department of Health and Human Services (DHHS) on June 2, 1993. The act became effective October 1, 1994, and requires all mammography facilities to meet quality standards as promulgated by the Food and Drug Administration (FDA). The FDA published interim regulations on December 21, 1993, as a mechanism for accrediting and certifying of facilities by October 1, 1994. Under this law there were four different requirements that mammography facilities must follow:

a. Be accredited by an FDA-approved accreditation body

b. Be certified by FDA, its State, as meeting the standards

c. Undergo an annual MQSA inspection

d. Prominently display the certificate issued by the agency

Unit 10. Nuclear Medicine

10A Federal Regulations and Radiation Protection..... 170
10.1 Department of Transportation..... 170
10.2 Regulation of Radioactive Materials..... 171
10B Generators and Radiopharmaceutical Shielding..... 172
10.3 99Mo/99mTc Generator and Radiopharmaceuticals..... 172
10.4 Radiopharmaceutical Shielding..... 172
10C Patient Examinations..... 173
10.5 Routine Examinations..... 173
10.6 On-Call Examinations..... 174

Nuclear medicine technologist engage in radiation protection activities nearly every day. Prevention of unnecessary radiation exposure to oneself, co-workers, patients, and the general public is a routine part in nuclear medicine operations. The Nuclear Regulatory Commission (NRC) and agreement states, U.S. Department of Transportation (DOT), and the Federal Drug Administration (FDA) are responsible for the safe production, transportation, and effectiveness of radiopharmaceuticals.

10A Nuclear Regulatory Commission and State Agencies

The NRC regulates the purchase, receipt, use, and disposal of radioactive materials. In nuclear medicine radionuclides are produced by a common rector and/or by common accelerator. Some states, known as agreement states, will accept responsibility of regulating all radioactive materials used by the licensee. The regulation must be no less strict than the NRC. All Federal facilities within agreement states are regulated by the NRC, such as the Veterans Affairs hospital and military installations.

10.1 Department of Transportation

The U.S. Department of Transportation (DOT) controls the packaging and interstate movement of radioactive materials. Safeguards must be put in place to adequately contain both the material and the radiation it emits. There are two type of classifications to ship radioactive material, Type A and Type B. Type A is used in nuclear medicine and is designed to survive normal transportation and minor accidents. Type A packages include cardboard boxes, wooden crates, and metal drums. Shipping labels will be on each package according to one of three categories based on the measured dose rate, in milliroentgens per hour (mR/hr), at the package surface, and at 1 meter (m) from the surface. The label must also specify the radionuclide and the amount of radioactivity contained in the package (Figure 1.1).

Figure 1.1 Transportation labels for radioactive material.

10.2 Regulation of Radioactive Materials

Food and Drug Administration

The U.S. Food and Drug Administration (FDA) regulates and monitors the manufacture, distribution, safety, and effectiveness of radiopharmaceuticals. All radiopharmaceuticals must be submitted for review by the FDA before it issues a new drug authorization (NDA). All drugs under investigation for the FDA will be called investigational new drug (IND) and may only be used in controlled conditions. A facility can only use radionuclides listed on the license and FDA approved which demonstrates the safety and effectiveness with reasonable assurance.

Radiation Areas

The NRC defines radiation areas as restricted and unrestricted areas. Unrestricted area is one in which access in not limited or under the direct control of the licensee. In unrestricted areas radiation levels must be less than 0.02 mSv (2 mRem) in any one hour. If the area exceeds 0.02 mSv (2 mRem), then the area is considered restricted and access must be limited. The NRC requires posted specific signs depending on the radiation levels present. The sign must have the magenta or black trefoil radiation symbol on a yellow background with one of the following phrases; Caution: radioactive materials, Caution: radiation area, Caution: high radiation area, Caution: very high radiation area (Figure 1.2).

Figure 1.2

Receipt of Radioactive Materials

All shipments of radioactive material are required to display radioactive label by the NRC (refer back to Figure 1.1) be checked for contamination and visually inspected for damage or to see if they are wet. A survey meter must be used and all packages must be monitored within 3 hours of receipt during regular working hours or, if delivered after hours, within 3 hours of the time the department reopens.

A radionuclide generator is used to provide a convenient source of short-lived radionuclide such as technetium-99m (99mTc). Most radiopharmaceuticals are compounded onsite by a nuclear medicine technologist using 99mTc. This section will cover the basics of a 99Mo/99mTc Generator as well as the principles of unit dose preparation.

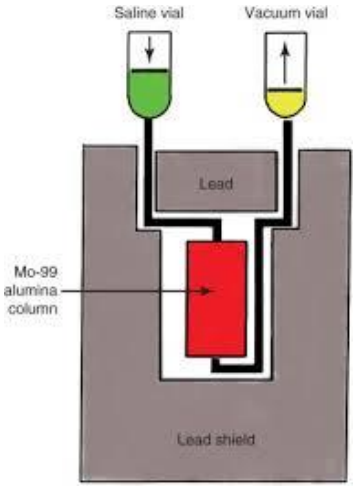
10B Generators and Radiopharmaceutical shielding

10.3 99Mo/99mTc Generator and Radiopharmaceuticals

In a radionuclide generator, a longer-lived radionuclide, called the parent, decays to a shorter-lived radionuclide, called the daughter. The daughter can be removed periodically as it is replenished by decay of the parent. A 99Mo/99mTc generator is such a system and through commercially development can supply a sterile, shielded, automatically operated device.

A 99Mo/99mTc generator is designated as either “wet” or “dry” column type. A wet column generator contains a supply of sterile saline within the generator itself. To elute this type of generator, the technologist chooses the appropriate size collection vial (5, 10, 20, 30 mL) to obtain the volume and activity concentration desired. A dry column generator requires that saline be added to the column for each elution (figure 1.3)

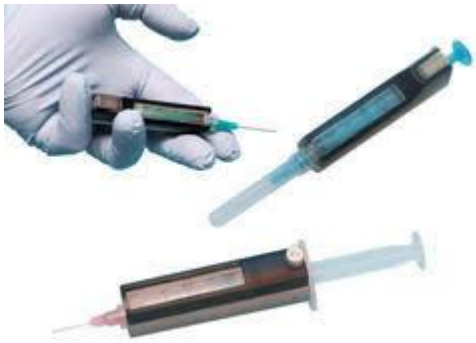
Figure 1.3 Cross-section of a radionuclide generator



10.4 Radiopharmaceutical Shielding

Radioactive materials should be handled with clamps, forceps, or other holding device, never picked up directly by fingers because high doses may result. Lead shielding is sufficient for all radiopharmaceuticals labeled with 99mTc. In nuclear medicine there are two general types of shielding; bench top shields, and syringe or vial shields. Syringe shields should be used when preparing a radiopharmaceutical kit or performing a radiopharmaceutical injection unless the use of the shield is contraindicated for that patient (Figure 1.4).

Figure 1.4 Syringe shield



10C Patient Examinations

10.5 Routine Examinations

For a nuclear medicine exam, the patient is given a small amount of radioisotope, either orally or by injection, to enhance the visualization of selected organs or vascular structures. Once the radioisotope has accumulated in the region of the body under study, the technologist positions a camera close to the region and begins the scanning process. The images are viewed on a computer monitor after the examination by a Radiologist who will communicate the results to the ordering physician. How to prepare for a nuclear medicine exam varies because each study is different, the following section will cover two routine examinations as well as 3 common on-call studies.

Myocardial Perfusion Imaging

Myocardial imaging can be used to demonstrate myocardial ischemia, myocardial infraction (MI), and hibernating and stunned myocardium. Myocardial imaging can be performed with thallium-201 (201Tl)-thallous chloride, technetium-99m (99mTc)-sestamibi, 99mTc-tetrofosmin, rubidium-82 (82Rb)-chloride, nitrogen-13, 13N-ammonia, and fluorine-18 (18F)-fluorodeoxyglucose (FDG).

Clinical indications for performing myocardial perfusion imaging include:

1. Diagnosis of CAD (presence, location, extent)
2. Assessment of coronary artery stenosis
3. Assessment of myocardial viability
4. Prognosis post-MI
5. Monitoring of the effects of treatment

Patient History and Preparation

Patients should be hemodynamically stable for at least 48 hours before undergoing the exam. The patient should fast for at least 4 hours before, and collect pertinent patient information such as family history, lifestyle, and recent symptom, previous history of heart disease or hypertension and current medications.

Myocardial perfusion single-photon emission computed tomography (SPECT) imaging can be acquired over 180 degree or 360 degree, using a circular or noncircular orbit with continuation or step-and-shoot motion (Figure 1.5). The patient is positioned with either both arms or only the left arm up over the head. The patient should be made as comfortable as possible in an effort to minimize motion resulted from discomfort. The technologist should explain the importance of remain still to the patient before the acquisition begins and should be closely monitored for motion during the acquisition.

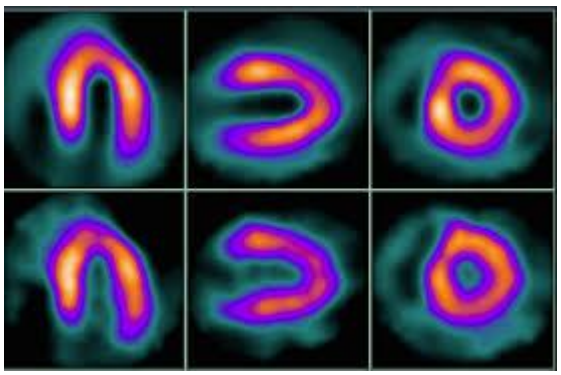


Figure 1.5 SPECT Myocardial Perfusion Imaging

Bone Imaging

Bone imaging is one of the most ordered procedures in nuclear medicine. It is referred to as a very sensitive scan but not specific. A good patient history to rule out recent deep bruises, trauma, recent surgery, etc., can show as positive results on the scan to increase the specificity.

Clinical indications for performing bone imaging include:

1. Staging of malignant disease
2. Evaluation of primary bone neoplasm
3. Diagnosis of skeletal inflammatory disease
4. Evaluation of skeletal pain of unknown cause
5. Determination of bone viability when blood supply to the area is in question
6. Detection of occult fractures not demonstrated radiographically

Patient History and Preparation

Collecting relevant medical history should include patients diagnosis, if known; any recent injuries and/or surgeries; previous injuries to bones; medications (some medications can alter tracer distribution); serum alkaline phosphate levels; prostate-specific antigen levels for prostate cancer patients; and therapy that may affect results (radiation, chemotherapy).

Patients are encouraged to drink two or more 8 ounces of water and to void frequently. Hydration helps clear the tracer from the body and frequent voiding decreases the bladder's exposure to radiation.

Imaging can begin 2 hours after the tracer administration. The patient should void before imaging due to large amount of radioactive urine in the bladder can obscure bony structures of the pelvis. Place the patient in a supine or prone position and place the detector (camera head) as close to the area being imaged minimizing the patient-detector distance. Images can be obtained by spot-image technique, whole-body technique, or single-photon emission computed tomography (SPECT). Below is an image of a whole-body bone scan.

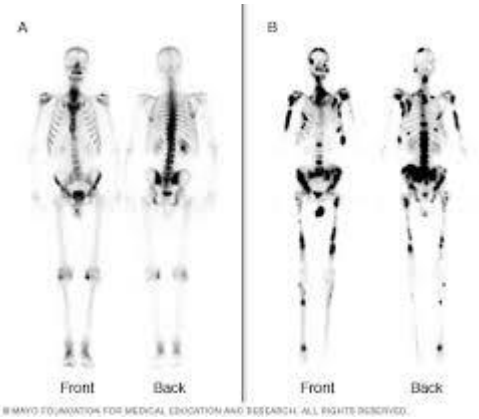


Image A is a bone scan with normal distribution of the radiopharmaceutical. Image B is a patient with metastatic disease demonstrating abnormal distribution.

10.6 On-Call Examinations

Ventilation and Perfusion Imaging

The most common clinical indication for lung imaging is evaluation of pulmonary emboli (PE), including initial screening to rule out PE or follow-up imaging to evaluate response to therapy. Diagnosing a PE is the primary use of radionuclide lung imaging. The technique is used less frequently for preoperative evaluation s and evaluation of lung transplant and right-to-left cardia shunts.

Relevant medical history includes the following:

1. Factors predisposing the patient to PE-recent surgery, cancer, chronic obstructive pulmonary disease, immobility, obesity
2. Symptoms of PE-shortness of breath, chest pain, fever (these signs and symptoms are not specific to PE and can occur in a variety of conditions)
3. Recent chest radiograph findings-needed for interpretation of the lung image; the chest radiograph should be obtained within 24 hours of imaging or within 1 hour for patients whose signs and symptoms have changed
4. Results of diagnostic tests for deep vein thrombosis (DVT)

There are no patient preparation requirements for this examination.

The examination is performed in two stages, perfusion and ventilation, and requires two different technical considerations. Perfusion imaging is used to demonstrate blood flow to the lungs, while ventilation imaging demonstrates the flow of air into and out of the lungs.

When performing perfusion imaging the patient should be placed in the supine position for injection of the radiopharmaceutical. Imaging can begin immediately after tracer administration. Static images are acquired for the following anatomic views: anterior, posterior, laterals, and posterior or anterior obliques (See figure 1.6)

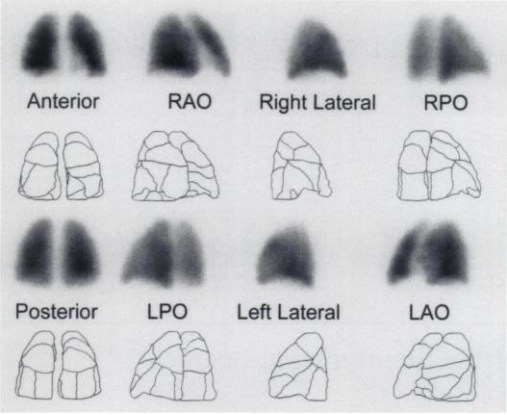


Figure 1.6 low-probability lung perfusion scan showing all eight views.

Ventilation imaging requires the radiopharmaceutical be administered through inhalation. The patient breaths through a face mask or mouthpiece attached to a spirometry system to inhale radioactive gas. The standard view is the posterior, because more lung area is exposed in this projection. Other views may be appropriate when a specific segment of the lung is of interest and would be better visualized with a different projection. The following image are obtained: single breath, acquired during initial inhalation of the gas; wash-in or equilibrium, collected whole the gas distribute throughout the aerated portion of the lungs; and washout, taken while the gas is cleared from the lungs (Figure 1.7).

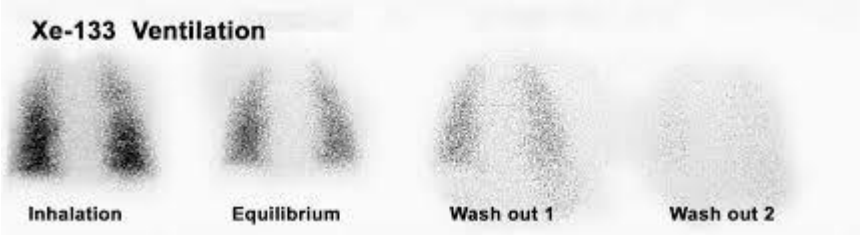


Figure 1.7 Ventilation images obtained by using radioxenon

The gastrointestinal (GI) system structure and function can assessed using a variety of nuclear medicine procedures. Hepatobiliary imaging and localization of GI bleeding are common exams for on-call studies.

Hepatobiliary Imaging

The gallbladder stores bile which is released into the small intestines to aid in digestion. Bile is a product of erythrocyte breakdown and hepatocyte metabolism. It is used to emulsify or breakdown fats, stimulate peristalsis, and enhance absorption of fatty acids. Hepatobiliary imaging is used to evaluate the functionality of the gall bladder.

Clinical indications for Performing Hepatobiliary Imaging:

1. Evaluation of patients experiencing upper abdominal pain is needed to rule out cystic duct obstruction (acute cholecystitis).
2. In the case of jaundice, hepatobiliary imaging can help differentiate the cause by ruling out obstruction of the biliary tract.
3. Delineate bile drainage and reflux following surgery.
4. Identify defects as normal or abnormal variations of the biliary system.
5. Pediatric applications include the detection of choledochal cysts, biliary atresia, or other congenital abnormalities of the biliary tree.

Patient History and Preparation

1. Patient diagnosis and/or clinical indication for the imaging procedure
2. Serum bilirubin level
3. Previous gallbladder surgery or other GI surgery
4. Medications that may affect the transit of the tracer through the biliary tract
5. Time and content of last meal and list of what was eaten

Narcotics, sedatives, or other drugs that relax the sphincter of Oddi should be discontinued for 6-12 hours before hepatobiliary imaging. Patients should fast for 2-4 hours before tracer administration, but should not fast for more than 24 hours.

The patient is placed in a supine position beneath the detector, so the liver appears in the upper left corner of the field of view. Imaging begins immediately after the tracer is administered intravenously. Sequential images are acquired for 45-60 min (figure 1.7). Anterior oblique or right lateral projections may be useful for delineating bowel activity or other structures such as the kidneys. If the gallbladder or biliary ducts are not visualized by 1 hr after tracer administration, delayed images should be obtained at intervals up to 24 hours, as necessary.

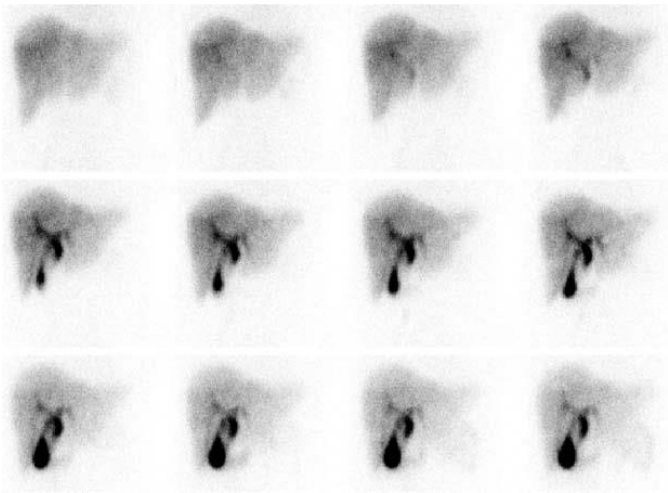


Figure 1.7 Normal hepatobiliary scan 5min/image

GI Bleed Localization

Detection and localization of the site of GI bleeding can be accomplished by the use of two radiopharmaceuticals. Labeled red blood cells (RBC) are the better choice when bleeding is intermittent, because

the tracer remains in the blood pool for a long period, which allows for delayed imaging.

Clinical indications for Performing Localization of Gastrointestinal Bleeding:

1. Investigation of GI hemorrhage
2. Detection and localization of GI bleeding

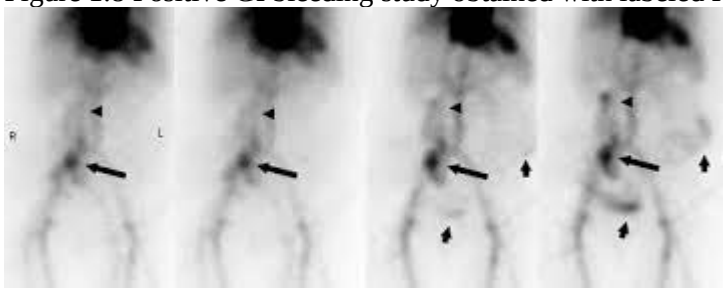
The common causes of lower GI bleeding in adults are diverticular disease, angiodysplasia, neoplasms, and inflammatory bowel disease.

Patient History and Preparation

There are no special preparation for this study. The presence of contrast material from a CT or radiographic procedure of the abdomen may cause attenuation, so the patient should wait several days after having a contrast study.

The patient is placed under the detector in the supine position with the abdomen centered in the field of view. Dynamic sequential images are acquired as the tracer is administered. Images are acquired for 60-90 min, delayed images may be obtained at intervals. Progressive tracer accumulation in other areas indicates a bleeding site (Figure 1.8).

Figure 1.8 Positive GI bleeding study obtained with labeled RBC



Unit 11. Diagnostic Medical Sonography

11A Patient Examinations..... 178
11.1 Abdominal Ultrasound..... 178
11.2 Small Parts Exams..... 179
11.3 Vascular Studies..... 180
11.4 OB/GYN..... 181
11B Cidex/Trophon..... 182

Diagnostic medical sonography utilizing specialized equipment to generate images utilized for assessing and diagnosing various medical conditions. Most associations with this profession is with performing Obstetrical anatomy scans for women who are pregnant. But as this section will go into further detail, there are many different examinations that can be performed using sound waves ranging from the neonatal head to cardiovascular exams in the ankle. This chapter will provide a basic understanding on the examinations performed in the Sonography department to include patient preparation and the sonographic applications performed by the medical device.

11A Patient Examinations

11.1 Abdominal Ultrasound

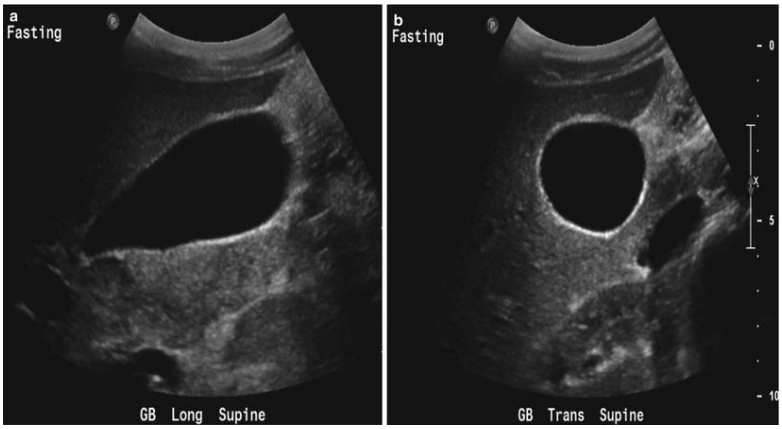
Abdominal ultrasounds cover both vascular and non-vascular organs covering the below anatomical organs. The patient preparations for the abdominal examinations reduces the amount of internal gas created by peristalsis along with ensuring that organs don't shrink or compress due to excretions i.e. gallbladder. Other patient directions to drink water within 1 hour of examination for the Kidney examination allows the sonographer to see the ureteral jets in the bladder.

1. ***Aorta***
    a. Patient Preparation: Nothing by mouth (NPO) after midnight the day prior to the scheduled exam.
    b. Sonographic Applications: The abdominal aorta is primarily evaluated to detect aneurysms and stenosis. An AP Aorta measurement greater than 3 cm suggests an aneurysm, which come several shapes: fusiform and saccular.
2. ***Liver***
    a. Patient Preparation: Nothing by mouth (NPO) after midnight the day prior to the scheduled exam.
    b. Sonographic Applications: Liver ultrasounds are extremely common and have numerous reasons to be performed. In some cases liver enlargement may be suspected, and depending on clinical assessments liver masses, benign or malignant, as well as, abscesses could be indicated.

    Less common indications for liver sonography would be for pleural effusions, seen in the supradiaphragmatic region, and ascites. Ascites may be seen as fluid collections in the subcapsular or intraperitoneal spaces surrounding the liver.

3. ***Gall Bladder/Common Bile Duct***
    a. Patient Preparation: Nothing by mouth (NPO) after midnight the day prior to the scheduled exam.

b. Sonographic Applications: Gallbladder and biliary tract ultrasounds are often performed in conjunction with other abdominal organs based on clinical assessment. Ultrasounds of the gallbladder are performed to assess the condition of the GB, as well as, any kind of GB mass to include possible adjacent liver masses. Another important aspect of the exam is to determine the presence of stones in the GB (cholelithiasis) or the biliary ductal system (choledocholithiasis).



4. Pancreas

a. Patient Preparation: Nothing by mouth (NPO) after midnight the day prior to the scheduled exam.
b. Sonographic Applications: Another vital organ in the abdomen, the pancreas, is a gland that has both exocrine and endocrine functions. The pancreas aids in the digestion of food and the metabolism of sugar in the bloodstream. Ultrasounds of the pancreas are performed to identify masses, assess for pseudocysts, and aids in the diagnosis and follow-up of acute and chronic pancreatitis.

5. Kidney/bladder

a. Patient Preparation: Nothing by mouth (NPO) after midnight the day prior to the scheduled exam. Have the patient drink 24 ounces of water 1 hours prior to the appointment time.
b. Sonographic Applications: Given the complexity of the urinary system there are many indications for performing an ultrasound of the kidneys. Some of the most common applications for ultrasound are: detections and composition of renal masses, urinary system obstruction, renal abscess, bladder masses, renal transplantation, Doppler evaluation for renal artery stenosis, and ultrasound guided biopsy.

6. Spleen

a. Patient Preparation: Nothing by mouth (NPO) after midnight the day prior to the scheduled exam.
b. Sonographic Applications: Examinations of the spleen are indicated for history of trauma to rule out hemorrhage, for suspected enlargement, or to rule out masses.

11.2 Small Parts Exams

Small parts ultrasounds cover range from breast to testicular ultrasounds. The patient preparations for theses examinations is nothing specific. These examinations can be performed to evaluate blood flow or torsion in testicular examinations to cancer in the breasts.

7. Breast

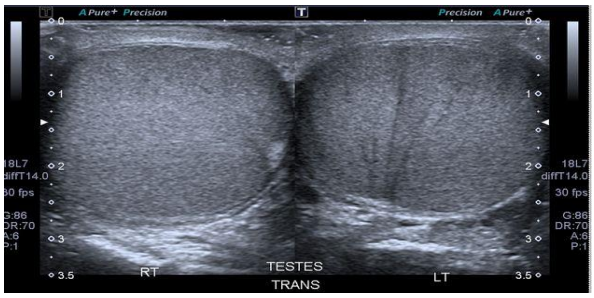
a. Patient preparation: No preparation is necessary
b. Sonographic Applications: Breast ultrasounds are an extremely sensitive exam for patients. Proper diagnosis is critical. Ultrasound is often used in conjunction with mammography to ensure the utmost accuracy. The most common application is to determine whether the identified mass is solid or cystic. Additionally, the presence of large collections of calcifications may be determined sonographically, however, each collection or individual calcification must be

fairly large. Lastly, invasive procedures are helpful in localizing masses for cyst aspiration and core biopsies.

8. Thyroid

a. No Preparation needed
b. Sonographic Applications: Thyroid ultrasounds are commonly ordered for several different reasons. Typically issues with a patient's thyroid gland are discovered through lab work or a palpable neck mass. Ultrasound is used to monitor and determine size, location, and appearance of thyroid masses, detecting an occult carcinoma, performing ultrasound guided biopsies, and the overall of appearance of non-properly functioning glands.

9. Testicles

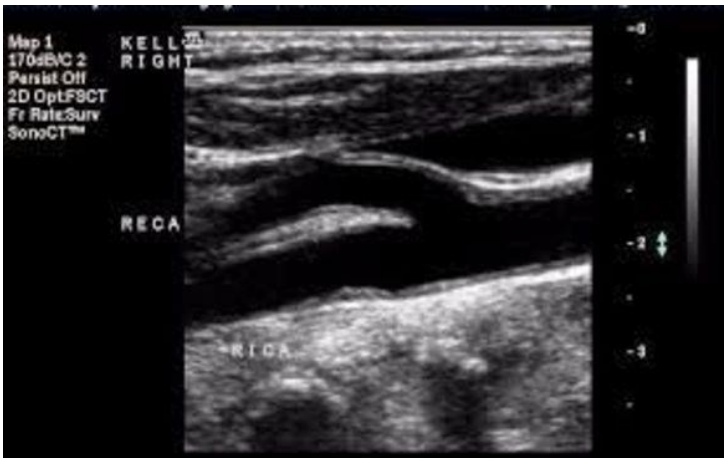


a. No patient preparation required
b. Sonographic Applications:
    i. Testicular size
    ii. Presence of a mass
    iii. Evaluation of scrotal trauma
    iv. Blood flow detection to rule out torsion
    v. Locate undescended testicles
c. Scrotal Trauma/Emergency
    i. Primary goal of U/S is to determine if a rupture of the testis has occurred
    ii. Surgery performed w/n 72 hrs can save 90% of ruptured testicles.
    iii. Torsion – occlusion of venous and arterial blood flow to the testicle.

11.3 Vascular Studies

Vascular ultrasounds focus on the cardiovascular system and the flow of blood throughout the body. These exams range from the carotids to the DVT or known as Deep Venous Thrombosis studies on the extremities. There is no preparation for these studies but require focus and time to ensure differentiation from thrombus and inadequate grey scale.

10. Carotid



a. No Preparation needed
b. Sonographic Applications: Carotid ultrasounds have many applications. The most urgent of those are evaluating patients for strokes or "classic" transient ischemic attacks (TIA). More routine exams include evaluation for carotid stenosis, transient monocular blindness, asymptomatic cervical bruit, follow-up progression of known atherosclerotic disease, post endarterectomy, and pre-op for major surgeries.

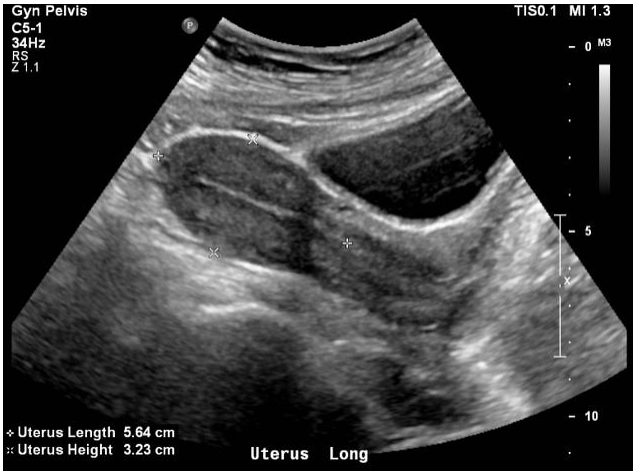
11. LE/UE DVT

a. No preparation needed.
b. Sonographic Applications: The presence of a blood clot in the leg could be threatening if it dislodges and travels cephalad to occlude the pulmonary artery, which is called a pulmonary embolism. The accuracy of a deep venous thrombosis (DVT) study has been reported greater than 90%. The usual symptoms pain (ischemia) and swelling (edema).

11.4 OB/GYN

Obstetrical and Gynecology ultrasounds cover all anatomy within the pelvis and the development process of fetus' within the womb. Patient preparation for all these require drinking of water for specific reasons within each examination breakdown. These exams performed mainly to evaluate for abnormalities aging from torsion to genetic abnormalities i.e. Trisomy 18 and 21 in obstetrics.

12. Pelvis



a. Patient preparation: The patient must drink 32 oz. of water and have the water completely finished one hour prior to the exam time. The patient should not void until the exam is done.
b. Sonographic Applications: The pelvic ultrasound is frequently requested to assess the size and shape of the uterus and ovaries. Further evaluation is performed when uterine and ovarian masses are suspected. Additional applications of pelvic sonography include but are not limited to the detection and placement of an intrauterine contraceptive device (IUD), managing infertility patients through frequent monitoring of follicular development, and using color and spectral Doppler for assessing the vasculature of the ovaries.

13. 1st Trimester OB

a. Patient preparation: The patient must drink 32 oz. of water and have the water completely finished one hour prior to the exam time. The patient should not void until the exam is done
b. Sonographic Applications: Often 1st trimester ultrasounds are performed due to vaginal bleeding, pain, or trauma. Ultrasounds help determine gestational viability or to rule out an ectopic pregnancy and abruption in the case of vaginal bleeding and/or pain. 1st Trimester ultrasounds are also performed to confirm gestational age, fetal well-being, patients with a history of miscarriage, or if a patient has a history of multiple gestations.

14. 2nd/3rd Trimester OB

a. Patient preparation: The patient must drink 32 oz. of water and have the water completely finished one hour prior to the exam time. The patient should not void until the exam is done
b. Sonographic Applications: All obstetrical ultrasounds assess fetal well-being to include, as well as, evaluating the placenta, amniotic fluid, cervix, and adnexal regions. During the 2nd and 3rd trimester, ultrasounds will also be performed to assess fetal age and weight, and to assess fetal growth.
    i. Sonographic Applications for multiple gestations: Sonographic evaluation is very complicated with multiple pregnancies, especially when the fetus is in the third trimester. Sonographers must try to determine the number and location of the fetuses, placentas, and amniotic sacs. During the 3rd trimester, it is almost impossible to evaluate the placentas if they are near the same locations.

11B Cidex/Trophon

A. There are exams in Ultrasound, such as the endovaginal sonogram, that require disinfection of the transducers following completion. In the Air Force there are two methods used to disinfect our transducers: (a) Disinfecting solution called Cidex (b) Trophon Disinfecting Unit

a. **CIDEX**® can be used to disinfect a wide range of medical instruments, made of aluminum, brass, copper, stainless steel, plastics and elastomers. **Cidex** is a 2.4% alkaline glutaraldehyde**solution** that destroys 99.8% of against bacteria, mycobacteria, viruses and fungi.

b. **Nanosonics Trophon** Disinfecting Unit:

Trophon uses a proprietary disinfectant liquid with 35% hydrogen peroxide chemistry to achieve effective high level disinfection of the entire ultrasound probe including the shaft and handle. After **use**, the disinfectant breaks down primarily into harmless, environmentally friendly water and oxygen. The compact design means it can be located at the point of care, helping to improve patient workflow, while the fully enclosed system helps protect both patients and staff by limiting exposure to harmful disinfectant chemicals.

Unit 12. Magnetic Resonance Imaging (MRI)

12A Equipment Safety and Zones..... 183
12.1 Safety Training and Environment Dangers…..... 183
12.2 Safety Zones..... 184
12.3 MRI System..... 185
12B Patient Examinations..... 187
12.4 Cranium, Neck and Spine..... 187
12.5 Abdomen and Thorax..... 188
12.7 Extremities..... 188

MRI utilizes specialized equipment to generate images utilized for assessing and diagnosing various medical conditions. This chapter will provide a basic understanding on the examinations performed in the MRI department to include safety practices, equipment, and the MRI examination basics to include positioning and equipment.

12A Equipment Safety and Zones

Due to potential risks in the Magnetic Resonance Imaging environment, attention to safety practices and procedures is mandatory. These risks can impact the patients, health care professional, family members interacting with the exam, and others. MRI Safety should be educated in every Military Treatment Facility. This is why there are MRI level 1 and 2 safety training sessions that are conducted in accordance with the nationally credentialing body's requirements i.e. Joint Commission, ACR, etc. Level 1 training is conducted to educate personnel in the treatment facility to ensure that they are not a danger to themselves or others in a MR environment. Level 2 training is conducted for personnel to educate on more extensive aspects of MR safety issues.

12.1 Safety Training and Environment Dangers

There are implants and physical conditions you will encounter that have different contraindications that can delay or prevent a MRI examination. Some of these include but are not limited to: electrically, magnetically or mechanically activated devices such as insulin pump, bio stimulators, neuro stimulators, cochlear implants, hearing aids, intracranial aneurysm clips (unless made of titanium), pregnancy (risk vs benefit ratio to be assessed), ferromagnetic surgical clips or staples, metallic foreign bodies in the eye, metal shrapnel and or bullets in the human anatomy. Understanding the importance for MRI screening is one of the most important aspects of working within a MRI environment.

RF Irradiation/Projectile Hazards/Quenching a Magnet

RF Irradiation/Thermal Burns

MRI uses non-ionizing radiation. The Radiofrequency induction in MRI has significantly lower energy than found in radiography or CT, but has safety hazard associations such as patient heating/burns. Radiofrequency induced heating burns, or thermal burns, can occur where naturally occurring loops are formed by the anatomical position in the magnet. If skin is in contact with other skin (hands on legs with skin to skin, or if the heels are resting against each other), with the side of the magnet, or with the looping of connecting cables from an imaging coil, the radiofrequencies can cause a "biological circuit" through which induced current may flow. Patient positioning and providing appropriate padding to insulate these body areas, and breaking any naturally occurring conductive loops, is beneficial to preventing the RF Irradiation/thermal burns.

Projectile Hazards

One serious danger towards patient safety that we will talk about is projectile hazards in the static field. A projectile hazard includes ferromagnetic projectiles (oxygen tanks, crash carts, stethoscopes etc.) that have a potential for being dangerous due to the static magnetic field having a strong magnetic pull (see image). Projectile hazards can be avoided by vigilance, the use of physical barriers, clear-cut warning signs, and MRI Safety Level 1 and Level 2 trained staff. Having a hand held magnet to screen for safety can be useful as well.

Magnet Quench

In the event of a large projectile incident, such as an oxygen tank or wheel chair where there is risk of life or limb, it is possible to immediately shut down, or quench the magnet to remove the projectile. Quenching is the sudden loss of absolute zero temperature (really low temperature) in the magnet coils (which would otherwise be extremely hot) so they cease to be superconducting magnets. The low temperatures of the magnet is maintained by liquid helium which has a boiling point of four kelvin. The already dangerous strong magnetic field, with the risk of a toxic gas, can make the MRI environment very dangerous, especially when handling patients. That is why you should only emergently quench the magnet if there is going to be immediate danger to life or limb. There is also incidents where the magnet may need to be quench due to poor maintenance. Patients or personal can get asphyxia from the liquid helium boiling off slowly through pipes. This is why the MRI department should be monitored by facilities, medical maintenance, and the MR personnel. To conclude, ramping down the magnet could be used if there is concern for small ferromagnetic items that could be trapped inside the scanner (steel-shot from "sand" bags etc.) which could affect image quality or geometry/distortion. This is where the magnetic field strength is lowered in order to remove the object, but can be brought back up. Both the quench, and ramping down the magnet is very costly to the Military Treatment Facility, which is why the magnet must be "ALWAYS ON".

12.2 Safety Zones

- **Zone 1:** all areas that are freely accessible to the general public. This area is typically outside the MR environment itself, and is the area through which all patients, healthcare personnel, another employees of the MR site access to the MR environment.

- **Zone 2:** interface between the publicly accessible, uncontrolled Zone 1 and the strictly controlled Zones 3 and 4. Zone 2 is where the answerers to MR screening questions, patient histories, PII I typically obtained.
- **Zone 3:** this region is free access by unscreened non-MR personnel or ferromagnetic objects or equipment. Because of this, this is one of the more dangerous areas, and could result in serious injury or death as a result of interactions between individuals or equipment in this particular environment. This area is physically restricted from general public access.

- **Zone 4:** This zone should be demarcated and clearly marked, as this is the most hazardous due to the presence of very strong magnetic fields. Should be marked "magnet is always on".

Distinguish what is safe, unsafe, and conditional in MRI Safety:

- **MR Safe**: an item that poses no known hazards in all MR imaging environments (non-conducting, nonmetallic, and nonmagnetic items, such as plastic)
- **MR Unsafe**: An item that is known to pose hazards in all MR environments (ferromagnetic scissors)
- **MR Conditional:** an item that has been demonstrated to pose no known hazards in a **specified** MR environment with **specified** conditions of use. In addition, there may be additional conditions that are specific to the item.

12.3 MRI System

A. **Magnetism**: There are three forms of magnetism, Diamagnetism, Paramagnetic, and Ferromagnetism.
   - Diamagnetic exhibit a weak repulsion to an external magnetic field
   - Paramagnetic exhibit a weak attraction to an external magnetic field, and form an internal and induced magnetic field in the direction of the applied magnetic field (This is what the MRI contrast agent Gadolinium is, and is used to display hypervascularity and associated pathology)
   - Ferromagnetism exhibit a large powerful attraction to an external magnetic field (The cause of projectile hazards as described in 6.2)

B. **Three main types of MRI scanners in Clinical Practice:**
   - Closed-bore systems: most popular and what is used in most clinical settings. The table moves in and out the MRI bore to image area of interest.
   - Open-bore systems: most advantageous for scanning large animals, humans with large habitus (broad or obese).
   - Extremity systems: dedicated to image limbs and are smaller in size.

C. **Imaging Coils**: The MRI imaging coils, as you may have heard from time to time in your work center, revolves around the equipment that acts as a radio wave receiver and transmitters in order to digitize an image. The coils generate radio waves in the desired frequency, and then transmitted into the anatomical area that is being imaged. Ones that can do both are called transceivers. For this study guide, they consist of:
   - Head Coil

   - Extremity Coil



- Volume /Body Coil

- Surface Coil

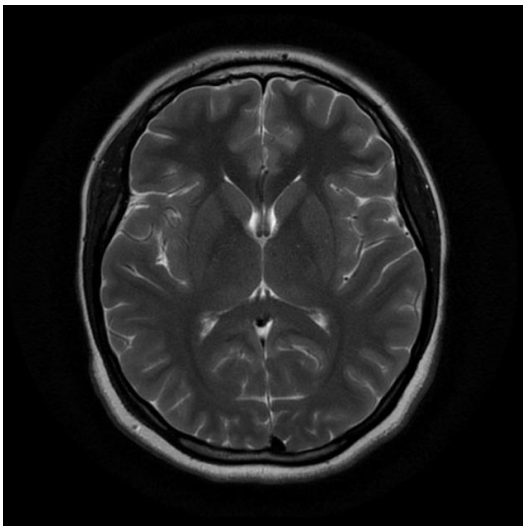

D. **MRI system**:

- Computer system and graphical user interface is the entire process of a MRI acquisition with a computer. The graphical user interface is where the technologist will input patient information and manage MRI parameters (similar to KVP, MAS etc. for X-Ray) to perform the scan. This is how the MRI system calculates how much signal will be coming from the location of the patient from a three-dimensional location. Each parameter is adjusted to digitally produce a specific sequence of images. The Radiologist will put together a protocol of sequences to read and diagnose the area of interest. This system is connected to a network to transmit images to the PACS system.

12B Patient Examinations

MRI patient preparations require questionnaire forms that have questions tailored specifically to items that are considered MR safe. Once the questionnaire has been completed, the patient will be changed into MR safe linen. Ensure that they have removed all metal objects including but not limited to keys, coins, wallet, and credit cards with metallic strips, jewelry, hearing aid and hairpins. After entering the magnet room (Zone 4), provide patient with hearing protection, give clear directions on the exam, and place the patient on the MRI table accordingly. Each imaging coil will be connected accordingly, and placed on the appropriate body part to acquire the image. The MRI Tech will then landmark the exam specified, and isocenter a laser. From that laser location, the patient will then be slid into the MRI bore for imaging.

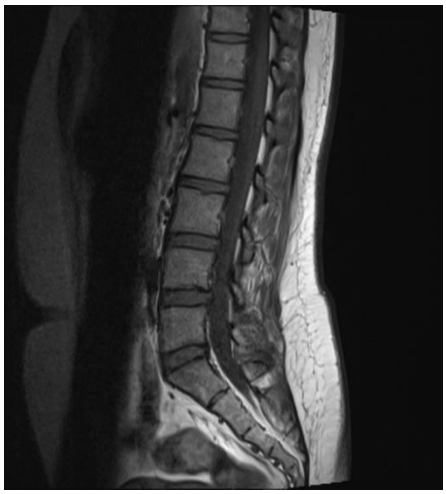
12.4 Cranium, Neck and Spine



1. Brain
    a. **Positioning**: Head first supine, position head in head coil and immobilize with cushions. Give cushions under the legs for extra comfort/prevent thermal injuries. Center the laser beam localizer over the glabella.
    b. **Equipment**: Head coil, immobilization pads and straps, ear plugs/headphones.

2. Neck
    a. **Positioning**: head first supine, position head in head and neck coil and immobilize with cushions, give cushions under the legs for extra comfort, center the laser beam localizer over the mid neck (1in below the chin in the chin down position).
    b. **Equipment**: Volume neck coil for cervical nodal involvement, head coil for pharyngeal area and base of skull, immobilization pads and straps, earplugs/headphones

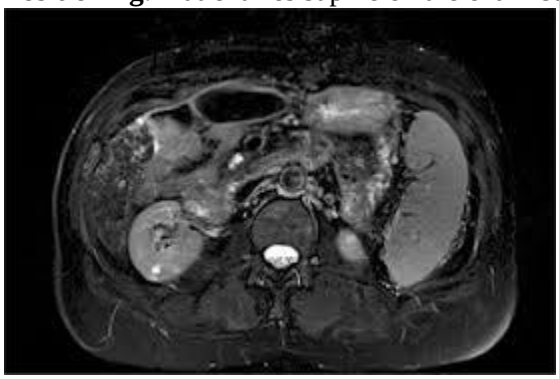
3. Spine



a. **Cervical Positioning**: Head first supine, position the head in the head and neck coil and immobilize with cushions, give cushions under the legs for extra comfort, center the laser beam localizer over the mid neck (2.5cm below the chin in the chin-down position)
Thoracic Positioning: Head first supine, position the patient in the spine and neck coils, give cushions under the legs for extra comfort, center laser beam over mid sternum or mid neck based on protocol
Lumbar Positioning: head first supine/feet first supine, position the patient with immobilization with cushions, cushion under legs for comfort, center laser over mid abdomen (around 4 inches above the iliac crest)
    b. **Equipment**: Head/Surface coil, immobilization pads, and earplugs/headphones

12.5 Abdomen and Thorax

4. Abdomen
    a. **Positioning**: Patient lies supine on the exam couch with bellows (if required) securely attached.



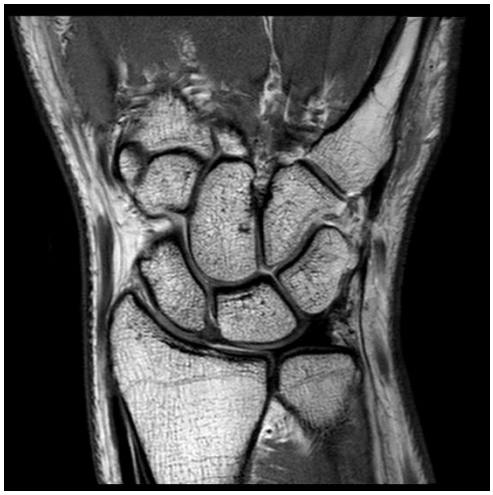
The patient is position so that the longitudinal alignment light lies in the midline, and the horizontal alignment light passes through the level of the third lumbar vertebra, or the lower costal margin.

    b. **Equipment**: Body coil, bellows for gating, immobilization pads, and earplugs/headphones

5. Pelvis
    a. **Positioning**: the patient lies supine on couch. Patient is positioned so the longitudinal alignment light lies in the midline, and horizontal alignment light passes through midway between the pubis symphysis and the iliac crest. Compression should not be applied in pregnancy or immediately post-caesarean section.
    b. **Equipment**: Body coil, compressions bands, immobilization pads, and earplugs/headphones

12.6 Extremeties

i. **Shoulder Positioning**: Supine position with head pointing towards magnet (head first), shoulder in the coil or flex coil and immobilize with sand bags, center laser over shoulder joint or mid line of coil
ii. **Humerus Positioning**: Supine position with head pointing towards magnet (head first), position patient over spine coil or place body coil over upper arm (from shoulder to elbow) securely tighten body coil using straps, give pillow under head with cushions for legs for extra comfort, center laser beam over mid humerus
iii. **Elbow position**: Can be both supine and prone, position elbow in small flex coil or suitable coil (knee coil), center laser beam over elbow joint
iv. **Forearm positioning**: Supine position or which is more comfortable for patient, can be over spine coil with body coil over or which is comfortable for patient, tighten body coil to prevent respiratory artifacts, pillow under head and legs for comfort, center beam over mid forearm
v. **Wrist/hand/finger positioning**: Head first, place supine or prone based off manufacturer and coil being used (dedicated wrist, knee, flex etc.), immobilize with cushions, center laser beam over wrist joint/hand/finger of interest



vi. **Hip positioning**: In supine position head first, patient will be over spine coil or with body coil over pelvis, secure coil to prevent respiratory artefacts, give pillow under head for extra comfort, and secure feet to externally rotate greater trochanters, center laser beam over hip joints.
vii. **Femur positioning**: Patient in supine with feet pointing towards the magnet, position over spine coil or with body coils over thighs, securely fasten with body coil straps, center laser beam over mid-thigh
viii. **Knee positioning**: Feet first supine, position knee in knee coil and immobilize, give cushions under ankle for extra comfort, center laser beam over lower border of patella

ix. **Tib/Fib positioning**: Position patient in supine position with feet pointing towards magnet (feet first supine), use spine coil or body coils over lower leg, tighten body coils with straps, and give pillows for comfort, center laser beam over middle of lower leg.
x. **Ankle positioning**: Position patient in supine position with feet pointing towards magnet, position the ankle in foot and ankle coil (use knee if not available), ankle should be at 90 degree angle, securely tighten the foot using cushions, give pillow for comfort, center laser beam over ankle joint
xi. **Foot positioning**: Patient in supine position with feet pointing towards the magnet (feet first supine), use ankle/foot coil (use head coil if not available) with foot at 90 degree angle and flatten to get good scans, secure with cushions, give pillow for comfort, center beam over foot or toe of interest

b. **Equipment**: Extremity coil/Head Coil/Volume Coil, immobilization pads, earplugs/headphones

Unit 13. Mammography

13A Mammography.....190
13.1 Benefits of mammography and breast cancer risk factors.....190
13.2 Breast anatomy and physiology.....193

MAMMOGRAPHY AND bone densitometry are two special areas of DI that benefit the health and well-being of women around the world. Mammography is a diagnostic method used to detect intramammary masses earlier than later. Intramammary masses were once only detectable by palpation. If a mass can be felt, it means the mass has grown to a size of 2–3 cm. In most cases when a mass has grown to that size, metastasis of the disease into the lymphatic system has already occurred. Early detection of potentially cancerous masses is the key to diagnosis and treatment of breast cancer; therefore, mammography is instrumental in the early diagnosis and survivability of breast cancer. Though small portions of men develop breast cancer, women are the center of attention when mammography is discussed.

Another disease affecting more women than men is osteoporosis. Osteoporosis is a bone-mineral disease, primarily affecting postmenopausal women, that weakens bones and increases the chances of fractures. The most often affected areas of the skeleton with osteoporosis are the proximal femur, spine, or forearm (radius and ulna). Bone-densitometry exams give radiologists a method of evaluating bone-mineral content to predict a patient's fracture-risk level better and to deliver treatment in strengthening bones.

The first section of this unit covers the benefits of mammography, breast cancer risk factors, and breast anatomy and physiology. In the second section, bone-densitometry principles, common exams, and QC within densitometry are discussed. We begin with the benefits of mammography and common breast cancer risk factors.

13A Mammography

For women, breast cancer is the second leading cause of death in the United States with greater than 200,000 new cases reported annually. Early detection, diagnosis, and treatment of the disease are essential to a high-survival rate. Intramammary masses, such as carcinoma, were once detectable only by palpation and identifiable only via biopsy. In many cases, by the time a cancer was detected it was so advanced that radical mastectomy was the only course of therapeutic action, and most of the time, metastasis had already occurred.

In the 1920s and 1930s, physicians began experimenting with radiography as a method of detecting breast cancer early enough to improve survivability rates. By the 1950s, mammography had evolved into a reliable and popular method of detecting and evaluating breast cancer. Continuous improvements in technology since then have made mammography an integral, safe screening tool that has helped improve survival rates of breast cancer patients tremendously.

This section covers the benefits of mammography and risk factors associated with breast cancer and finishes with a discussion of breast anatomy and physiology. We begin with benefits and risk factors.

13.1 Benefits of mammography and breast cancer risk factors

Breast cancer was once a deadly disease for nearly all women who developed the disease. Now, breast cancer is one of the most curable types of cancer. The earlier the disease is detected, the better.

Mammography is a modality of DI that aims to achieve just that, early detection. As you will learn in this lesson, detecting a lesion before it can be felt is of great importance.

Breast cancer

Chances are, one out of every eight women in the United States who live to the age of 95 will be diagnosed with breast cancer at some point in their lifetime. Before the development of early detection techniques (mammography being the most important), the five-year survival rate for women diagnosed with breast cancer was fewer than 5 percent. Early detection of breast cancer is the most important factor in improving the chances for survival because it is highly metastatic through the lymphatic system.

On average, it takes a breast tumor 10–12 years to grow large enough to palpate (equaling 1 cm). The average size of a tumor, when a woman herself detects it, is 2–3 cm. By the time a tumor reaches this size, it has already metastasized in 50–60 percent of the cases. By contrast, mammography can detect a cancer at least 2 years before it becomes palpable. This translates into a survival rate of 5 years, of 80 percent or better, when the cancer is confined to the breast. Figure 4–1 illustrates the approximate cancer incident rate by location within the female breast.

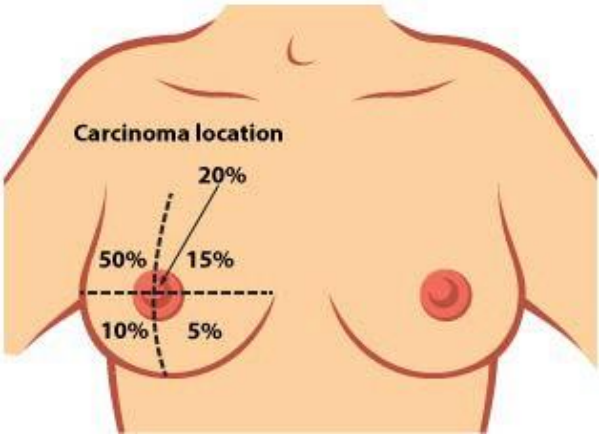


Figure 13.1 Percent of cancer incidence by location within the female breast

Unfortunately, males are not immune to developing breast cancer. In fact, approximately 1,300 males develop the disease in the United States annually, and one- third of them die of the disease. Most males who develop breast cancer are at least 60 years of age. Male symptoms include nipple retraction, crusting, discharge, and ulceration. The five-year survival rate for males is 97 percent as long as the breast cancer is contained to the breast tissue. Like in females, once the cancer has metastasized through the lymphatic system, survival rates decrease dramatically.

Mammography development

Mammography is a radiation-based imaging modality for the breast. Over the last 70 years, it has evolved from a crude technique to a well-developed science. In the early days of mammography, standard X-ray equipment and fine grain, industrial film were used, which required large amounts of radiation to produce a readable image. Average patient doses were in the 8–12 rad range for a single examination.

In the early 1970s, xeroradiography was developed as an alternative that required much less radiation (2–4 rads per exam) and produced images with better contrast and edge enhancement. Xeroradiography still used standard X-ray equipment but used a different method of recording the image. Instead of film, selenium plates and a special xeroradiographic processor were used. For the past 30 years, multiple advances in technology have allowed for the production of high-quality mammographic images while significantly reducing the radiation exposure dose to the patient. Some of these advances include dedicated mammography units, highly detailed screen-film combinations, and, of course, digital mammography. Today, the average gland dose per exposure in digital mammography is around 200 millirad (mrad) or 2 mGy. In addition, patient dosage should not exceed 600 mrad or 6 mGy for a standard two-view mammogram.

The primary goal of mammography is to detect breast cancer prior to the tumor growing to the size necessary to be palpable. Although mammography is a superb method for detecting breast cancer, it is rightfully important to note that mammography does *not* diagnose breast cancer.

Screening versus diagnostic mammography

A *screening mammography* exam is a procedure performed on a patient who is asymptomatic of any known breast problems. Early detection and diagnosis is essential to increasing a patient's survivor rate. Currently, the American College of Radiology and the American Cancer Society recommend all women receive a baseline mammographic examination at some point, prior to the onset of menopause (approximately 35–40 years of age) for comparison during subsequent mammograms. In addition, it is recommended all women age 40 and above undergo a mammography exam annually for as long as they are in good health otherwise. Screening is not recommended for women under the age of 35 because of the low incidence of breast cancer in that age group and the increased radiosensitivity of the breast at younger ages.

A *diagnostic mammogram* is an exam performed on patients who have clinical evidence of possible breast problems. Potential issues could be a suspicious area identified on a routine screening exam or the result of the patient feeling something during self-examination. Diagnostic mammograms include specific images designed to show a suspicious area and, in essence, rule out cancer. Although most diagnostic mammographic studies end up as benign findings, some patients are referred to have other diagnostic breast procedures, such as a sonogram or an MRI exam, to evaluate a suspicious area further. Lesions may appear malignant, yet turn out to be totally benign. In this case, the only true way to diagnose a lesion as cancerous or not is to do a biopsy on the lesion. During a biopsy, a pathologist extracts tissue from the lesion for evaluation. A pathologist can only diagnose breast cancer after microscopically evaluating the tissue cells from a lesion.

Benefits of mammography versus radiation exposure risks

Since we have known for some time that radiation has the ability to induce cancer, many individuals believe that having routine mammograms increases a woman's chances of developing breast cancer. However, extensive research indicates mammography detects far more breast cancers than it could conceivably cause.

The primary sources of data for radiation-induced breast cancer come from three groups: (1) survivors of atomic bomb explosions at Hiroshima and Nagasaki, (2) a group of women with tuberculosis who were fluoroscoped repeatedly while being treated for the disease, and (3) a group of women who were treated for postpartum mastitis (inflammation of the breast) with radiation. Data gathered from those sources show a definite increase in the number of breast cancers developed in these women who received tremendously high amounts of radiation (600–700 rads) compared to lower levels received (approximately 200 mrad) during a routine diagnostic examination. To apply this data to diagnostic exposure levels, physicists assume a linear, nonthreshold dose-response relationship to extrapolate the likely risk of induced cancer from low levels of radiation.

Some studies have estimated that for every rad of exposure, a woman increases her risk of developing breast cancer 1 percent over the natural incidence. Keep in mind, though, no definite direct evidence exists to suggest the small doses of radiation received during a mammographic study actually induce breast cancer. The accepted norm is the benefit derived from routine screening mammography exams far outweigh the potential risk involved.

Risk factors

Breast cancer risk factors affect a person's chance of getting the disease. Having a breast cancer risk factor, or even more than one, does not totally conclude a person will get the disease. Breast cancer risk factors can be organized into two groups: those not related to a person's personal choice and those related to a person's lifestyle.

Factors not related to personal choice

The following list relates to the most common factors associated with this category:

- **Gender—**Women are 100 times more likely to develop the disease than men.

- **Aging—**Risk increases as a woman ages; women 45 years and younger have a one in eight chance of developing invasive breast cancer while two out of three invasive breast cancers are found in women 55 years of age and older.
- **Genetics—**Hereditary plays a role in approximately 5–10 percent of breast cancer cases.
- **Family or personal history—**When a woman's mother, sister, or daughter has breast cancer, the risk is approximately doubled. As well, when a woman develops breast cancer in one breast, they then have an increased risk of developing it in the other breast or another part of the original breast.
- **Race and ethnicity—**Caucasian women are more likely to develop the disease but less likely to die of it. African-American women are less likely to develop the disease but more likely to die of it. Asian, Hispanic, and Native-American women seem to have a lower risk of developing and dying from the disease.
- **Dense breast tissue—**Women with dense breast tissue have a one to two times increased risk of developing breast cancer.
- **Menstrual periods—**Women who started menstruating before the age of 12 or continued menses after the age of 55 have a higher risk of developing the disease.

Lifestyle-related risk factors

The following list relates to the most common lifestyle-related factors:

- **Pregnancy—**A woman who has her first child after the age of 30 or doesn't have any children seems to slightly increase her risk of breast cancer. Those who become pregnant at a younger age or have multiple pregnancies seem to have a reduced risk of developing the disease. This lifestyle-related factor is listed because of the effects on the development of the disease as a result of the hormonal changes that occur in a woman during pregnancy.
- **Birth control—**Women who take an oral contraceptive have a slightly increased risk as compared to those who have never used birth control pills. In addition, the risk tends to revert to normal over time after the medication is stopped.
- **Hormone therapy—**Some hormone therapy treatments have shown to increase the risk of developing breast cancer. Patients should always discuss the risks with their physician prior to starting any medication/hormone-therapy regimen.
- **Overweight or obese—**Postmenopausal, overweight women have shown to have a higher risk of developing the disease.
- **Alcohol consumption—**The risk increases with the amount of alcohol consumed. Two to five drinks a day causes a 1.5 times increase in the risk of developing breast cancer or other diseases.
- **Physical activity–**Women who exercise regularly on a weekly basis seem to have a reduced risk for breast cancer. One to three hours of brisk walking in a week may reduce a woman's risk up to 18 percent.
- **Breastfeeding—**Women who breastfeed for 18 months to 2 years may also have a slightly lower risk of developing breast cancer due to the fact that breastfeeding reduces the total number of menstrual cycles in their lifetime.

13.2 Breast anatomy and physiology

Functionally, the female breasts are accessory glands of the reproductive system. They are comprised primarily of three different types of tissue that exist in varying amounts, depending on the patient's age and other physiologic conditions. We divide our discussion of breast anatomy into three areas: external anatomy, internal anatomy, and physiological changes.

External anatomy

The female breasts are cone-shaped glands that lie on the anterolateral surfaces of the chest. The portion of the breast that lies in contact with the chest wall is called the *base*. The base usually extends from the level of the second or third rib down to the level of the sixth or seventh rib, laterally to the edge of the latissimus dorsi muscle, and medially to the sternal edge. The breast tapers outward from the base to the nipple.

The surface landmarks of the breast (fig. 4–2) include the nipple and the areola (the highly pigmented area surrounding the nipple). Other external landmarks are the tail and the inframammary crease. The tail is that portion of the breast that extends upward into the axilla, and the inframammary crease occurs where the inferior portion of the base of the breast attaches to the chest wall (at the level of the sixth or seventh rib).

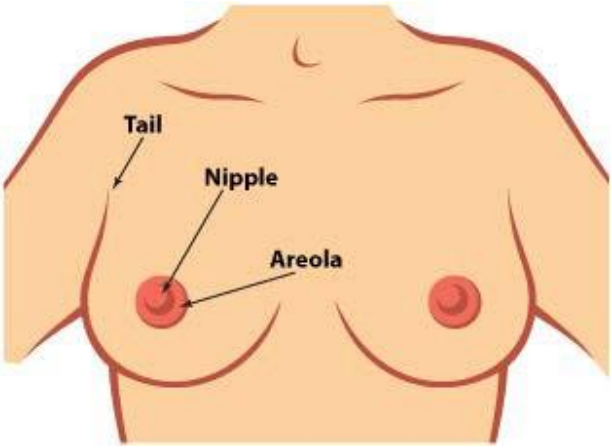


Figure 13.2 Female breast external anatomy

Internal anatomy

The internal anatomy of the breast can be divided into three different types of tissue: fibrous (or connective), glandular, and fatty (adipose) (fig. 4–3).

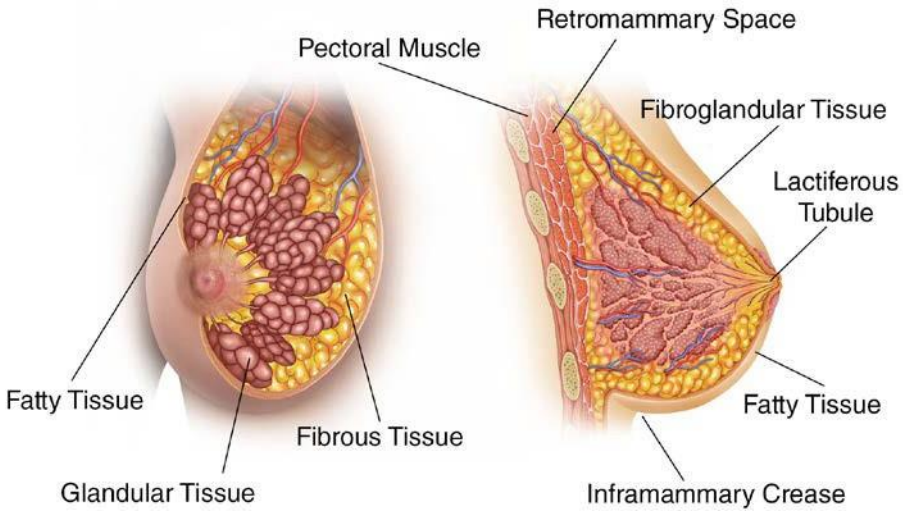


Figure 13.3 Internal breast anatomy.

Fibrous tissue

Fibrous breast tissue consists of two layers of fascia, suspensory ligaments, and an irregularly pitted framework for the glandular tissue. The fascia layers are superficial and deep; they are joined and completely house the mammary gland. The suspensory ligaments, called Cooper's ligaments, are vertical bands of elastic fibrous tissue that connect the deep layer of fascia with the skin. The remainder of the fibrous tissue comprises the honeycombed framework for the mammary glands.

Glandular tissue

The glandular tissue component of each breast (mammary gland) consists of 15–20 lobes, each of which is made up of numerous lobules. Each lobule is comprised of smaller units, called *acini*, which

are the functional units of the mammary gland. A functional unit is the smallest division of a gland, or organ, which can perform the function (in this case, produce milk) of the gland or organ. They are all interconnected by the lactiferous ducts, which form a distinct network. The tiny ducts from the lobules empty into the larger main ducts. These, in turn, empty into the lactiferous tubules that extend from each lobe into the nipple.

Fatty tissue

Fatty (adipose) tissue completely surrounds the glandular tissue in varying amounts and is distributed within, depending on body habitus and genetics. The amount of fatty tissue in the breast greatly influences its radiographic appearance because fat is much less dense than the glandular tissue. We rely on a certain amount of fat being present in the breast to produce the contrast necessary to visualize the glandular tissue.

Between the posterior portion of the mammary gland and the pectoral muscle is the retromammary space (or retromammary fat space) (see fig. 4–3). This is another area where fat is distributed. This space is radiographically significant because, for some views, visualization of this space is an indication that all of the posterior breast tissue has been included on the image.

Physiologic changes

The density of the breast and, consequently, the exposure required depends in part on the ratio of fibrous and glandular (fibroglandular) tissue to fatty tissue. Fibrous tissue and glandular tissue are approximately equal in densities while fatty tissue is the least dense radiographically of the three types of breast tissue. The more fibroglandular tissue contained in the breast, in relation to the amount of fatty tissue, the greater the density of the breast.

The breasts usually undergo a gradual change in tissue ratio from the adolescent years to postmenopausal years. The total amount of glandular tissue in the breast varies with the patient's age, hormonal changes, pregnancy, lactation, and menopause.

- The adolescent breast has a rudimentary ductal system and consists mainly of fibrous and glandular tissue. Radiographically, the adolescent breast appears very dense with little subject contrast present.
- The mature (prepregnancy) breast still consists mainly of fibroglandular tissue, but there is an increasing proportion of adipose tissue.
- During pregnancy, hormonal stimulation causes an increase in the size of the breast. Glandular tissue grows and replaces much of the fat. As a result, the lactating (milk-producing) stage compares with the adolescent breast in terms of radiographic density.
- As a woman approaches and passes through menopause, the glandular tissue decreases in size as a result of reduced hormone production, and there is a further increase in adipose tissue.
- After menopause, the lack of hormonal stimulation causes the glandular tissue to atrophy. At this stage, adipose tissue has completely replaced the fibroglandular tissue. The atrophic breast is least dense, radiographically.