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Diagnostic Imaging Journeyman

Volume 4. Digital Radiography Concepts and Specialty Imaging

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THIS CAREER Development Course (CDC) Z4R051, *Diagnostic Imaging Journeyman—Digital Radiography Concepts and Specialty Imaging*, is devoted to digital radiography concepts and specialty imaging within Diagnostic Imaging (DI). It includes lessons on computed radiography (CR), direct radiography (DR), picture archiving and communication system (PACS), fluoroscopy, mobile radiography, computed tomography (CT), mammography, and bone densitometry. While not everyone agrees on which procedures are "special" and which are "routine," the procedures covered in this volume are not performed at every USAF DI facility. For this reason, topics in units two, three, and four are for the most part, special to our career field. 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.

Unit 1 discusses digital radiography, PACS and PACS concepts, CR, DR, digital acquisition, and digital image processing considerations. A PACS system overview is provided, as well as a discussion on the composite health care systems and associated system downtime functions.

Unit 2 covers fluoroscopy and mobile radiography. In this unit digital fluoroscopy concepts and image intensification are discussed, as well as mobile radiography in the inpatient care areas of neonatal wards, intensive care units, and in operating rooms.

Unit 3 is devoted to CT. CT is, quite possibly, the fastest, ever-evolving imaging specialty within DI. If you have a CT scanner at your facility to learn the imaging concepts, do so. CT is used throughout the DI community at home and in a deployment setting. Lessons include the fundamentals of CT, CT system components, patient preparation, and radiation safety. We examine technical aspects of CT images, types of CT scanners, and cross-sectional anatomy. In addition several CT system components are discussed, including the patient apparatus and operator's console. We also examine preparing patients and CT radiation safety.

In the final unit, unit 4, mammography and bone densitometry are discussed. Though many of you may never work in either of these special imaging areas, certain aspects are outlined for your benefit as you progress through your imaging career. The benefits of mammography, breast cancer risk factors, and the anatomy and physiology of the breast are addressed. In the bone densitometry lesson, basic principles, performance of common exams, and quality control features are outlined.

A glossary is included for your use.

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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, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Page

Unit 1. Digital Radiography and Picture Archiving and Communication System........1–1
1–1. Digital Radiography Concepts 1–1
1–2. Picture Archiving and Communication System 1–22
Unit 2. Fluoroscopy and Mobile Radiography 2–1
2–1. Fluoroscopy.. 2–1
2–2. Mobile Radiography.. 2–10
Unit 3. Computed Tomography...3–1
3–1. Fundamentals of Computed Tomography 3–1
3–2. Computed Tomography System Components.. 3–23
3–3. Patient Preparation and Radiation Safety 3–35
Unit 4. Mammography and Bone Densitometry 4–1
4–1. Mammography 4–1
4–2. Bone Densitometry.. 4–8

Glossary.. *G–1*

Unit 1. Digital Radiography and Picture Archiving and Communication System

1–1. Digital Radiography Concepts 1–1
601. Computed radiography 1–1
602. Direct radiography...1–5
603. Acquiring digital images..1–9
604. Digital image processing 1–13
1–2. Picture Archiving and Communication System 1–22
605. Picture archiving and communication system overview..1–22
606. Composite Health Care System 1–29
607. System downtime functions..1–31

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!

1–1. 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.

601. 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).

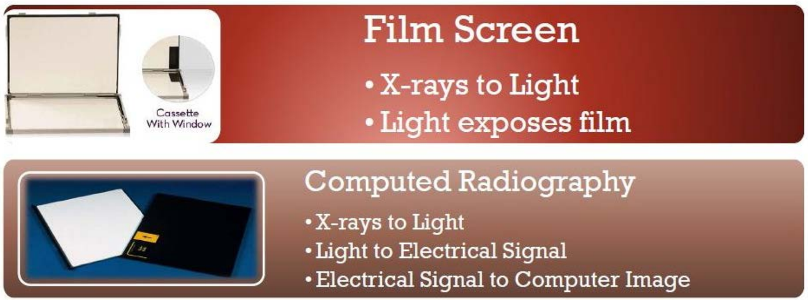


Figure 1–1. Film-screen and CR comparison.

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 imiages 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 (fileroom) 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.


Figure 1–2. Sample PACS server storage towers.

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 becomemore 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 transversing the photostimulable phosphor screen from top to bottom and another 2,500 squares transversing 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.

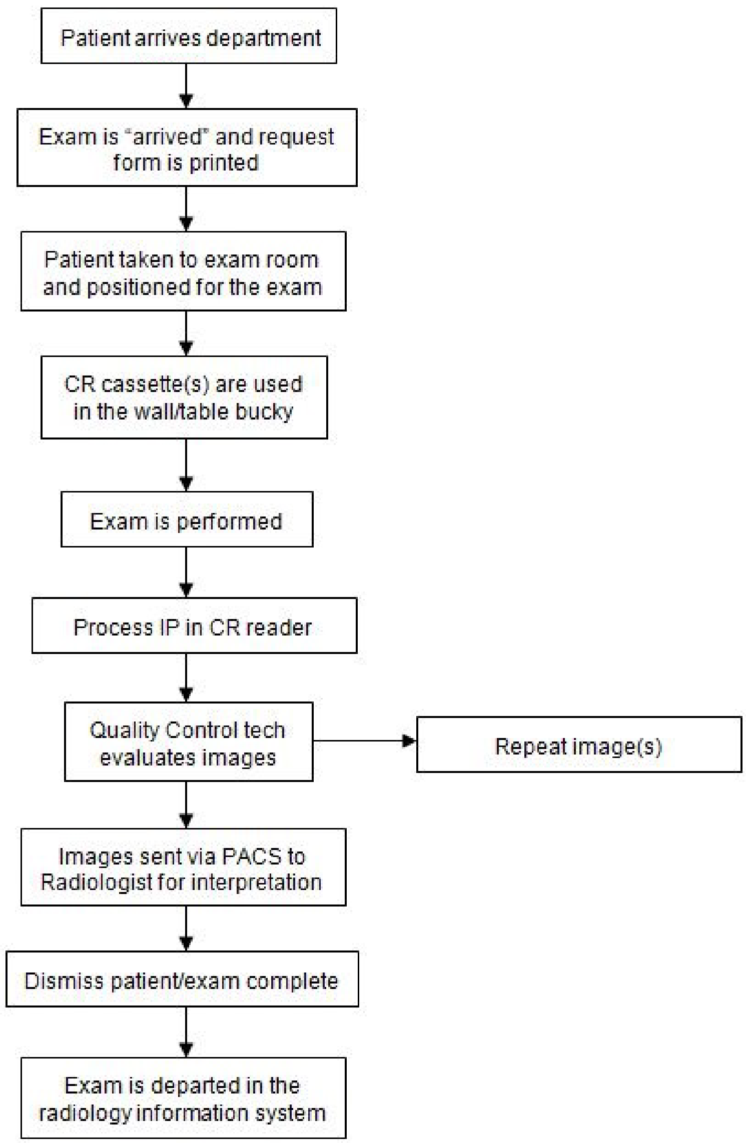


Figure 1–3. CR workflow process.

602. 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, nonconducting 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.

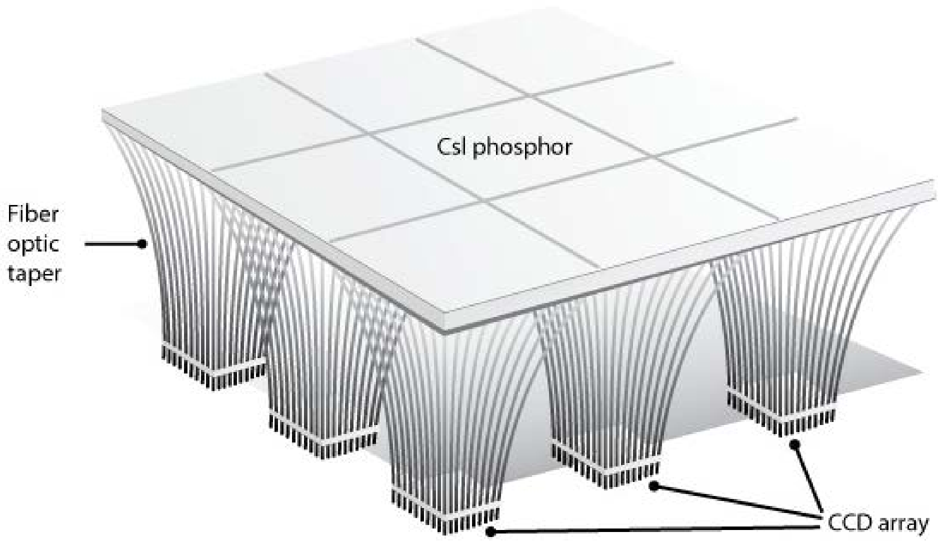


Figure 1–5. CCD array with fiber-optic bundles illustration.

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.

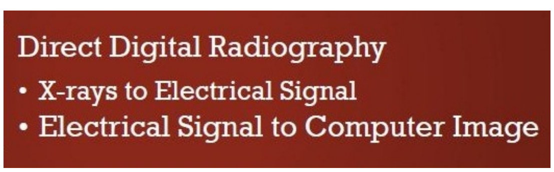


Figure 1–6. Direct capture digital radiography.

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.

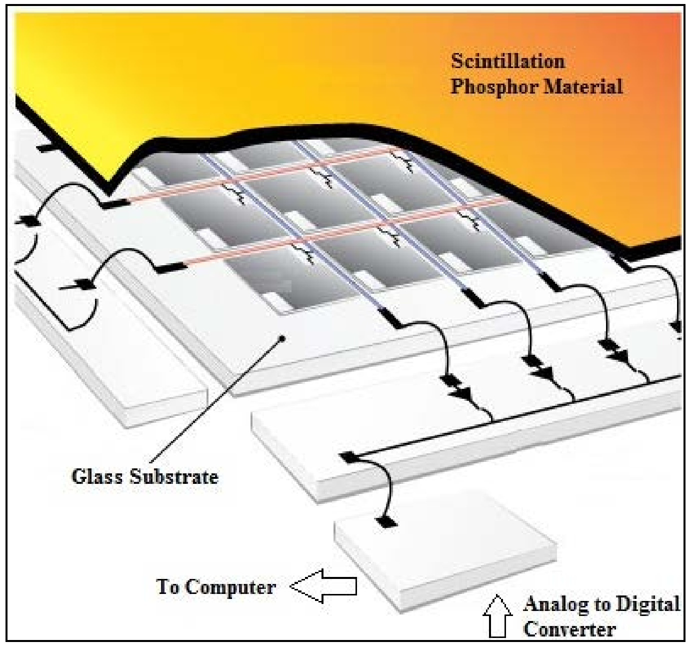


Figure 1–7. Active matrix array of thin-film transistors illustration.

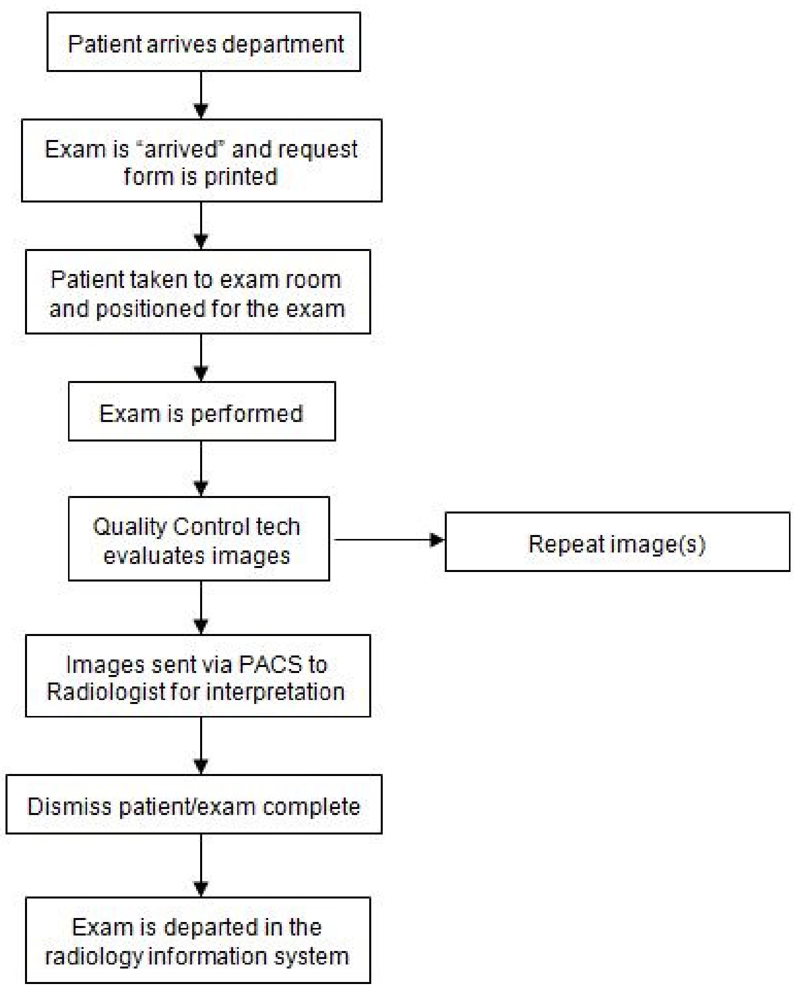


Figure 1–8. DR workflow process.

603. 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. By this point in your imaging career, 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 chose 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.

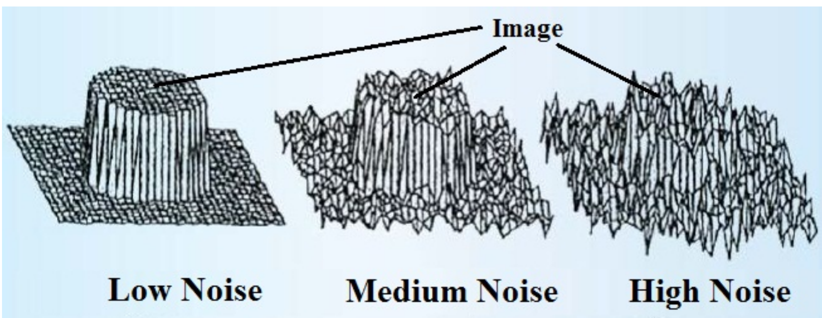


Figure 1–9. Quantum noise levels.

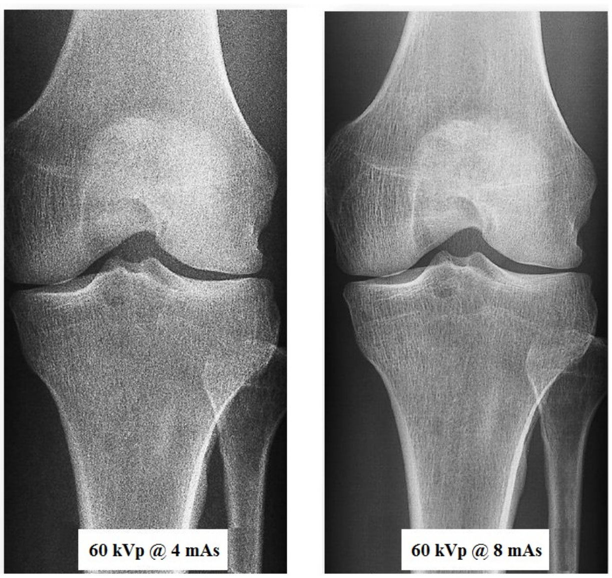


Figure 1–10. Quantum noise in a knee radiograph.

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 postprocessing, 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.

604. 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 postprocessing 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 postprocessing 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.

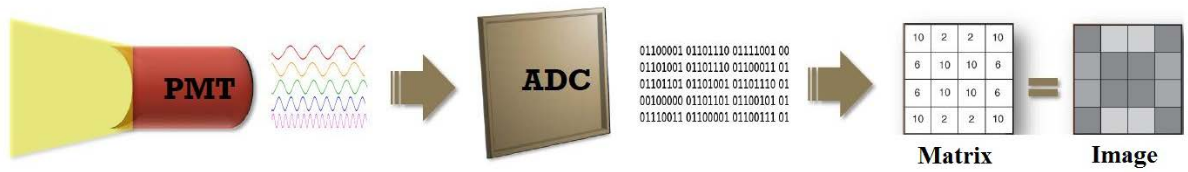


Figure 1–12. Digitizing an image.

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 multicassette 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. Multicassette 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, postprocessing 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, postprocessing 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 postprocessing. The following are some of the most common software-driven–postprocessing 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 postprocessing 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).

Many manufacturers provide an analysis package for review of how the deviation index results matchup to the set target values. To determine TEI values, manufacturers either average a limited number of previous studies or set them to fixed values. These methods lead to nonoptimized TEIs and inconsistencies among units. The Air Force performs a more statistically rigorous analysis to establish both reasonable and standardized TEI values that are used throughout the Air Force today.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

601. Computed radiography

1. Name three disadvantages of using conventional radiography versus CR.

2. What type of laser causes the photostimulable phosphor screen to emit light?

3. Why is a high-exposure (wide) latitude a benefit of CR?

4. What becomes the film library for CR?

5. What is the purpose of an ADC converter in CR?

6. What changes the digital image information back to an analog state for visualization on a monitor?

7. What does the term *imaging plate* actually reference?

8. What are CR photostimulable phosphor screens made of?

9. What is photostimulable luminescence?

10. To what does pixel bit depth reference?

11. If a pixel's bit depth is eight, how many shades of gray are available for that particular pixel?

602. Direct radiography

1. What items are used to receive and measure the remnant radiation and form the data into a digital image?

2. What is the capture element used in DR?

3. What acts as the coupling element that allows electronic signals to be sent to the collection component in DR?

4. What are photodiodes?

5. What type of DR capture element is made up of a semiconducting layer (normally amorphous silicon) sandwiched between (or painted on the surface of) supporting, nonconducting layers that are commonly glass?

6. What do thin-film transistors gather? Why?

7. What is scintillation?

8. What is the scintillator in conventional radiography, CR, and DR?

9. Explain the difference between indirect and direct capture flat-panel receptors.

603. Acquiring digital images

1. How does field size affect spatial resolution?

2. Why is it important to choose the smallest cassette (field size) that will cover the body part being imaged?

3. What produces the moiré pattern artifact? What eliminates it?

4. When selecting a grid to reduce scatter radiation, what kinds of grid ratio should be used for fixed versus mobile CR imaging?

5. How should you always collimate the useful beam?

6. What happens if too much collimation is used?

7. What is the optimal kVp range for CR?

8. What causes the image noise artifact known as quantum mottle?

9. Explain what DQE refers to in DR.

10. Which digital imaging type(s) produce(s) better DQE?

11. What happens to the spatial resolution of an image when the quantity of pixels increase and the size of the pixels decrease?

12. Why is it not necessarily a good idea to produce digital images with a large matrix of several very small pixels?

604. Digital image processing

1. In general, what is the definition of digital images?

2. What is the main advantage of using digital imaging technology versus film-screen radiography?

3. What is a histogram?

4. What is the purpose of a look-up table?

5. Why is it important to select a look-up table that is *always* as close to the body part you imaged?

6. What does the final displayed digital image on the viewing monitor represent in correlation to the look-up table?

7. During the process of digitizing an image, when are the pixel's numerical values organized into a matrix?

8. When is patient demographic information assigned to a DR image receptor? For a CR image?

9. When selecting the algorithms (look-up tables) for the individual imaging plates, why is it important for you to demonstrate a higher level of attention to detail?

10. What is considered postprocessing?

11. What postprocessing function allows you to combine multiple IPs to be displayed as one image?

12. What is adjusted on the digital image when you adjust the window setting?

13. What does the level setting determine on your digital image?

14. Explain how signal interpolation corrects for pixel defects.

15. What is the digital imaging processing problem called image lag?

16. What type of method is considered more reliable at interpreting the exposure quality of a digital image?

17. What is dose creep?

18. What is the EI metric designed to be for radiologists and technologists?

19. What does the deviation index tell you about your digital image?

1–2. 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.

605. 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 operational fully, 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, followed by 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 the CHCS.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 workflow. 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, depending upon 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 postprocessing 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.

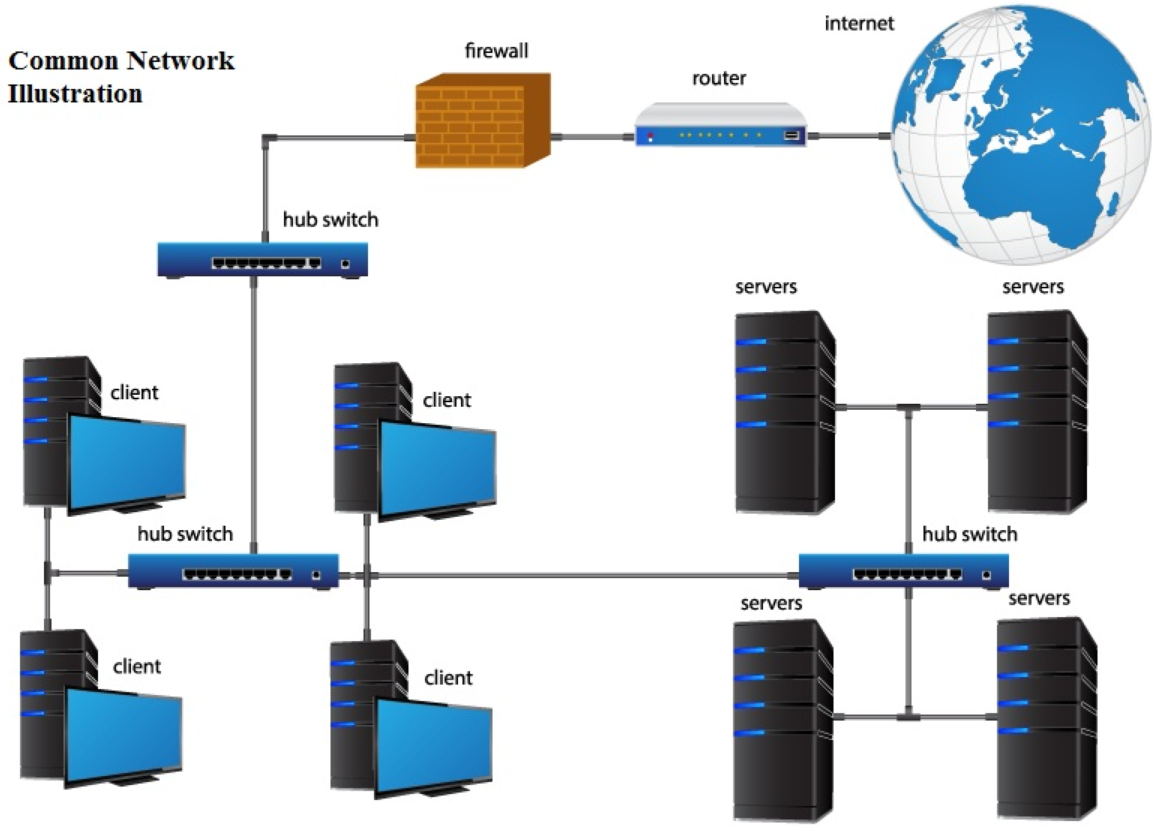


Figure 1–13. Computer network illustration.

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.

Peripheral components

In addition to the acquisition equipment and the PACS, there are three other common components attached to the system to help you perform your job. These components are the film digitizer, the compact disk (CD) burner, and the laser imager (printer).

Film digitizer

The primary purpose of a laser film digitizer (commonly known as a film digitizer) (fig. 1–14) is to take a piece of conventional X-ray film in its analog form and convert it into an exact digital copy. After digitizing, the digital image can be manipulated and archived just as if it was acquired via an IP. This feature scans and uses old films and films from another facility as a comparison study. Digitizing the image is a simple process from the technologist's standpoint.

Films are placed in the receiving tray of the digitizer; the film is fed into the unit where a helium neon laser scans the film. A photomultiplier tube picks up the light that is transmitted through the film, and it is made into an analog electronic signal. The analog signal is sent to an ADC and translated into numbers based upon the light intensity for every area on the film. The numbers are then applied to a look-up table, which assigns a shade of gray to every number that is formed into a digital image.

Though the resultant digital image is typically lower image quality than that of the original hard-copy radiograph, the degradation of the image is not enough to preclude digitizing the film. In its final form, the newly formed digital image, and all of its information, is now stored on the PACS and available to be read (or used in comparison to another radiograph) by a radiologist.

Figure 1–14. Film digitizer.

Compact disk burner

The CD (or digital video disk [DVD]) burner (fig. 1–15) has become a vital peripheral component for PACSs. In an effort to reduce costs associated with printing digital images for patients to check out (and other services), CD burners allow radiographic exams to be uploaded to a CD with a universal viewer program already installed. Now, patients can have copies of their radiology exams for outside provider appointments for pennies compared to laser printing all the images. Another benefit is that images do not have to be returned to your DI department for safekeeping. The master images are continuously maintained on the PACS no matter how many times a patient requests images to be uploaded onto a CD. CD burners also act as a contingency device when your PACS is down or network connectivity to your teleradiology site is lost.

Figure 1–15. CD burner jukebox.

CD burner capabilities can be local to your workstation using the PACS application, or can be set up as a stand-alone system, which has its own client and operating system along with a jukebox that contains hundreds of CDs waiting for data to be written to them. In the latter setup, the PACS sends a DICOM request to the burner workstation to initiate the CD-writing task. The stand-alone system is also flexible enough to query the PACS directly to pull and burn images. The stand-alone method is preferred because the device also has printing capabilities, which places a label with proper patient information on each disc. Many CD burners can also act as an acquisition device, capable of uploading outside studies into PACS for comparison purposes.

Laser imager (printer)

A laser printer, or imager (fig. 1–16), gives us a means of producing hard-copy films of digital images, creating a conventional-style radiograph from the digital information. This component also serves as a backup when the archival system is down, allowing the printed film to be digitized and archived at a later time.

Figure 1–16. Laser imager (printer).

In other situations, digital images may need to be printed for surgery or orthopedic specialty cases. Many times, these entities use hard-copy images for prosthetic templates and true size measurement representation. No matter how technologically advanced we become, there will always be a need to have a laser printer attached to the PACS.

606. 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, DI-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.

Diagnostic-imaging specific functions

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. Though it is not an end-of-the-world type of mistake; however, it is still a mistake that needs 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. Avoid this scenario if possible.

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 exposing 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.

607. 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

Our primary purpose, as radiologic technologists, 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: Chest X-Ray PA/Lat

AGE: 25 | SEX: M | SSN *(Sponsor)*: 20/123-45-6789 | WARD/CLINIC: ICU | REGISTER NO.:

FILM NO.: | PREGNANT: ☐ YES ☒ NO

REQUESTED BY *(Print)*: Dr. Steve Excellent | TELEPHONE/PAGE NO.: 222-2222

SIGNATURE OF REQUESTOR: Steve Excellent | DATE REQUESTED: 20 July 15

SPECIFIC REASON(S) FOR REQUEST *(Complaints and findings)*: r/o pneumothorax

DATE OF EXAMINATION *(Month, day, year)*: July 20 2015 0820 | DATE OF REPORT *(Month, day, year)*: July 20, 2015 | DATE OF TRANSACTION *(Month, day, year)*: 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)*

Doe, John J AD/USAF
20/123-45-6789
DOB 12 June 1990

LOCATION OF MEDICAL RECORDS: 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/MIR 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 readable. 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 backup 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.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

605. Picture archiving and communication system overview

1. In general, what is a PACS?

2. What is a standard method used to transmit medical images across networked devices called?

3. What is the RIS used in Air Force MTFs?

4. What are the four basic system components of a PACS?

5. What is any source that sends images to the PACS?

6. What is the acquisition system worklist, and where is it located?

7. What is a display system?

8. What is the master-filing system within the archival system?

9. What is the responsibility of the PACS image manager?

10. What term is used to identify short-term storage on a PACS? Long-term?

11. Why is it necessary to have redundancies built into the various levels of storage within an archival system?

12. Define an interconnected computer network?

13. What does the IP address identify?

14. When a device is connected to a PACS, what *minimum* three requirements are needed?

15. What is teleradiology?

16. How does teleradiology reduce patient dose exposure?

17. Which peripheral component converts a piece of conventional film to an exact digital copy?

606. Composite Health Care System

1. Which portion of the CHCS password may the user change at any time?

2. What is the purpose of electronic security keys in the CHCS?

3. Why is it important to log off the CHCS terminal before leaving it?

4. List five functions performed with the CHCS in a DI department.

5. Why is the CHCS *not* actually a paperless system?

6. What is workflow?

607. System downtime functions

1. When the PACS malfunctions, who is responsible for figuring out the cause of the problem and finding a solution?

2. Who does the PACS administrator rely on for information to ultimately figure out the root of a problem?

3. What form is used when the CHCS is down to document radiology orders?

4. Why should every DI department have a contingency plan of operations?

5. In cases of irreversible disasters, whether from natural or intentional actions, what should every DI facility be prepared to do?

6. What are the three basic forms of system backups?

7. Match the region in column B with the USAF disaster-recovery backup location in column A. Each answer in column B may only be used once.

Column A	*Column B*
____ (1) Elmendorf AFB, Alaska.	a. West region.
____ (2) Scott AFB, Illinois.	b. West central region.
____ (3) Ramstein AB, Germany.	c. East Central region.
____ (4) Travis AFB, California.	d. East region.
____ (5) Lackland AFB, Texas.	e. European region.
____ (6) Langley AFB, Virginia.	f. Pacific region.

Answers to Self-Test Questions

601

1. 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.
2. A helium-neon laser.
3. It allows for the acquisition of diagnostic images even in slightly under or overexposed radiographs.
4. Vertical computer server towers.
5. To change the analog image information into a binary code so the computer can read it.
6. A digital-to-analog converter.
7. The combination of the cassette housing and the photostimulable phosphor screen located inside.

8. Barium fluorohalide coated with a trace amount of europium.
9. The process that allows stored light, following X-ray exposure, to be emitted later when exposed to a different type of light source.
10. The number of gray shades that are available for each pixel.
11. 256.

602

1. A solid-state flat-panel receptor or CCD.
2. It is a flat-panel receptor that is made up of either CsI tiled to a CCD array, CsI and an amorphous silicon thin-film transistor, gadolinium oxysulfide and an amorphous silicon thin-film transistor, or an amorphous selenium active matrix array.
3. A fiber optic assembly or a contact layer.
4. They are a semiconducting device that converts light into current.
5. A thin-film transistor.
6. Electrons; because they are sensitive to charges.
7. It is the process of emitting light.
8. In screen-film radiography, it is the intensifying screen within the cassette; in CR it is the photostimulable phosphors within the screen; and in DR the most common type is cesium iodide.
9. Indirect capture receptors change remnant radiation into light; direct capture receptors change remnant radiation directly into electrical signals.

603

1. As the field size decreases, the image's spatial resolution increases.
2. It will make sure the spatial resolution will be at its greatest for that particular image.
3. It is produced when the photostimulable phosphor screen is scanned parallel to stationary grid lines. Using a moving grid in a bucky system eliminates the artifact.
4. A high grid ratio (12:1) for fixed imaging, and a low grid ratio (6:1) for mobile imaging.
5. To only what is needed to expose the body part properly.
6. It increases the volume of tissue being irradiated and the amount of scatter radiation produced.
7. Between 60 and 110.
8. It is a result of insufficient X-ray transmission data caused by selecting the wrong mAs setting for the body part being imaged.
9. It refers to the efficiency of a detector in converting incident X-ray energy into an image signal.
10. DQE is better with DR than CR and is better with direct capture DR versus indirect capture.
11. Spatial resolution increases.
12. Because the digital images produced 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.

604

1. They are defined as any imaging acquisition process that produces an electronic image that can be viewed and manipulated via a computer.
2. The ability to manipulate the radiographic image before and after processing.
3. It is a graphic representation of the exposure values collected from the CR phosphor screen during the process of photostimulable luminescence.
4. 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.
5. Because the computer matches key points in the acquired image data to the look-up table that you select during preprocessing.
6. It represents the appropriate appearance for each pixel in terms of brightness (density) and contrast (gray tones).

7. After the ADC assigns a numerical value to each pixel corresponding to the electronic signals.
8. DR, prior to image acquisition; CR, before or after image acquisition.
9. Because mistakes often happen at this step, which causes the digital image to be displayed incorrectly.
10. Anything you do to the digital image after its acquisition to optimize the appearance of the image for improved pathological viewing.
11. Stitching.
12. The number of gray shades to be displayed on a particular image.
13. It determines the density, or brightness, of the structures shown on the digital image.
14. It takes into account signal values from the pixels surrounding the defective pixel to come up with an average value and assigns the averaged value for the defective pixel.
15. It is a condition created when an image receptor fails to release its entire electronic latent image completely.
16. The EI metric.
17. It is the result of technologists using more exposure technique than what necessarily might be needed to make certain they use enough technique to produce a radiographic image for interpretation.
18. To be a feedback mechanism to identifying possible over or underexposures.
19. It helps to show the adequacy of your exposure technique for each digital radiographic image.

605

1. It is a connection of multiple systems working together to provide medical-imaging communication, image access, and storage.
2. DICOM.
3. CHCS.
4. Acquisition device, display workstation, archival system, and an interconnected network.
5. An acquisition device.
6. It displays a list of patients that have a radiologic exam in “ordered” or “arrived” status in the CHCS; available on your acquisition station and is populated by CHCS. .
7. Any computer monitor that views digital radiographic images.
8. The image manager of a PACS.
9. Receiving, fetching, and distributing the stored images throughout the archival system as well as controlling all the archival system’s DICOM processes.
10. Cache; archive.
11. To copy data across several other hard drives, allowing for data restoration if one of the drives fails or becomes corrupt.
12. (1) Two or more digital/electronic objects 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.
13. Each device on the network to make sure data is sent to the proper destination.
14. The IP address, port number, and AE title.
15. It is the concept of sending digital radiographic images to another location for a radiologist to interpret.
16. Because similar exams do not need to be repeated every time a patient is transferred to a different MTF.
17. The film digitizer.

606

1. The verify code.
2. To limit the user’s access only to the functions needed to perform his or her job.
3. Because any operation performed under your password is directly attributable to you.
4. Any five of the following: (1) ordering exams, (2) viewing arriving- and departing-patient exams, (3) departing-patient exams, (4) scheduling exams, (5) tracking exam progress, (6) transcribing and electronically signing reports, (7) tabulating workload, (8) looking up scheduling backlogs (9) calculating patient wait times.

5. Because it has reduced paperwork, not eliminated it, such as when DI departments print a patient's hard copy of the examination order.
6. It consists of all the materials, services, and information that are systematically organized to perform complete a repeatable pattern of doing a task from beginning to end.

607

1. The PACS administrator.
2. You (the technologist).
3. SF 519B.
4. In case of an extended PACS downtime.
5. To recover and restore operations with minimal loss of information.
6. Full, incremental, and differential.
7. (1) f.
   (2) c.
   (3) e.
   (4) a.
   (5) b.
   (6) d.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (601) In computed radiography (CR), which component *records* the latent image?
   a. Photostimulable phosphor screen.
   b. Charge-coupled devices.
   c. Thin-film transistors.
   d. Photomultiplier tube.

2. (601) Scale of contrast adjustments are possible in computed radiography (CR) because photostimulable phosphor screens have a
   a. high exposure latitude.
   b. thick scintillation layer.
   c. narrow exposure latitude.
   d. high photoluminescent characteristic.

3. (601) In what *format* is the signal *acquired* in computed radiography (CR)?
   a. Binary.
   b. Digital.
   c. Analog.
   d. Pulsating.

4. (601) The purpose of the analog-to-digital converter is to
   a. upgrade the electrical signal.
   b. change the information into a binary code.
   c. assign whole numbers to the light intensity levels.
   d. change the signal into a format that allows the image to be displayed on a monitor.

5. (601) Which element is responsible for the storage characteristics, of the phenomenon known as photostimulable luminescence, in photostimulable phosphor screens?
   a. Europium.
   b. Silver halide.
   c. Crystal lattice.
   d. Barium fluorohalide.

6. (601) The workload of your imaging department and imaging plate maintenance determines the approximate life expectancy of a photostimulable phosphor screen. How many exposures *should* be expected from the screen?
   a. 5,000.
   b. 10,000.
   c. 15, 000.
   d. 25, 000.

7. (601) Which term refers to the number of gray shades that are available for each pixel in digitized signals?
   a. Matrix.
   b. Bit depth.
   c. Pixel pitch.
   d. Megapixel.

8. (602) Which type of direct radiography device is sensitive to electrical charges that gather electrons?
   a. Photodiode.
   b. Thin-film transistors.
   c. Charge-coupled device.
   d. Cesium iodide fiber optic bundles.

9. (603) What is the *optimum* kilovoltage peak (kVp) range for computed radiography (CR) when acquiring an image?
   a. 60 to 80.
   b. 60 to 100.
   c. 60 to 110.
   d. 60 to 120.

10. (603) When choosing an exposure technique, what factor causes a quantum mottle effect on your image, if it is *insufficient* for the body part being imaged?
    a. Time.
    b. Milliamperage (mA).
    c. Kilovoltage peak (kVp).
    d. Milliamperage and seconds (mAs).

11. (603) In direct radiography (DR), what is used to evaluate the quality of a digital image in relationship to noise and contrast?
    a. Signal-to-noise ratio and quality of the useful beam.
    b. Signal-to-noise ratio and spatial frequency.
    c. Detective quantum efficiency.
    d. Modulation transfer function.

12. (603) In direct radiography (DR), which signal-to-noise ratio is recommended as a *low* system noise for a better quality image?
    a. 1000 to 1.
    b. 500 to 1.
    c. 200 to 1.
    d. 100 to 1.

13. (603) When manually performing beam-part-image receptor alignment, when should you align the transverse reference line displayed by the collimator light to the center of the computed radiography (CR) image receptor?
    a. After closing the bucky tray.
    b. When the bucky tray is open.
    c. Prior to inserting the CR cassette.
    d. Prior to the patient entering the room.

14. (604) A graphic representation of the densities collected from a computed radiography phosphor screen is a/an
    a. voxel.
    b. algorithm.
    c. histogram.
    d. look-up table.

15. (604) Why would you refer to look-up tables before processing an image?
    a. To demonstrate the photoluminescent values of the phosphor screen graphically.
    b. To represent all the exposure values along every point of the image receptor graphically.
    c. To allow the computer to map key points in the matrix that you select during post processing.
    d. To provide a method for mapping the exposure values along every point of the image receptor.

16. (604) What type of condition is created when an image receptor fails to release the electronic latent image completely?
    a. Image lag.
    b. Line noise.
    c. Quantum mottle.
    d. Signal interpolation.

17. (605) What is considered the master filing system within the archival component of the picture archiving and communication system?
    a. Cache manager.
    b. Image manager.
    c. Virtual storage server.
    d. Redundant array of independent disks server.

18. (605) What picture archiving and communication system component allows exams to be visualized simultaneously at different locations throughout a medical treatment facility?
    a. Image manager.
    b. Global satellites.
    c. Network interface card.
    d. Interconnected network.

19. (605) Which three pieces of information are the *minimum* requirements for connecting a device to a picture archiving and communication system?
    a. Port number, application entity, and structured query address.
    b. Internet protocol address, port number, and application entity title.
    c. Hypertext transfer protocol, internet protocol address, and health level–7 title.
    d. Digital imaging and communication in medicine, health level–7 title, and port number.

20. (605) What type of *network* is used to send digital images from one facility to another facility anywhere in the world?
    a. Wireless.
    b. Wide area.
    c. Local area.
    d. Fiber optic.

21. (605) Which peripheral picture archiving and communication system device converts an analog image into an exact digital copy?
    a. Film imager.
    b. Film digitizer.
    c. Image duplicator.
    d. Compact disk burner.

22. (605) Which component of a picture archiving and communication system allows you to produce hard copy films?
    a. Imager.
    b. Network.
    c. Digitizer.
    d. CD burner.

23. (606) Which characteristic of the Composite Health Care System limits individual user's access to certain system functions such as ordering radiologic procedures?
    a. Menus.
    b. Passwords.
    c. Hidden commands.
    d. Electronic security keys.

24. (606) In the Composite Health Care System, primary menus are assigned to each
    a. terminal.
    b. user password.
    c. electronic security key.
    d. group of terminals in a functional area.

25. (607) What form do physician use to request radiologic exams when the Composite Health Care System connection is down?
    a. AF Form 601.
    b. AF Form 623a.
    c. Standard Form 519b.
    d. Department of Defense Form 1348–6.

26. (607) Which type of picture archiving and communication system backup copies data on the system from the last *full* backup?
    a. Cache.
    b. Redundant.
    c. Differential.
    d. Incremental.

Please read the unit menu for unit 2 and continue ➔

Student Notes

Unit 2. Fluoroscopy and Mobile Radiography

2–1. Fluoroscopy 2–1
608. Digital fluoroscopy 2–1
609. Image intensification 2–6
2–2. Mobile Radiography 2–10
610. Operating mobile equipment in inpatient care areas 2–11
611. Operating mobile equipment in the operating room 2–14

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.

2–1. 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.

608. 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.

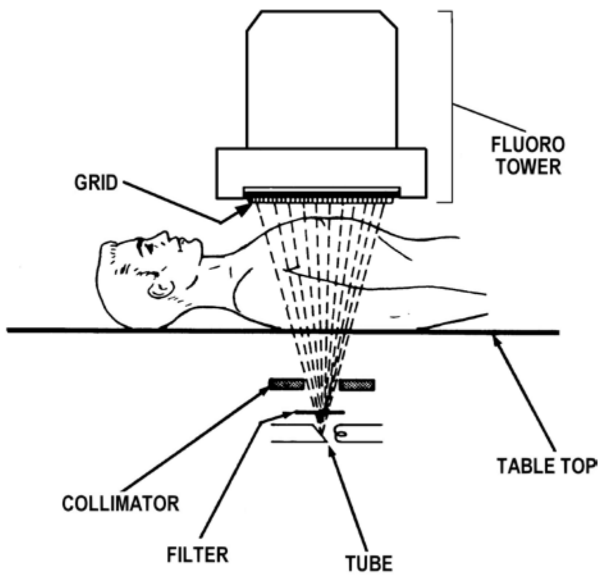


Figure 2–2. Standard fluoroscopic equipment design.

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 nonuniform 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.

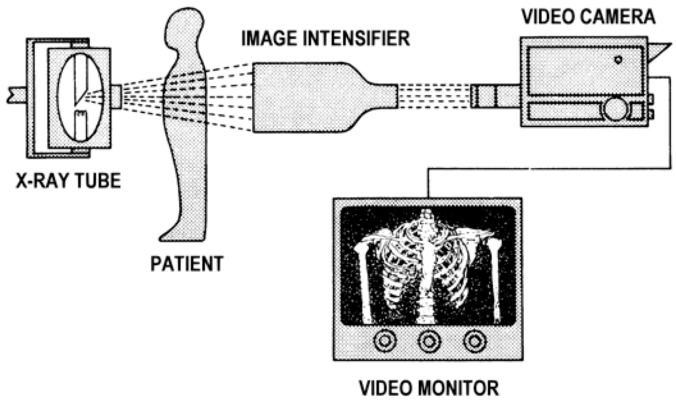


Figure 2–3. Fluoroscopic video monitor schematic.

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 the patient 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 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 postprocedure overhead radiographs (as necessary).
- Discussing and providing postprocedure care instructions to the patient and answering any questions he or she may have.

609. 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.

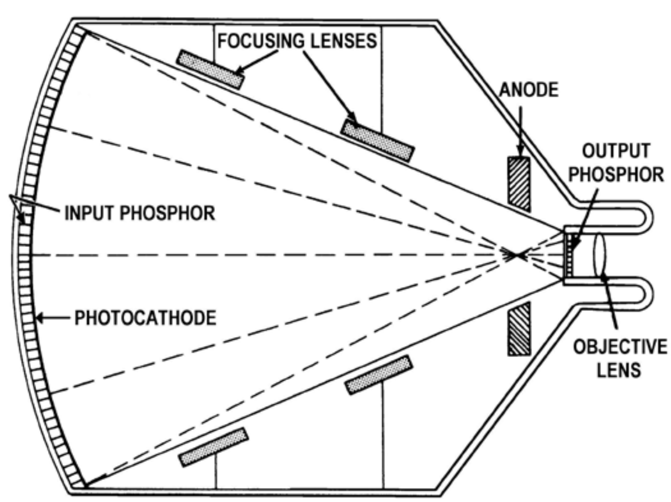


Figure 2–4. Image-intensifier tube.

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.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

608. Digital fluoroscopy

1. Where is the X-ray tube located in most fluoroscopic units?

2. What is the *minimum* allowable tube-to-tabletop distance for fluoroscopy?

3. What is the normal current level for conventional fluoroscopic X-ray tubes?

4. Since the tube operates in radiographic mode during digital fluoroscopy, how is tube current measured?

5. What are the two types of image receptors used in digital imaging?

6. Name the seven advantages flat-panel image receptors have over CCDs.

7. What type of monitor used in DI is lightweight and allows images to be easily viewed?

8. What is the only disadvantage of active-matrix LCDs?

9. What is video used for in fluoroscopy?

10. In digital fluoroscopy, what is the video tubes' *minimum* required signal-to-noise ratio? What does the ratio mean?

11. At what point does the fluoroscopy exposure timer usually trigger an audible alarm?

12. What two attachments are securely fastened to the radiographic table to allow the patient to be safely rotated into a trendelenberg or upright position?

13. When wearing a front-covering lead apron, what should you *never* do when the fluoroscopy is on during a fluoroscopy examination?

14. Many types of fluoroscopic procedures should be performed only by a physician. Why?

15. List four different types of physicians trained in the use of fluoroscopy.

16. What is the traditional role of the radiographer during fluoroscopy?

609. Image-intensification

1. Match the image intensifier component in column B with the appropriate function in column A. Each item in column B may be used only once.

Column A	Column B
____ (1) Converts the light image into an equivalent electron form through a process called photoemission.	a. Input phosphor.
____ (2) Part of the viewing system that collects the diverging light image and converts it into a parallel beam image.	b. Photocathode.
____ (3) Places a potential difference of about 25–30 kV across the tube.	c. Anode.
____ (4) Converts remnant radiation into a visible image.	d. Focusing lenses.
____ (5) Converts the electron image back into light.	e. Output phosphor.
____ (6) Focuses the electron image down to the size of the output phosphor.	f. Objective lens.

2. What two factors affect brightness gain during image intensification?

3. What is the standard range for brightness gain for most image intensifiers?

4. What is the ultimate disadvantage associated with magnifying the fluoroscopic image?

2–2. 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.

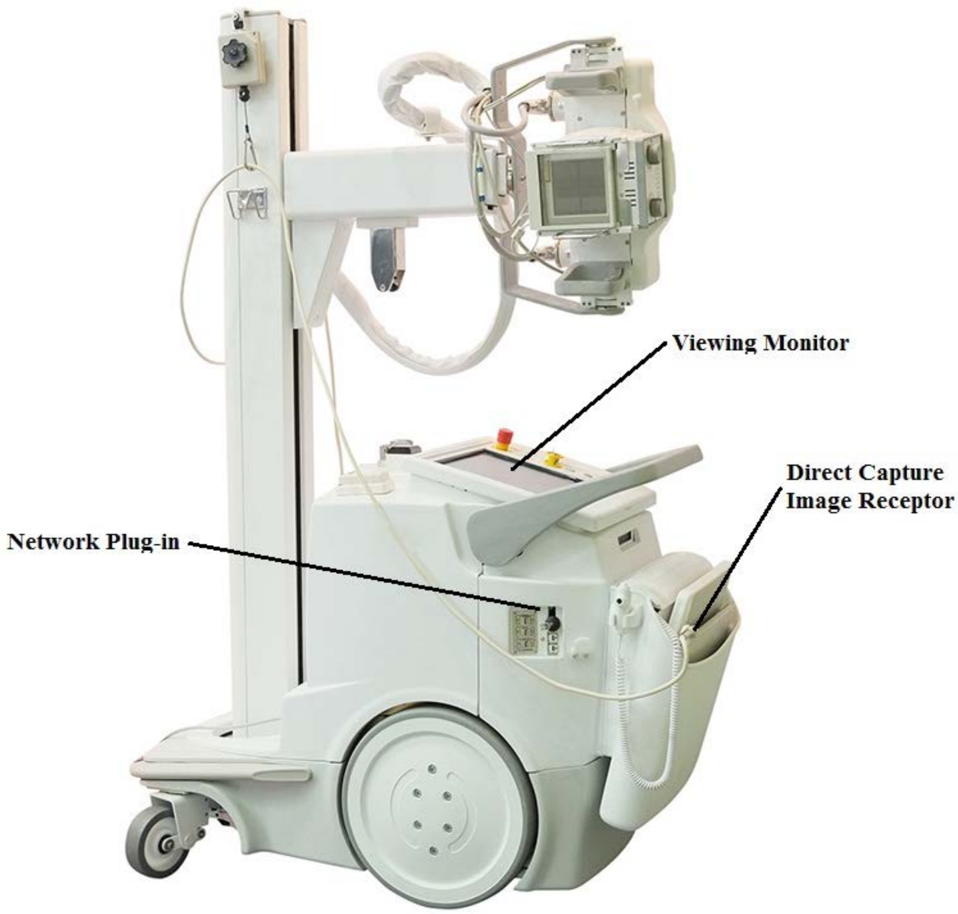


Figure 2–5. Direct capture (direct radiography) mobile imaging machine.

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

610. 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 infant patient's nurse and identify to him or her which infant you are imaging. Survey the unit for any hazards, and scan the nursery 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 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 and anger the ICU staff.

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.

611. 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 facility ; 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 certiain 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. If you do, one thing is certain—the individual will not be happy and you will likely be told to exit the OR suite, requiring another DI member to replace you.

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 anesthethic 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.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

610. Operating mobile equipment in in-patient care areas

1. Why are radiographs on newborns usually requested as mobile exams?

2. Why should you leave your mobile X-ray unit outside the neonatal nursery when you first arrive?

3. What is the purpose of an incubator?

4. When an imaging tray is available underneath the incubator, why should it be used versus placing the image receptor directly under the infant?

5. What can be done to reduce the risk of infection if the incubator does not have an imaging tray?

6. When should you retrieve the mobile X-ray unit and bring it into the nursery?

7. Why should you include the lead shielding device within the edge of the collimated X-ray field?

8. What special circumstances in the ICU environment can create problems when performing mobile radiographs?

9. What should you do before attempting to move or adjust any of the equipment connected to an ICU patient?

10. When positioning a patient with a chest tube, how should you roll or lift the patient for receptor placement?

11. What action should you *always* take before bringing the mobile X-ray unit into an ICU room?

12. Why is it important to explain what you are doing to the patient even if the person is unconscious?

13. Who should you check with if you are unsure what movements are tolerable for a patient in orthopedic traction?

14. Why should you *never* try to release traction without the assistance of nursing personnel?

15. Why should you contact the patient’s nurse to see if it is a good time for the staff and patient to take the portable image?

16. What is the *minimum* SSD requirement for mobile radiography?

17. What is the *minimum* recommended distance to stand away from the radiation source?

18. What is the *minimum* amount of lead equivalent for a protective apron used during mobile radiography?

19. What is the proper method of announcing you are ready to make an exposure with the mobile X-ray machine?

20. When should you say “clear” loudly?

611. Operating mobile equipment in the operating room

1. Why must special surgical clothing, or scrubs, be worn in the OR?

2. Why should all clothes and undergarments worn in the operating room be made of cotton?

3. When must shoe covers be discarded?

4. What does it mean to wipe down the mobile X-ray or C-arm unit thoroughly?

5. Some surgeons may require you to cover the tube head. Why would this be necessary?

6. What is included in the sterile area of the OR?

7. Who are the only people allowed in the sterile corridor?

8. Why must you align the X-ray beam perpendicular to the image receptor?

9. Why is speed important when performing mobile radiographs in the OR?

10. How can you help prevent grid cutoff when performing mobile radiography in the OR?

11. When should you ensure sterile members of the surgical team don lead gowns?

12. Where is a TLD worn in the OR when you have on a lead gown?

13. When you are running the C-arm unit in for a surgical procedure, why should you state "X-ray on" and "X-ray off"?

Answers to Self-Test Questions

608

1. Within the patient-positioning table.
2. 12 inches.
3. Less than 5 mA.
4. In hundreds of mA.
5. A CCD or a flat-panel image receptor.
6. They are (1) smaller, (2) lighter, (3) allow for easier over-the-patient movement, (4) capture the image uniformly over the entire receptor, (5) distortion-free images, (6) improved contrast resolution, and (7) images are acquired in a square/rectangle format, better associating with the display monitor.
7. Active-matrix LCDs.
8. Angular dependency of viewing.
9. Live viewing of the fluoroscopic image.
10. 1000 to 1, meaning the output signal strength will be 1000 times stronger than the inherent background noise.
11. After 5 minutes.
12. The footboard and shoulder rest.
13. Turn your back to the fluoroscope.
14. Because of the potential for injury to the patient or because the exam itself is interpretive in nature.
15. Orthopedic surgeons, pulmonologists, gastroentereologists, and radiologists.
16. To set up the equipment, gather all necessary supplies, and assist the radiologist during the procedure.

609

1. (1) b.
   (2) f.
   (3) c.
   (4) a.
   (5) e.
   (6) d.
2. Electron acceleration and image minification.
3. Between 5,000 and 30,000 times brighter.
4. Higher patient exposure dose to compensate for the reduction in minification gain.

610

1. To maintain reverse isolation, which protects the newborn from potential sources.
2. To speak to the nurse, identify which infant you are imaging, and to perform a general survey of your surroundings to identify any hazards.
3. To provide extra warmth, moisture, and oxygen to the infant to facilitate growth, while reducing the possibility of the newborn being exposed to an airborne infectious agent.

4. To reduce the risk of infection to the infant.
5. 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.
6. 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.
7. To serve as documented proof that shielding was used.
8. Large amounts of life-sustaining equipment connected to the patient by a maze of cables and tubes.
9. 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.
10. Toward the tube.
11. Survey the immediate area around the patient's bed.
12. The patient may be aware of what is going on even if he or she is unable to respond.
13. Nursing personnel who are familiar with the patient's condition.
14. Because the sudden release of traction can cause serious complications such as bone fragments lacerating a blood vessel or pain-induced shock.
15. Because most routine portable exam orders do not need to interrupt a patient's meal time, nap, or visitation time with family and friends.
16. 12 inches.
17. 6 feet.
18. 0.25 mm.
19. Say "X-ray" loudly.
20. After the exposure is complete.

611

1. To reduce the amount of bacteria introduced into the OR.
2. To prevent the discharge of static electricity, which could cause a flash fire due to the oxygen and other flammable gasses used by the anesthetist.
3. Once they are worn outside of the surgery area.
4. Using a germicidal wipe to disinfect the entire piece of equipment, concentrating on areas of the mobile unit that are inherently the dirtiest.
5. To further reduce the danger of contamination.
6. Areas immediately surrounding the patient, his or her incision, the surgeon and the surgical assistant, surgical instruments, the tables, trays, and stands that hold the instruments; and the sterile corridor.
7. The surgeon and surgical assistant.
8. So there is no shape distortion of the body part.
9. To minimize the amount of time the patient is under anesthesia.
10. Use a grid with a low grid ratio.
11. Prior to making an exposure.
12. At the collar level and outside of your clothing and your lead gown.
13. To communicate the need for OR staff members to step back and seek lead protection, and to communicate with the surgeon that you heard and performed his or her request for an image.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

27. (608) What is the *minimum* amount of total permanent filtration used to filter the fluoroscopic beam?
    a. 1.0 mm aluminum equivalent.
    b. 2.0 mm aluminum equivalent.
    c. 2.5 mm aluminum equivalent.
    d. 3.5 mm aluminum equivalent.

28. (608) Which is *not* a function, or part, of the digital fluoroscopic tower?
    a. Allows for operation of the imaging system.
    b. Serves as an image receptor.
    c. Houses the video camera.
    d. Houses the X-ray tube.

29. (609) During image intensification, which system component converts the light image into an equivalent electron form?
    a. Photocathode.
    b. Input phosphor.
    c. Focusing lenses.
    d. Output phosphor.

30. (609) Which image intensification system component *reduces* the electron image down to the size of the output phosphor that is free of distortion?
    a. Collimator.
    b. Focusing cup.
    c. Focusing lenses.
    d. Objective lenses.

31. (610) Which precautionary method, if any, is *normally* used when performing mobile radiography in the neonatal nursery?
    a. Sterile technique.
    b. Isolation technique.
    c. Reverse isolation technique.
    d. No special precautions are normally required.

32. (610) Before moving an infant from the incubator, you should *first* seek permission from the
    a. radiologist.
    b. obstetrician.
    c. infant's mother.
    d. neonatal nursing staff.

33. (610) Before performing a mobile radiograph in the intensive care unit (ICU), you should *always*
    a. discuss the situation and the patient's condition with nursing personnel.
    b. disconnect any cables or wires that would interfere with the radiographic examination.
    c. become familiar with the operation of the various life-sustaining equipment used in ICU.
    d. find out if the patient can be brought to the radiology department for a better quality exam.

34. (610) Which action should you take *before* leaving the radiology department to perform a routine mobile radiographic examination?
    a. Disinfect the mobile X-ray unit.
    b. Ensure the mobile X-ray unit is charged to full capacity.
    c. Call the requesting physician to make sure it needs to be a portable exam.
    d. Call the patient’s nurse to ensure you arrive at a good time for the patient and staff.

35. (610) During mobile radiography, what is the *minimum* source-to-skin distance (SSD) allowed?
    a. 10 inches.
    b. 12 inches.
    c. 15 inches.
    d. 18 inches.

36. (610) Which item *must* be kept with a mobile X-ray unit?
    a. Grid.
    b. Lead apron.
    c. Technique chart.
    d. Germicidal disinfectant.

37. (611) Why is it a requirement to change into scrubs *prior* to entering the restricted area of the operating room?
    a. To identify members authorized in and around the surgical area.
    b. To reduce the amount of bacteria introduced into the surgical area.
    c. To allow surgical members more comfort during long surgical cases.
    d. To prevent your regular uniform from being stained by blood and other body fluids.

38. (611) Why are scrubs, which all surgery department personnel *must* wear, made of cotton?
    a. They can be sterilized.
    b. They are more comfortable.
    c. To prevent static electricity discharge.
    d. To reduce the infectious agents brought into the operating room.

39. (611) To reduce the amount of bacteria introduced into the operating room, you *must*
    a. use standard precautions.
    b. remain within the sterile corridor.
    c. keep a mobile X-ray unit in the surgery department at all times.
    d. clean the mobile unit with a germicidal wipe before entering the restricted area.

40. (611) Why is performing mobile radiographs in the operating room quickly such a critical factor?
    a. To minimize the anesthesia time.
    b. Because surgeons are very impatient.
    c. Because the operating room schedule is very tight.
    d. To further reduce the risk of infection from the mobile unit.

41. (611) You can help prevent grid cutoff when performing mobile radiographs on larger body parts in the operating room by using a grid with a
    a. low ratio.
    b. high ratio.
    c. low frequency.
    d. high frequency.

42. (611) When wearing a lead gown in the operating room, place a *single* thermoluminescent dosimeter (TLD) at the level of your
    a. waist line, outside of the lead gown.
    b. collar, under the lead gown.
    c. collar, outside of the lead gown.
    d. waist line, under the lead gown.

Please read the unit menu for unit 3 and continue ➔

Student Notes

Unit 3. Computed Tomography

3–1. Fundamentals of Computed Tomography 3–1
612. Technical aspects of computed tomography image formation 3–1
613. Types of computed tomography scanners..3–7
614. Cross-sectional anatomy 3–12
3–2. Computed Tomography System Components 3–22
615. Gantry assembly and patient couch apparatus 3–22
616. Computer system 3–25
617. Operator's console..3–27
3–3. Patient Preparation and Radiation Safety 3–34
618. Patient preparation..3–34
619. Radiation safety in computed tomography 3–39

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.

3–1. 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.

612. 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.

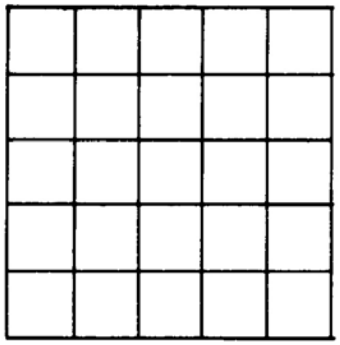
Image visualization creation

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.

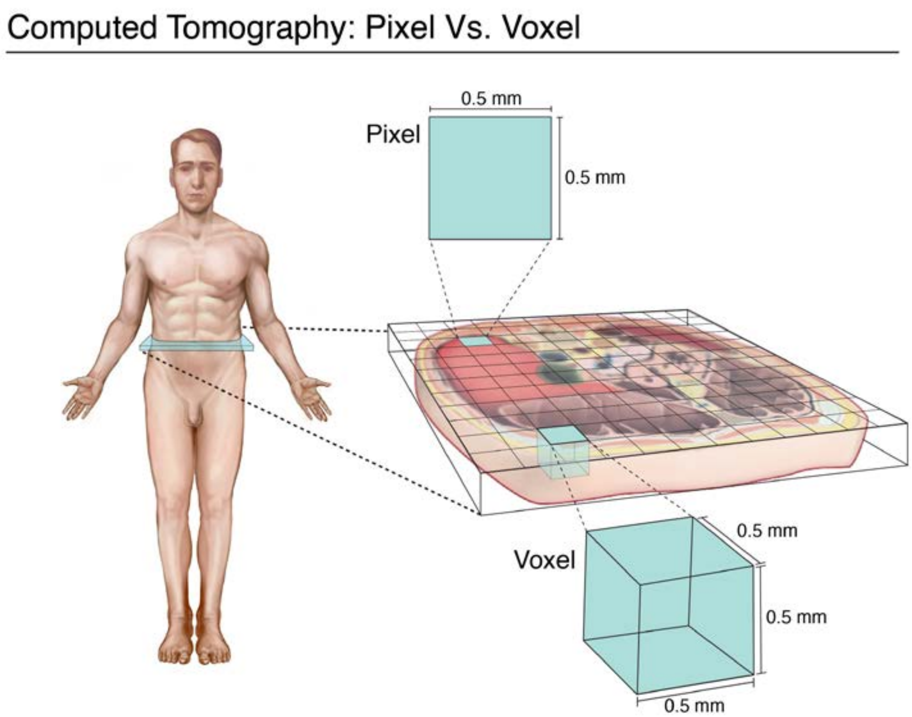


Figure 3–2. Pixel and voxel CT slice illustration.

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.

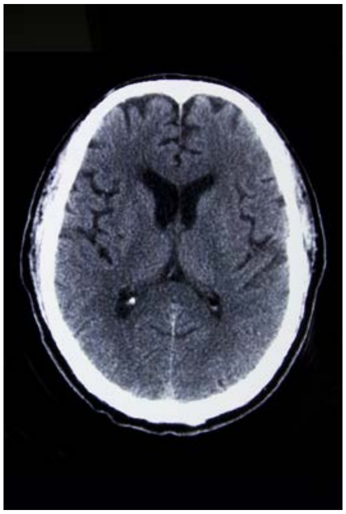


Figure 3–4. Axial CT scan through the middle of the skull.

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 postprocessing 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 postprocessing 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.

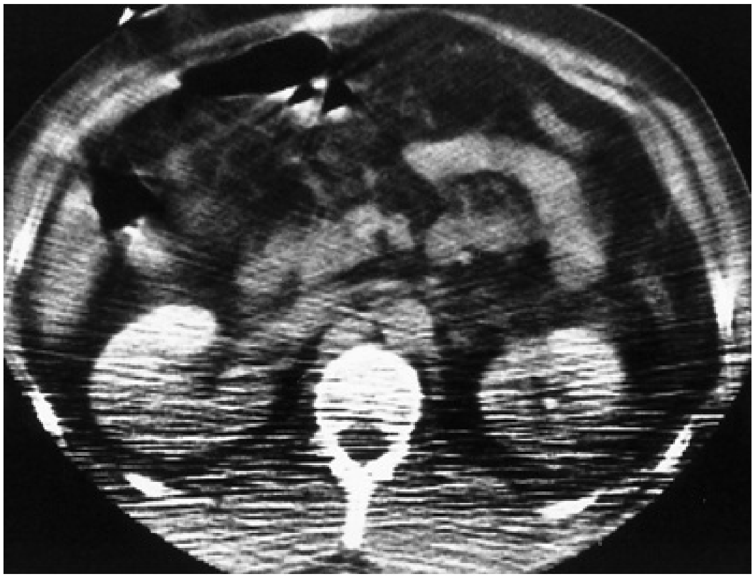


Figure 3–5. Beam-hardening artifact.

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.

613. 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 multislice 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.

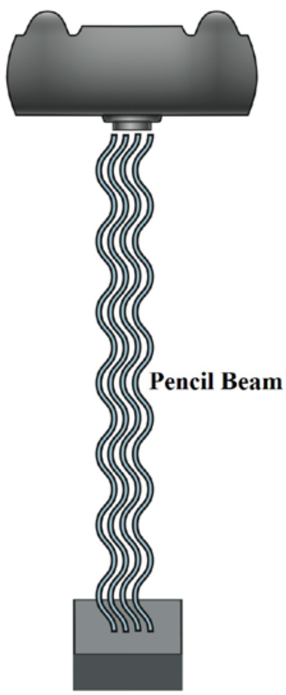


Figure 3–6. First-generation scanner pencil beam.

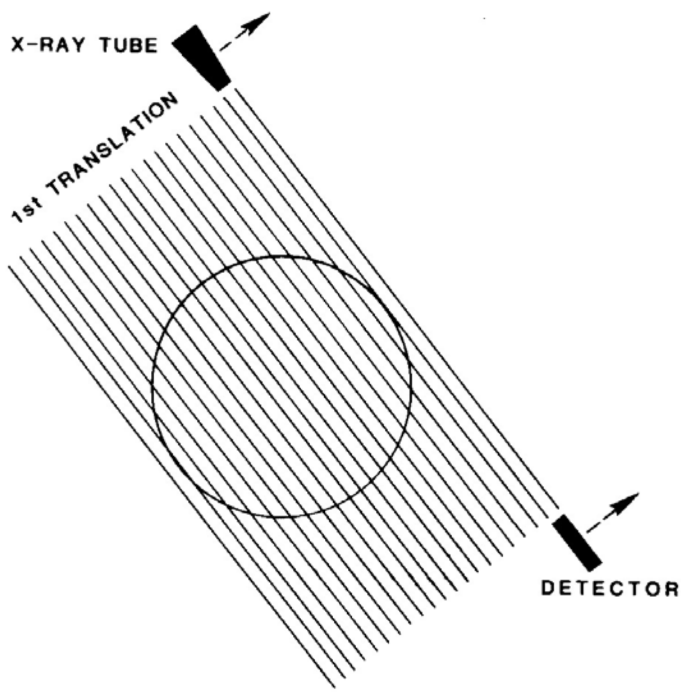


Figure 3–7. First-generation scanner translation movement.

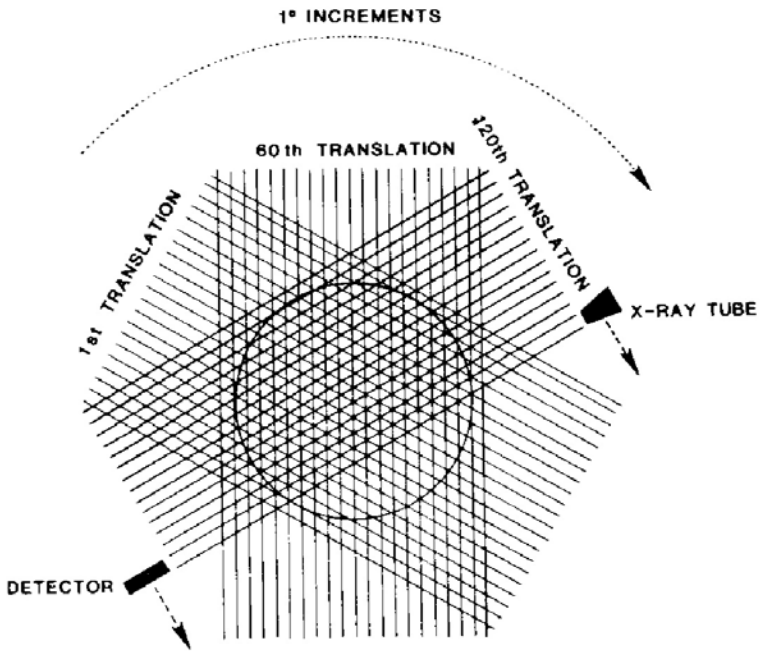


Figure 3–8. First-generation scanner translation and rotation movements.

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.

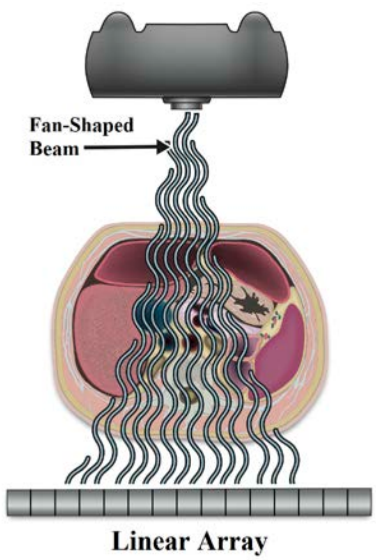


Figure 3–9. Second-generation scanner fan beam and linear detector array illustration.

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.

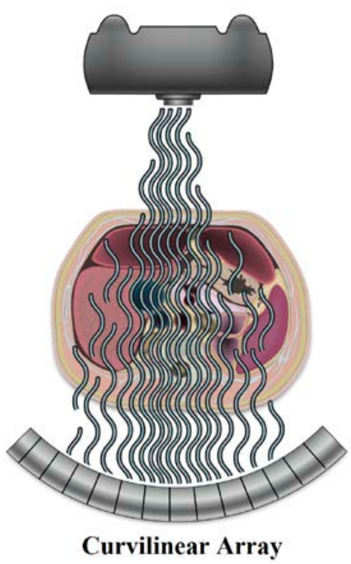


Figure 3–10. Curvilinear third-generation detector array illustration.

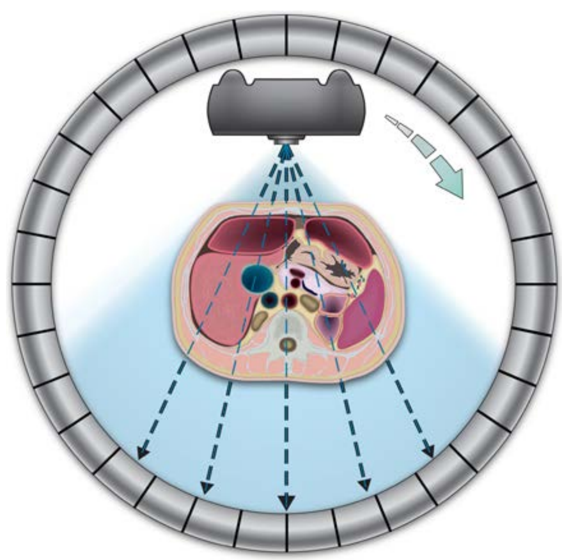


Figure 3–11. Fourth-generation CT scanner detector configuration.

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.

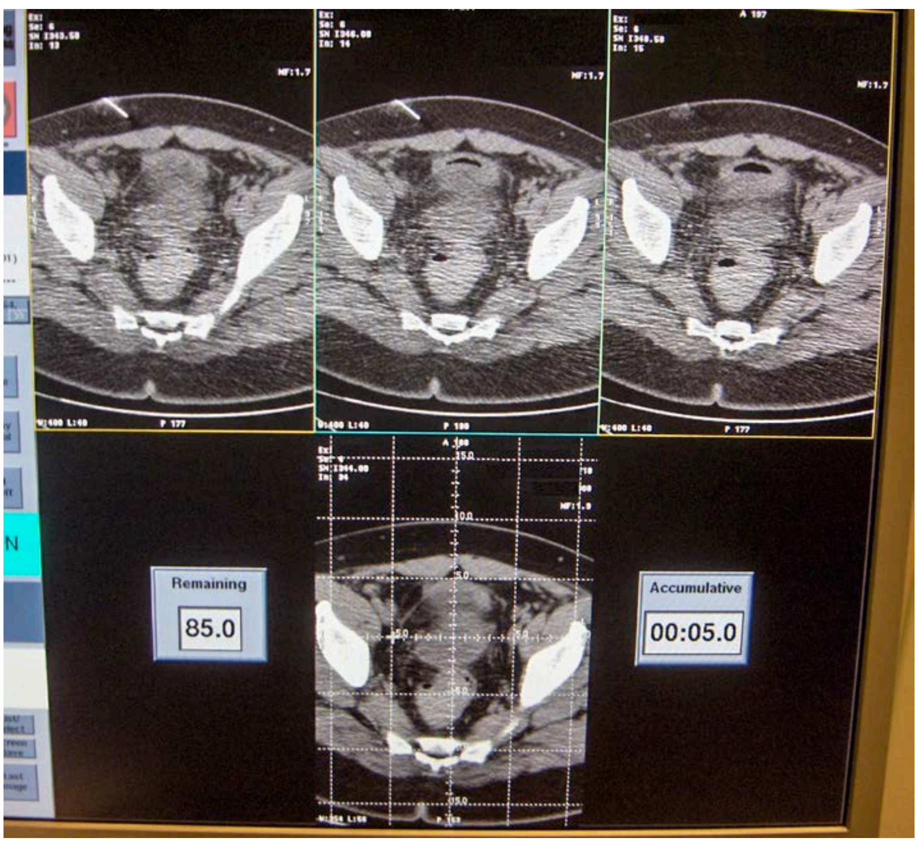


Figure 3–12. Sample images using real-time CT imaging.

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.

614. 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.

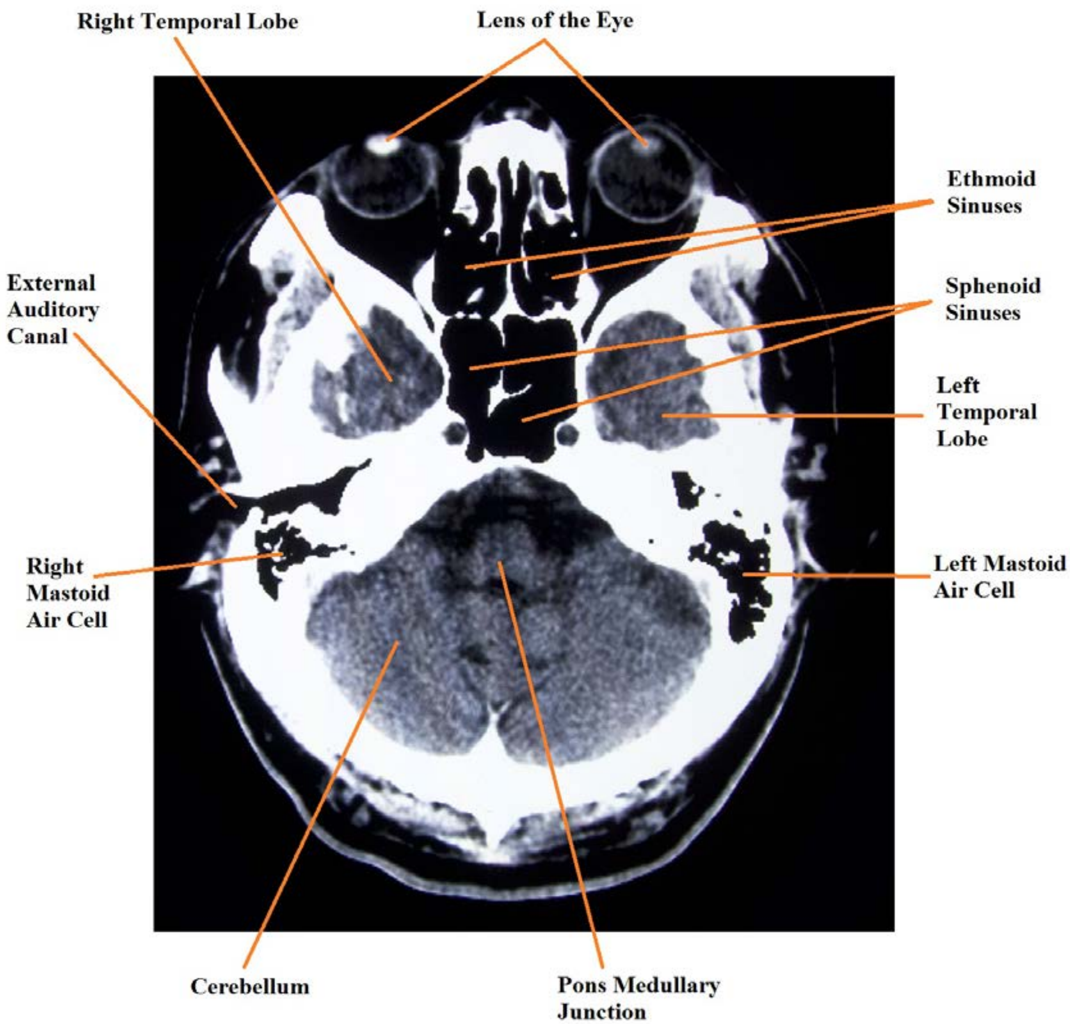


Figure 3–14. Illustration of cross-sectional anatomy displayed within figure 3–13.

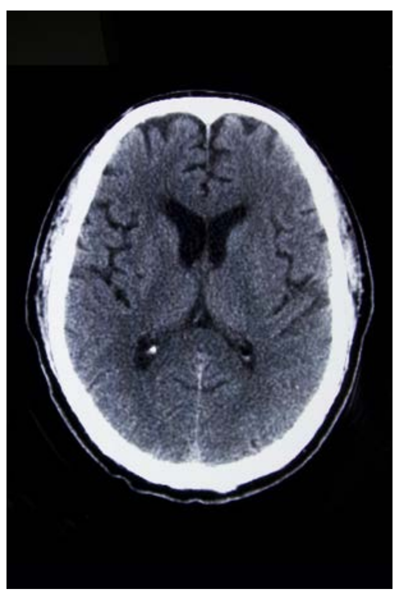


Figure 3–15. Middle portion of the brain axial CT image.

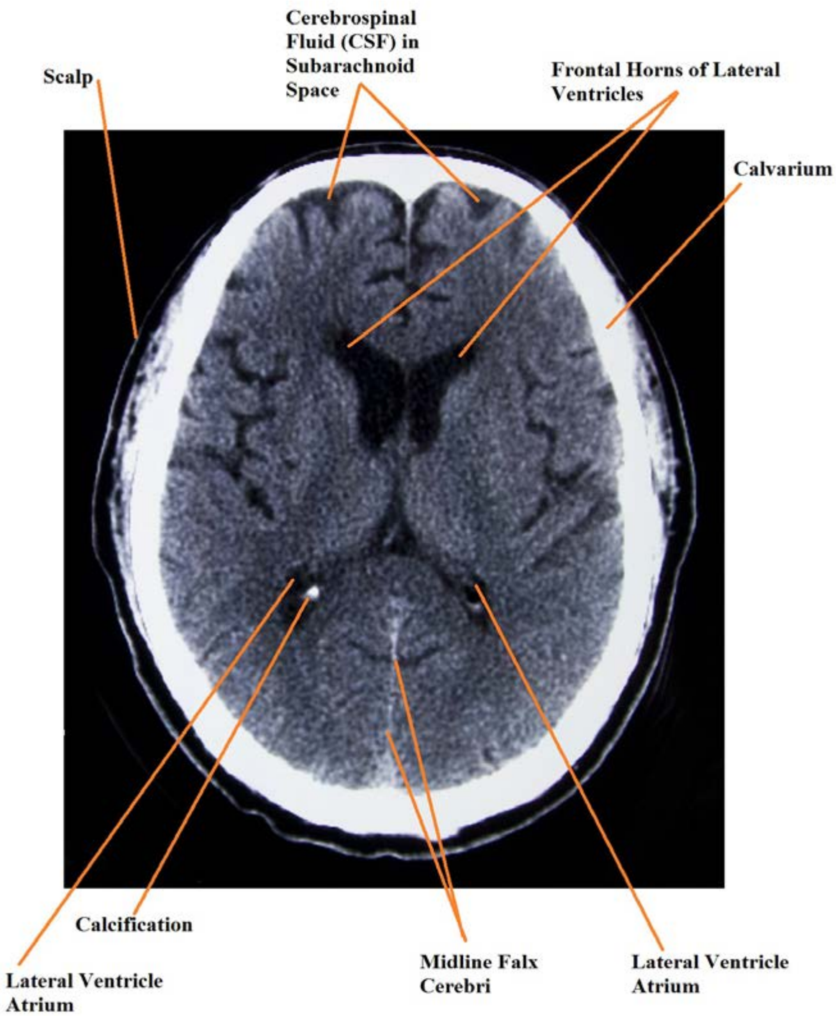


Figure 3–16. Illustration of cross-sectional anatomy displayed within figure 3–15.

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.

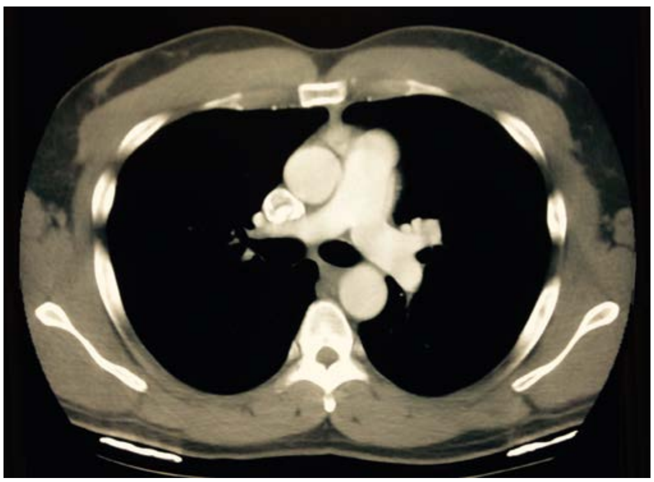


Figure 3–17. Axial CT image of the chest displayed in a soft-tissue window setting.

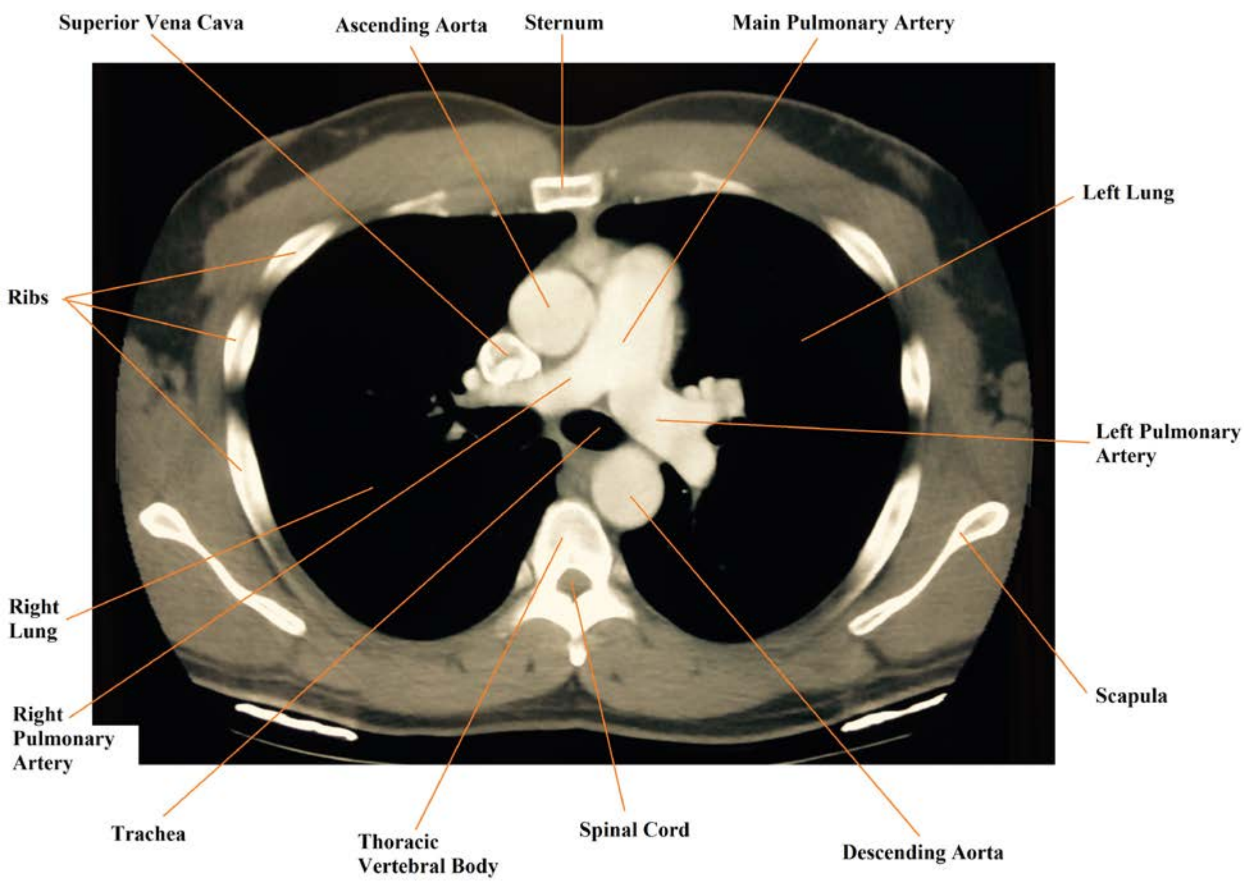


Figure 3–18. Illustration of cross-sectional anatomy displayed within figure 3–17.

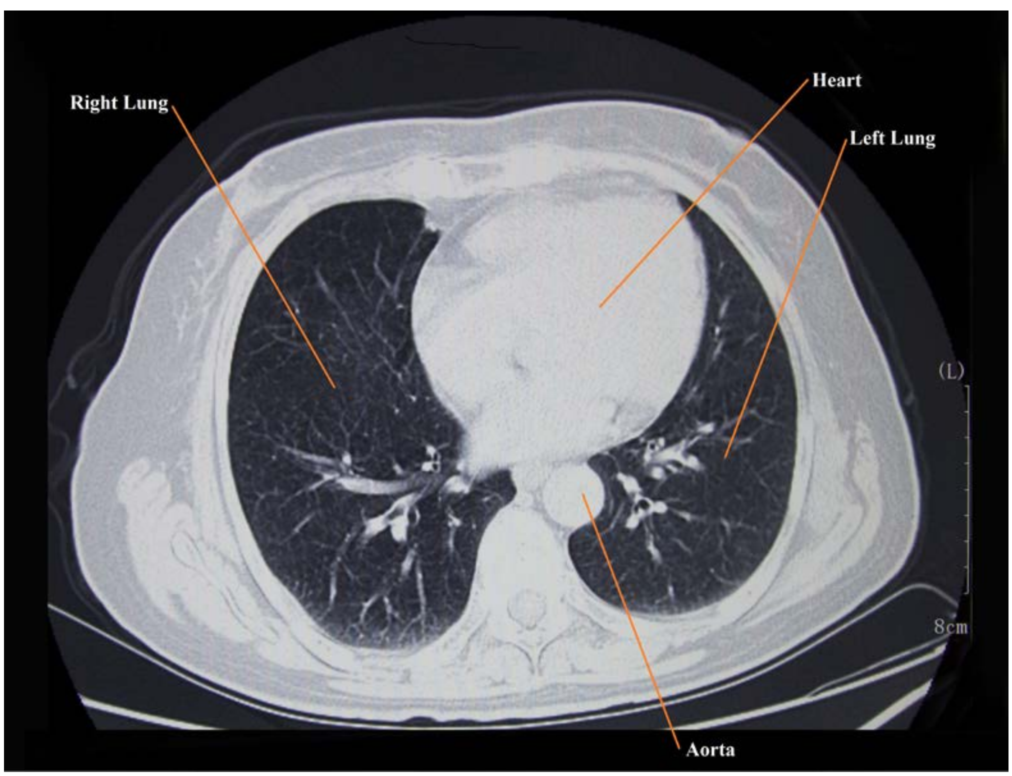


Figure 3–19. Illustration of cross-sectional chest anatomy displayed with a lung window setting.

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.

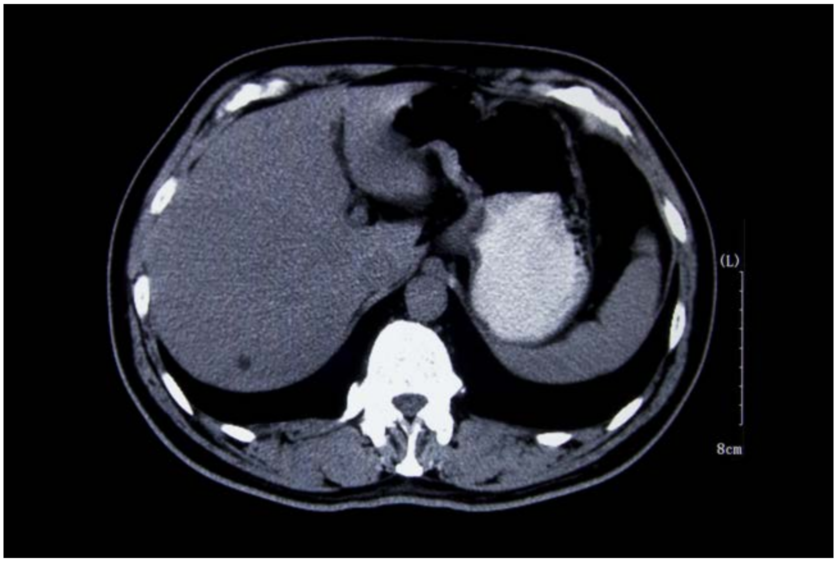


Figure 3–20. Axial CT image of the upper abdomen.

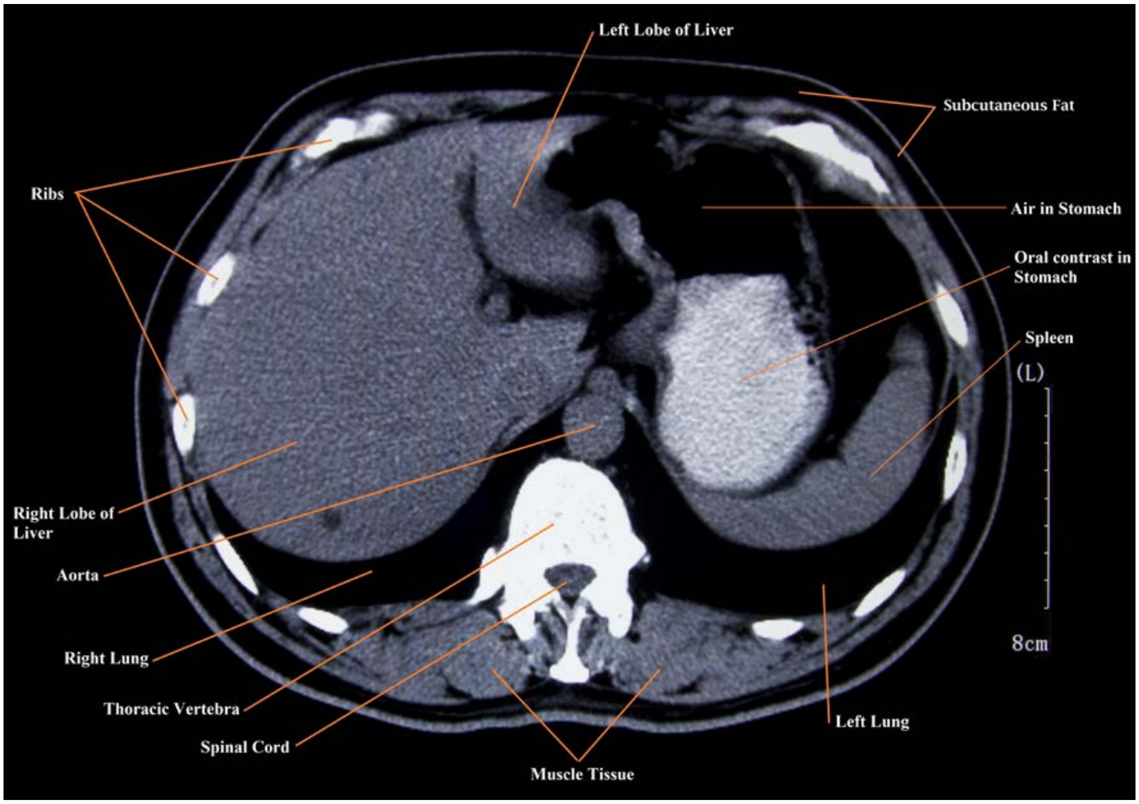


Figure 3–21. Illustration of cross-sectional anatomy displayed within figure 3–20.

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

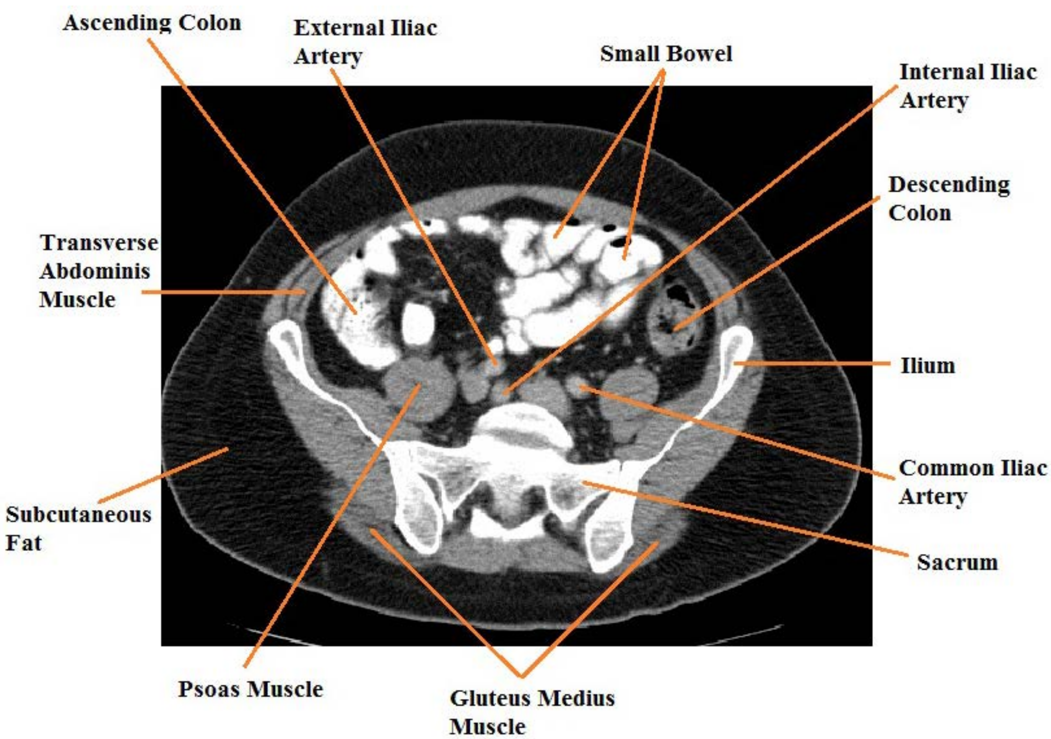


Figure 3–23. Illustration of pelvic cross-sectional anatomy displayed within figure 3–22.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

612. Technical aspects of computed tomography image formation

1. In CT, what does the X-ray tube do while the body part is exposed?

2. As the detector assembly captures remnant radiation, a signal is created. What is assigned to each of the signals?

3. How does the CT computer calculate the density of an object?

4. What does the linear attenuation coefficient represent?

5. What is a matrix?

6. Which CT image matrix provides for increased image detail: 256 x 256 or 512 x 512? Why?

7. What does a pixel on a CT image represent?

8. What are numbers called that are assigned to each pixel in the matrix of an image representing the linear attenuation coefficient of the tissue density within each voxel?

9. Why is water used as a reference point for Hounsfield units? What value is it assigned on the Hounsfield scale?

10. In comparing conventional radiography and CT, which is better at imaging soft tissue? Why?

11. Why is CT able to provide excellent high-contrast resolution?

12. How does noise appear on a CT image?

13. What artifact can result from greater attenuation of low-energy X-ray photons than high-energy X-ray photons as they pass through tissue?

14. What type of CT artifact is produced when image noise results from insufficient X-ray transmission data caused by inappropriate radiation settings for the size of the patient?

613. Types of computed tomography scanners

1. Match the CT scanner generation in column B with the appropriate description in column A. Each answer in column B may be used more than once. Each description in column A may have more than one correct answer.

Column A	*Column B*
____ (1) Uses a 360° rotation-only movement.	a. First-generation.
____ (2) Uses a fan-shaped beam.	b. Second-generation.
____ (3) Uses translation-rotation movement.	c. Third-generation.
____ (4) Uses a pencil-shaped beam.	d. Fourth-generation.
____ (5) Times to scan reduced to around 20 seconds/slice.	
____ (6) Uses a curvilinear detector array.	

2. What does slip-ring technology allow that previous CT scanner generations did not?

3. What type of scanning has developed as a result of slip-ring technology?

4. What major technical advancement was introduced in CT imaging?

5. What is the key advantage of MDCT?

6. What does pitch reference?

7. What type of pitch ratio allows for a greater coverage area being imaged and a reduction in radiation dose to the patient?

8. What type of CT technology allows for real-time CT imaging?

9. What type of CT unit uses two X-ray sources and two X-ray detectors to expose tissues simultaneously to determine how tissue behaves at different radiation energy levels?

614. Cross-sectional anatomy

1. How does the axial plane transect the body?

2. When viewing cross-sectional CT images of the body, how are the images displayed?

3. Identify the lower cranium/brain cross-sectional anatomy displayed in figure 3–24.

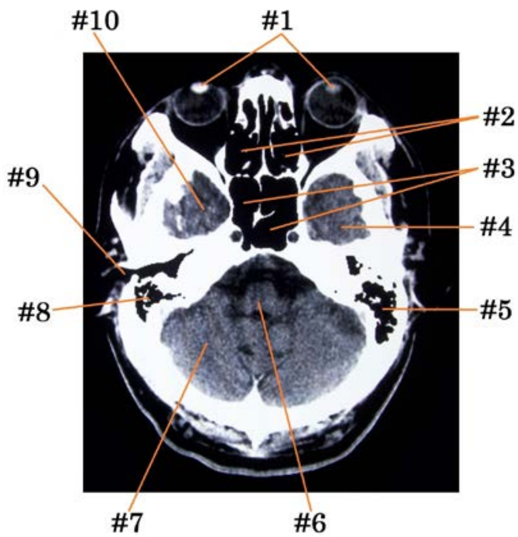


Figure 3–24. CT axial cross-sectional image of the cranium/brain.

4. Identify the middle brain cross-sectional anatomy displayed in figure 3–25.

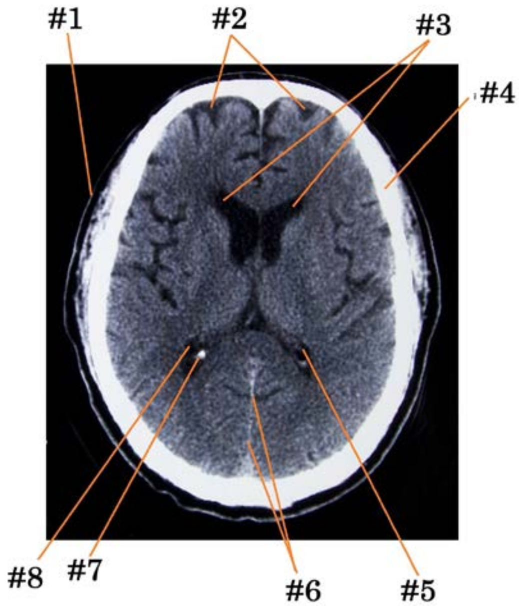


Figure 3–25. CT axial cross-sectional image of the middle brain.

5. Identify the thoracic cross-sectional anatomy displayed in figure 3–26.

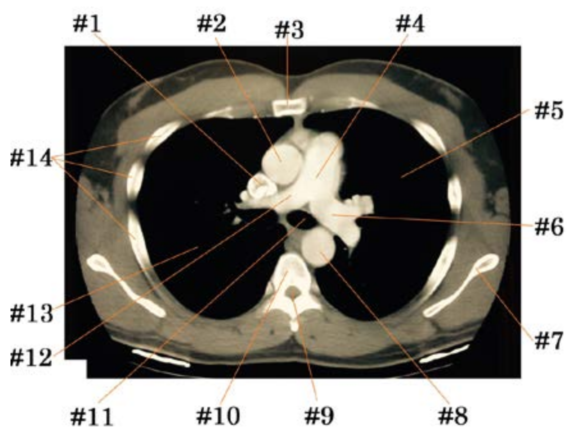


Figure 3–26. CT axial cross-sectional image of the thoracic region.

6. Identify the upper abdomen cross-sectional anatomy displayed in figure 3–27.

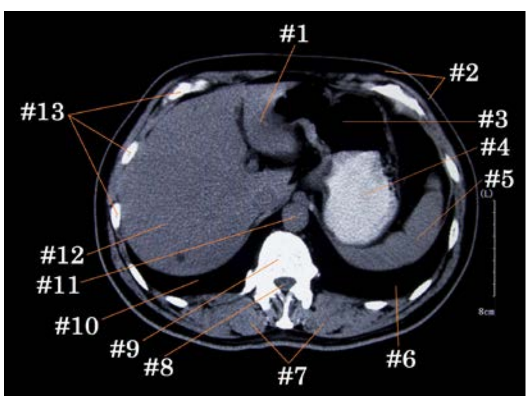


Figure 3–27. CT axial cross-sectional image of the upper abdomen.

7. Identify the pelvic (lower abdominal) cross-sectional anatomy displayed in figure 3–28.

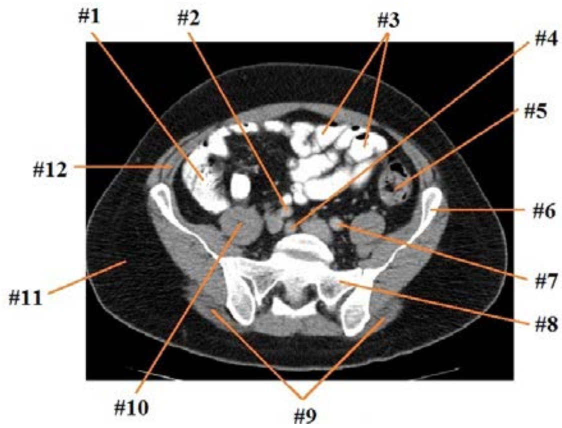


Figure 3–28. CT axial cross-sectional image of the pelvic region.

3–2. 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.

615. 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).

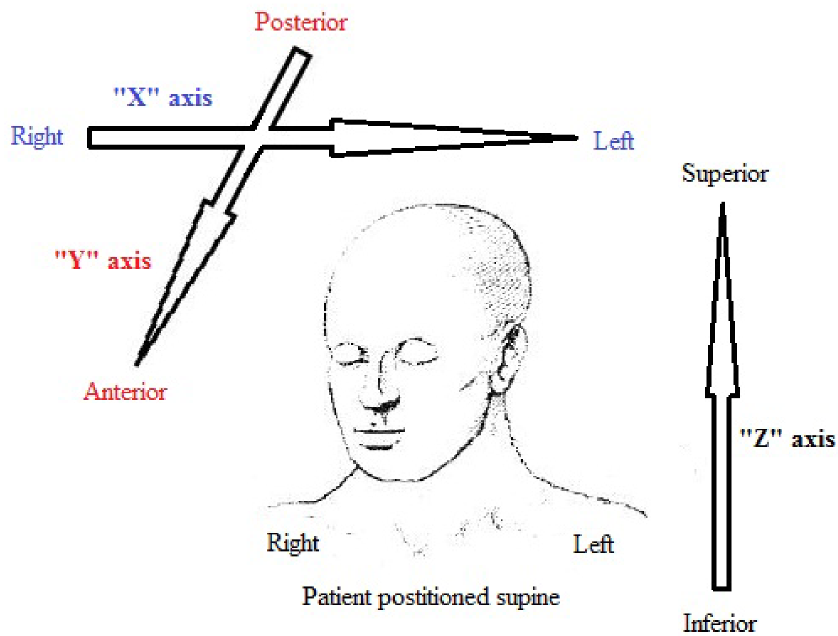


Figure 3–29. CT scan axes.

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.

616. 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 postprocessing software applications are available for use across the spectrum of manufacturers like the following:

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

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

Multiplanar reformations are the most common postprocessing 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 postprocessing applications to manipulate the image for optimum visualization and pathology interpretation.

617. 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 postprocessing 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.

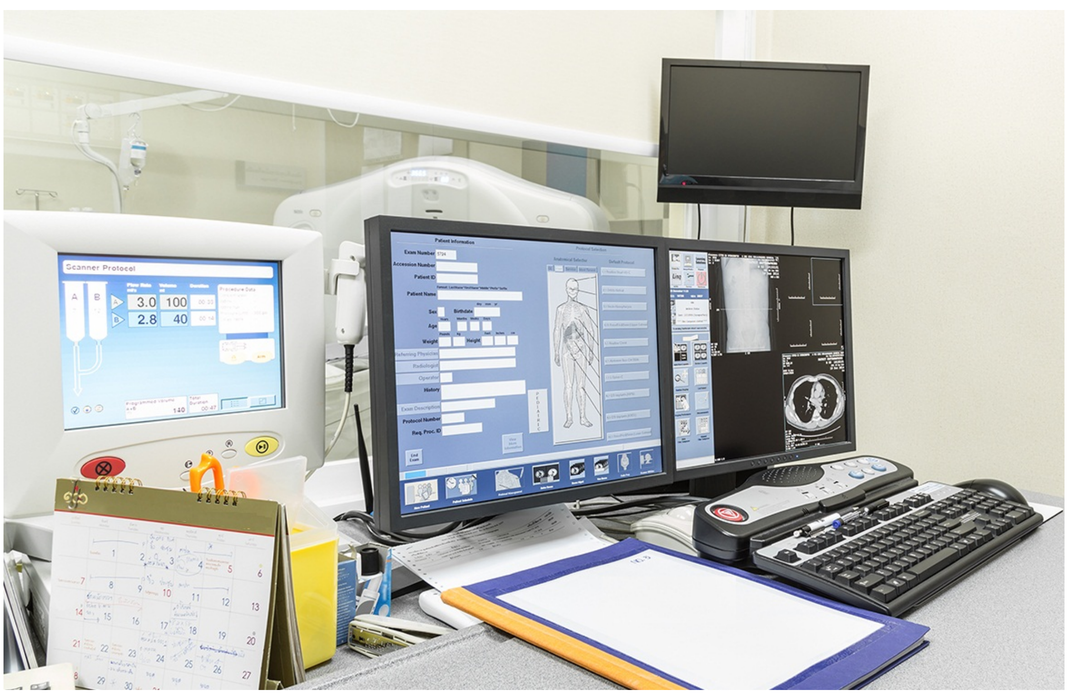


Figure 3–32. Typical CT operator's console.

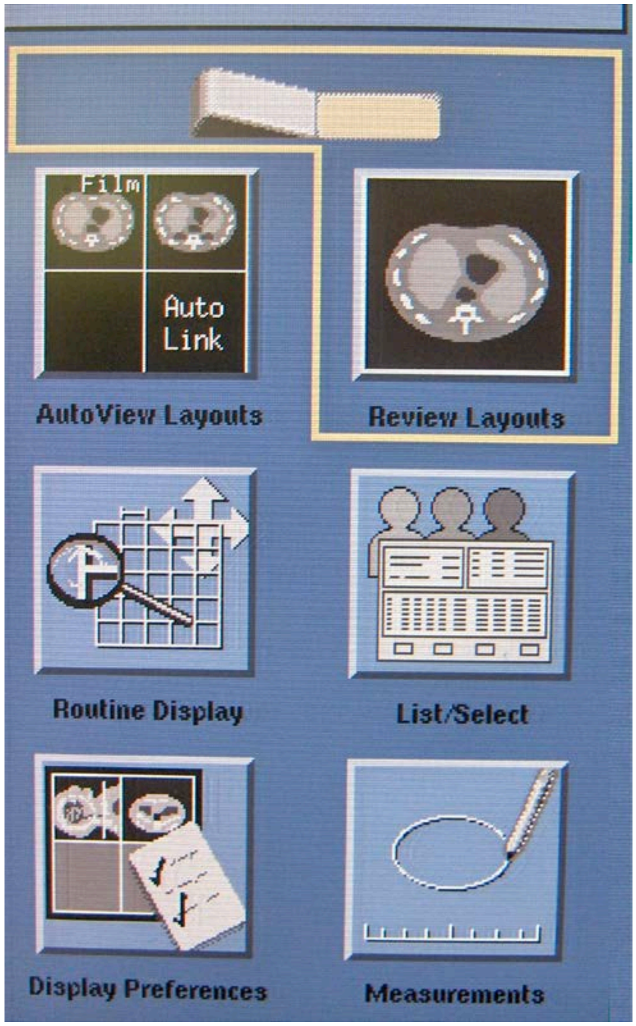


Figure 3–33. Common CT system applications.

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.

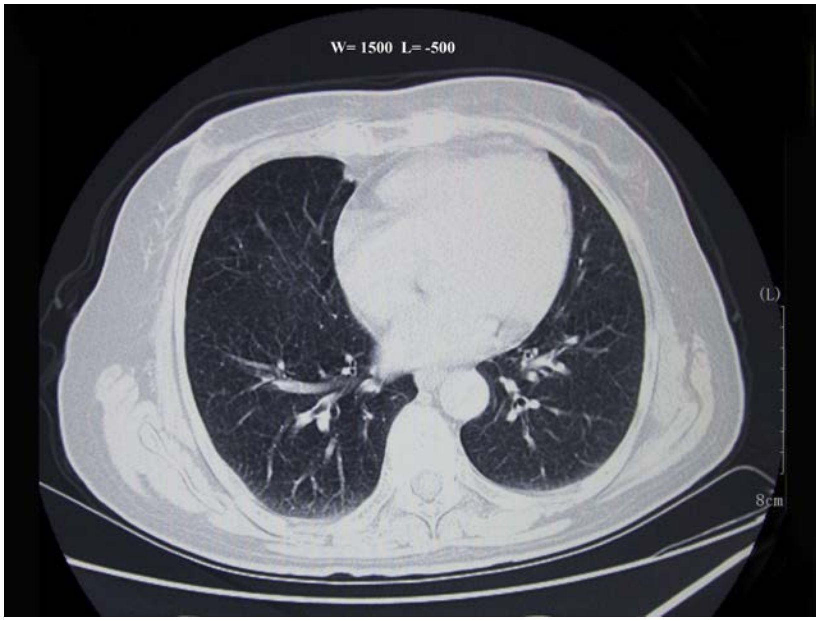


Figure 3–35. Axial CT image of chest (lung window).

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.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

615. Gantry assembly and patient couch apparatus

1. List the components contained within the CT scanner gantry.

2. What is the hole in the gantry called that the patient transverses in and out of for the CT scan?

3. How can you, the technologist, try to gain the claustrophobic patient’s cooperation for a CT scan?

4. How are the laser lights used?

5. How are the three axes in CT identified? Explain how they increase positively on a patient positioned supine.

6. What major performance characteristic distinguishes CT tubes from conventional radiography tubes?

7. What is a megatube?

8. What must be done to prevent thermal shock of the CT tube?

9. What are the two types of detectors used in CT scanners?

10. What is the primary advantage of solid-state detectors?

11. What is the function of the DAS?

12. What is the purpose of a U-shaped head cradle when used to image a patient's head?

616. Computer system

1. What is the basic function of the CT computer?

2. What is image reconstruction?

3. What does the operating system do?

4. What does the multiplanar reformation application software allow you to do?

5. What is it called when CT images are transferred from the host computer to a long-term storage device?

617. Operator's console

1. What is the intercom used for at the CT operator's console?

2. What controls the number of shades of gray displayed on the CT image?

3. Explain the difference between a narrow- and wide-window setting.

4. What does the level setting control?

5. Which level setting is best for visualizing bone? Explain.

6. Where is image data stored temporarily to facilitate rapid image recall for viewing and manipulation?

7. What type of media tends to be the storage medium of choice in most departments since their storage capacity is dramatically more than other options?

8. What is the function of the automatic injector?

9. Define flow rate. How is flow rate expressed?

3–3. 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.

618. 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 noncontrast, 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.

Premedications 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 premedicated, 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 (feetfirst) 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:

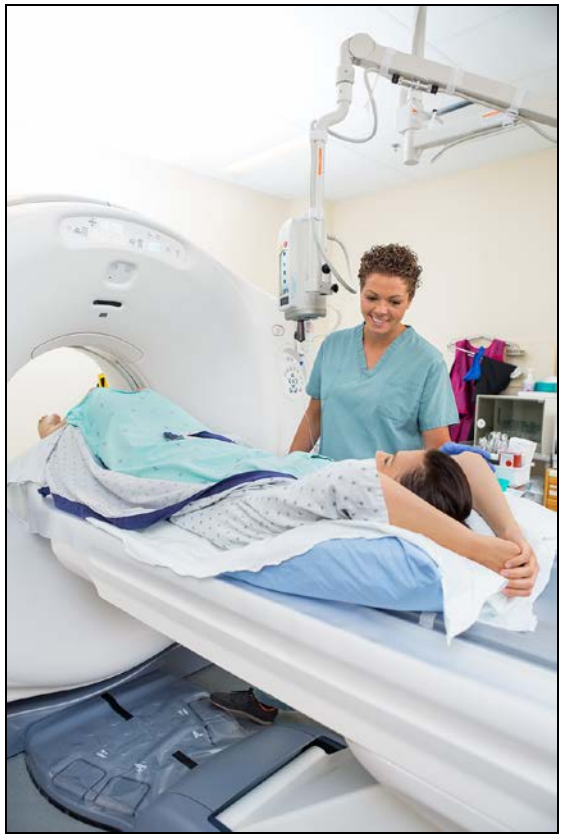


Figure 3–39. CT patient positioned comfortably feetfirst.

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

619. 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.

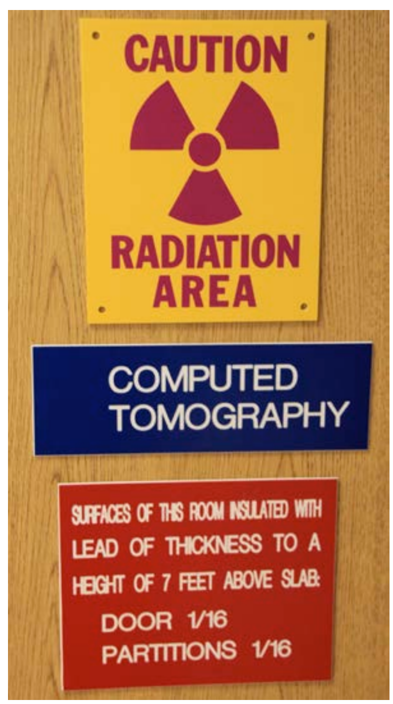


Figure 3–41. Notification of lead lined walls.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

618. Patient preparation

1. Who determines the CT exam protocols in your department?

2. What do the letters “c” and “s” stand for when referencing the use of a particular type of contrast?

3. What type of contrast administration is being referenced when a CT order states with (or without) contrast?

4. What is oral contrast designed to do?

5. Whenever IV contrast is indicated for a CT study, what must you do for each patient before beginning the injection for the examination?

6. Name the three common lab tests used to measure how well the kidneys are functioning.

7. What type of treatment is given to patients who require an IV contrast media injection for their CT exam even though they have had a prior contrast-induced allergic reaction?

8. What is the most common patient position used for CT examinations?

9. Name two ways to reduce patient motion during a CT scan.

619. Radiation safety in computed tomography

1. What is an individual’s estimated percent risk for developing cancer by normal means in a lifetime?

2. What percent of all diagnostic X-rays performed is by CT?

3. What percent does CT contribute to a patient's cumulative effective radiation dose?

4. Who has primary responsibility to limit CT use for children and infants?

5. What can you do as the technologist to reduce exposure doses for pediatric CT scans?

6. In which trimester is the radiation exposure risk to the unborn fetus greatest?

7. When the uterus region is not the primary area of interest during a CT scan, what causes radiation exposure to the fetus?

8. What is equal to the DLP metric?

9. What two ways is dose reported representing radiation output from a CT scanner?

10. What was mandated from NEMA publishing the technical standard XR–25?

11. What must the dose-check system include?

12. Explain the difference between the two dose-checks levels mentioned in the previous question.

13. Who is primarily responsible for protecting a patient and fellow medical staff members from undue or excessive exposure to ionizing radiation in the performance of their duties?

14. What radiation protection concept should a technologist use to reduce his or her own radiation exposure in CT?

Answers to Self-Test Questions

612

1. It rotates around the body in a 360° circle, exposing all aspects of the body part to ionizing radiation.
2. Whole numbers.
3. It uses the linear attenuation coefficient of the X-ray beam.
4. The amount of radiation that was absorbed by the body part.
5. It is a composition of small blocks, or cells, arranged in rows and columns.
6. The 512 x 512 image, because as the image matrix gets larger, the individual cells become smaller on the screen.
7. A two-dimensional representation of the average density of a volume of tissue.
8. Hounsfield units.
9. Because it is sufficiently available throughout the body and it has a consistent density; 0.
10. CT; CT detects minute tissue difference; conventional radiography requires approximately 10 percent difference in tissue density to separate structures, while CT needs only 0.25 percent difference.
11. Because of its ability to amplify differences in adjacent structures that are similar in tissue composition.
12. As graininess.
13. Beam-hardening.
14. Quantum mottle.

613

1. (1) c and d.
   (2) b.
   (3) a and b.
   (4) a.
   (5) b.
   (6) c.
2. Constant tube rotation without having to reset to a starting position between slices.
3. Helical, or spiral, scanning.
4. MDCT, which utilized the principles of helical scanning while incorporating multiple rows of detector rings.
5. Speed.
6. The movement of the patient couch and the width of the X-ray beam relationship.
7. Greater than 1:1.
8. CT fluoroscopy.
9. Dual-source, or dual-energy, CT.

614

1. From anterior to posterior, side to side, and divides the body into superior and inferior portions.
2. As if you are looking up from the patient’s feet, meaning the CT image is oriented with the patient’s left on your right.
3. Figure 3–24:
   (1) Lens of eyes.
   (2) Ethmoid sinuses.
   (3) Sphenoid sinuses.
   (4) Left temporal lobe.
   (5) Left mastoid air cell.
   (6) Pons medullary junction.

(7) Cerebellum.

(8) Right mastoid air cell.

(9) External auditory canal.

(10) Right temporal lobe.

4. Figure 3–25:

(1) Scalp.

(2) Cerebrospinal fluid in subarachnoid space.

(3) Frontal horns of lateral ventricles.

(4) Calvarium.

(5) Lateral ventricle atrium.

(6) Midline falx cerebri.

(7) Calcification.

(8) Lateral ventricle atrium.

5. Figure 3–26:

(1) Superior vena cava

(2) Ascending aorta.

(3) Sternum.

(4) Main pulmonary artery.

(5) Left lung.

(6) Left pulmonary artery.

(7) Scapula.

(8) Descending aorta.

(9) Spinal cord.

(10) Thoracic vertebral body.

(11) Trachea.

(12) Right pulmonary artery.

(13) Right lung.

(14) Ribs.

6. Figure 3–27:

(1) Left lobe of liver.

(2) Subcutaneious fat.

(3) Air in stomach.

(4) Oral contrast in stomach.

(5) Spleen.

(6) Left lung.

(7) Muscle tissue.

(8) Spinal cord.

(9) Thoracic vertebra.

(10) Right lung.

(11) Aorta.

(12) Right lobe of liver.

(13) Ribs.

7. Figure 3–28:

(1) Ascending colon.

(2) External iliac artery.

(3) Small bowel.

(4) Internal iliac artery.

(5) Descending colon.

(6) Ilium.

(7) Common iliac artery.

(8) Sacrum.

(9) Gluteus medius muscle.

(10) Psoas muscle.

(11) Subcutaneous fat.

(12) Transverse abdominis muscle.

615

1. The X-ray tube, the detector assembly, slip rings, collimators, and the DAS.
2. The aperture, nicknamed the doughnut.
3. By thoroughly explaining the exam to include exactly what portion of the patient’s body will be placed into the aperture and how long he or she will remain inside.
4. To position the patient for the scout scan, and, in turn, set the coordinates for the rest of your CT scan.
5. As X, Y, and Z axes that are axial slices through the XY plane of the body part. 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.
6. CT tubes are able to withstand and dissipate enormous amounts of heat units.
7. An X-ray tube capable of storing a million or more heat units.
8. Follow the manufacturer’s tube warm-up procedures.
9. Solid-state scintillation and xenon-gas ionization.
10. They are extremely efficient, converting 99 percent of the absorbed photons into light.
11. To convert the electrical impulses from the detectors into digital information (numbers).
12. To center the head to the patient table and to help hold the head still in a comfortable position.

616

1. It receives and analyzes information from the DAS and converts it into a video form so that an image can be displayed on a monitor.
2. It is the actual operation the computer performs when the raw data is turned into a cross-sectional image by way of mathematical equations.
3. It controls the hardware components and runs accessory programs loaded into the primary memory of the host computer.
4. Reformat axial images into coronal, sagittal, or oblique planes.
5. Archiving.

617

1. It allows the CT technologist to speak to the patient by giving instructions or updates regarding the progress of the scan.
2. The window setting.
3. A narrow window has a low number value; it displays fewer shades of gray and is considered high contrast. A wide window has a high number value; it displays many shades of gray and is considered low-contrast.
4. 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.
5. To visualize bone, you would set a relatively high level (500 or more) because denser structures are more difficult to see.
6. On the host computer’s hard drive.
7. Optical disks.

8. To provide rapid injection of IV contrast media during the CT scan.
9. It is the amount of contrast material delivered per unit of time; in cc/sec.

618

1. The radiologist.
2. "C" means with contrast and "s" means without.
3. IV contrast.
4. It 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.
5. Prescreen the patient for contraindications to the iodinated contrast material.
6. Serum creatinine, BUN, and GFR.
7. A prophylaxis treatment.
8. Supine.
9. Make them as comfortable as possible using a pillow, place to rest arms, and provide low back support; use immobilization techniques such as Velcro straps.

619

1. 23 percent.
2. 10 percent.
3. Approximately 70 percent.
4. The radiologist and ordering physician.
5. Always use reduced techniques (kVp, mA, and time) that are appropriate for the size and age of the pediatric patient you are scanning.
6. The first trimester.
7. Scatter radiation produced from within the patient.
8. $CTDI_{vol}$ multiplied by the length of the scan and is given in units of mGy-cm.
9. $CTDI_{vol}$ and DLP.
10. That CT scanners implement a dose-check system to monitor for potentially high-patient doses.
11. Include a notification level and an alert level dose check.
12. 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 while 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.
13. The technologist (you).
14. Time, distance, and shielding.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

43. (612) Computed tomography (CT) produces images of the body using
    a. radiation.
    b. sound waves.
    c. electromagnetism.
    d. electrical impulses.

44. (612) The computed tomography (CT) image is actually a composition of blocks that have been arranged into rows and columns that is called a
    a. pixel.
    b. voxel.
    c. matrix.
    d. window.

45. (612) What happens to the computed tomography (CT) image as the matrix size increases?
    a. Detail increases.
    b. Detail decreases.
    c. Scale of contrast increases.
    d. Scale of contrast decreases.

46. (612) Each cell of a computed tomography (CT) image matrix is called a
    a. pixel.
    b. voxel.
    c. Hounsfield unit.
    d. region of interest.

47. (612) Within a computed tomography (CT) image matrix, what is a voxel?
    a. An element of the CT detector.
    b. A single block of an image matrix.
    c. The volume of tissue represented by a pixel.
    d. A number representing the linear attenuation coefficient.

48. (612) This number represents air on the Hounsfield scale?
    a. –1000.
    b. 0.
    c. 100.
    d. 1000.

49. (612) What number represents dense bone on the Hounsfield scale?
    a. –1000.
    b. 0.
    c. 100.
    d. 1000.

50. (612) Which of the following is an *advantage* of computed tomography (CT) over conventional radiography?
    a. It is preferred for dynamic studies.
    b. It can resolve objects as small as 0.1mm.
    c. It reduces radiation exposure to the patient.
    d. The superimposition of structures can be visualized.

51. (612) Which image quality factor refers to the *degree of blur* that is apparent on a computed tomography (CT) image?
    a. Noise.
    b. Spatial resolution.
    c. Volume rendering.
    d. Contrast resolution.

52. (613) Which generation(s) of computed tomography (CT) scanners used translation and rotation scanning motion?
    a. First only.
    b. First and second.
    c. Second only.
    d. Second and third.

53. (613) Which generation of computed tomography (CT) scanners was the *first* to use rotational movement *only*?
    a. Second.
    b. Third.
    c. Fourth.
    d. Helical.

54. (613) Which generation of computed tomography (CT) scanners uses a curvilinear detector array?
    a. First.
    b. Second.
    c. Third.
    d. Fourth.

55. (613) What *major* advancement in computed tomography (CT) scanners accompanied the development of slip ring technology?
    a. Helical scanning.
    b. Stationary detectors.
    c. Multiplanar reformations.
    d. Three-dimensional reconstruction.

56. (613) Which term identifies the relationship between the movement of the patient couch and the width of the X-ray beam?
    a. Pitch.
    b. Helical.
    c. Isotropic.
    d. Dynamic.

57. (613) Which pitch ratio allows computed tomography (CT) images to overlap?
    a. 0.5:1.
    b. 1:1.
    c. 1:1.6.
    d. 1:2.0.

58. (613) Which pitch ratio, in computed tomography (CT) images, causes the patient to receive a higher radiation dose?
    a. 1:2.0.
    b. 1:1.6.
    c. 1:1.
    d. 0.5:1.

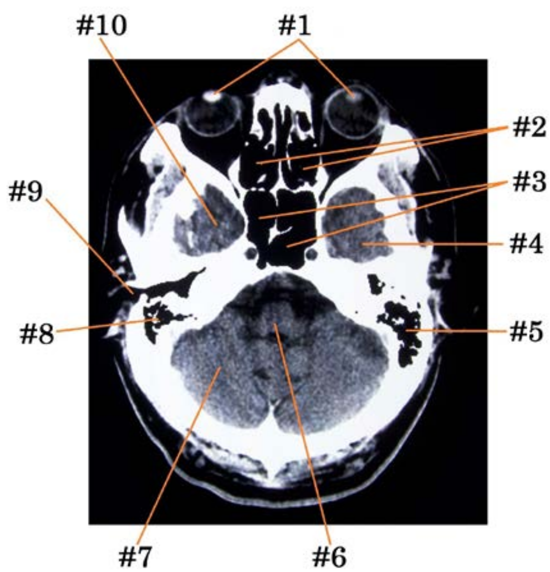
59. (613) Which computed tomography (CT) technological advancement allows for real-time imaging?
    a. Helical.
    b. Fluoroscopy.
    c. Dual-source.
    d. Multi-detector.

60. (614) How are cross-sectional anatomy computed tomography (CT) images obtained?
    a. At right angles to the long axis of the body.
    b. At right angles to the transverse plane.
    c. Perpendicular to the axial plane.
    d. Parallel to the body part.

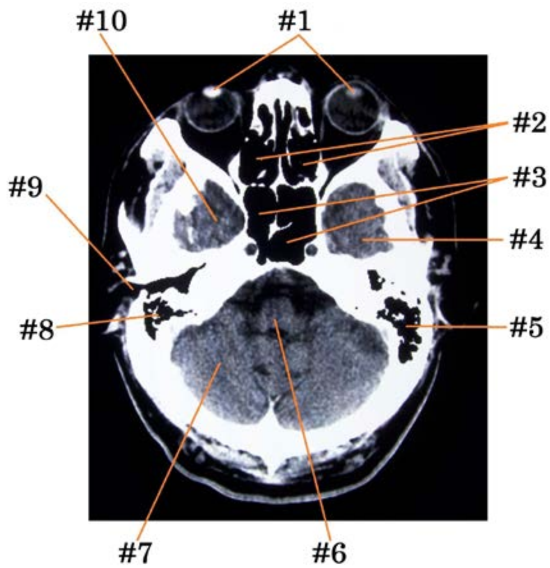
61. (614) Which body *plane* divides the body into superior and inferior portions in cross-sectional imaging?
    a. Coronal.
    b. Sagittal.
    c. Transverse.
    d. Mid-Sagittal.

62. (614) When computed tomography (CT) images are viewed on a monitor, they are viewed as if you are looking
    a. in a mirror.
    b. up from the patient's feet.
    c. down from the patient's head.
    d. opposite of conventional X-ray.

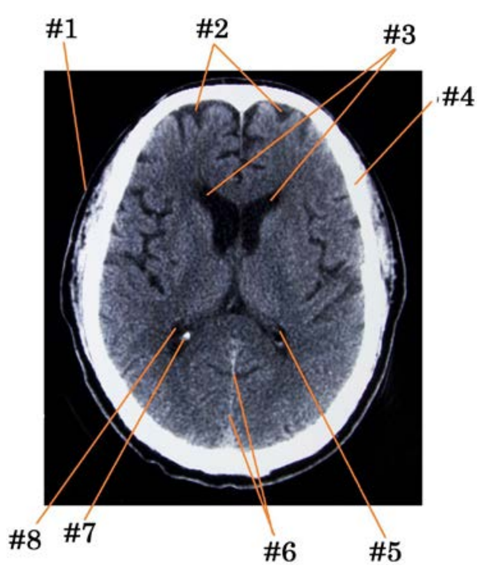
63. (614) Which number on the cross-sectional lower brain anatomy image identifies the cerebellum?
    a. 4.
    b. 6.
    c. 7.
    d. 10.



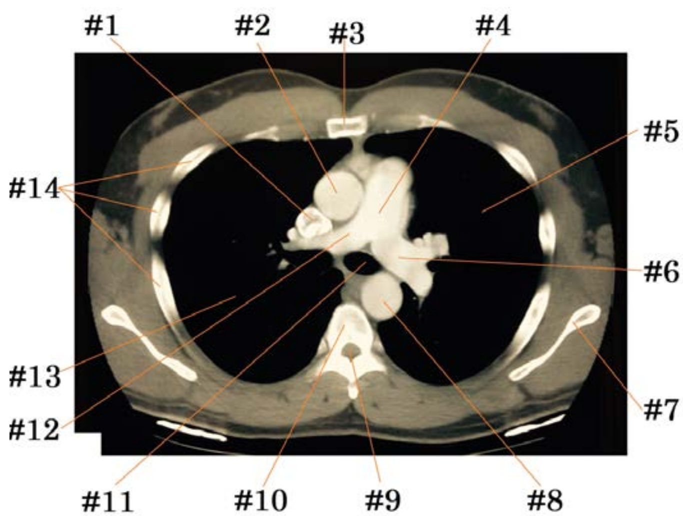
64. (614) Which number on the cross-sectional lower brain anatomy image identifies the right temporal lobe?
a. 1.
b. 6.
c. 7.
d. 10.



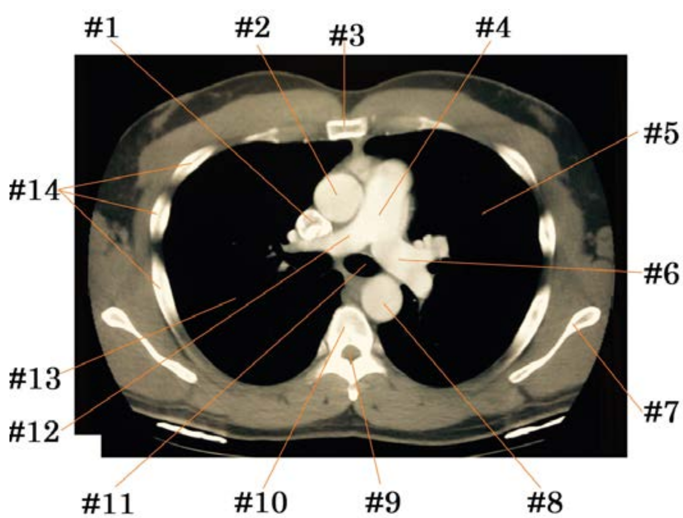
65. (614) Which number on the cross-sectional middle brain portion of the image identifies the cerebrospinal fluid (CSF)?
a. 1.
b. 2.
c. 3.
d. 4.



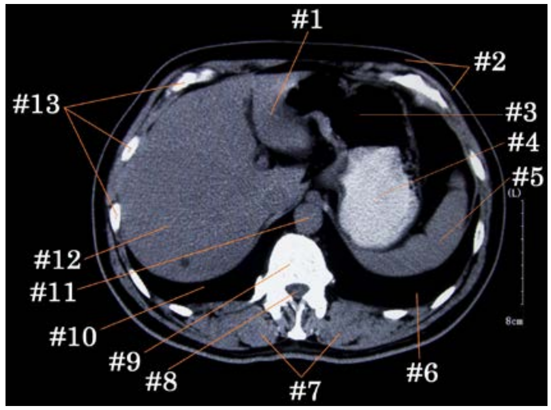
66. (614) Which number on the cross-sectional chest anatomy of the image identifies the descending aorta?
    a. 2.
    b. 4.
    c. 6.
    d. 8.



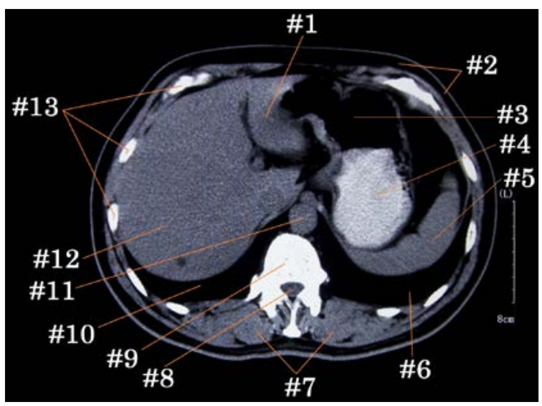
67. (614) Which number on the cross-sectional chest anatomy of the image identifies the sternum?
    a. 3.
    b. 7.
    c. 10.
    d. 14.



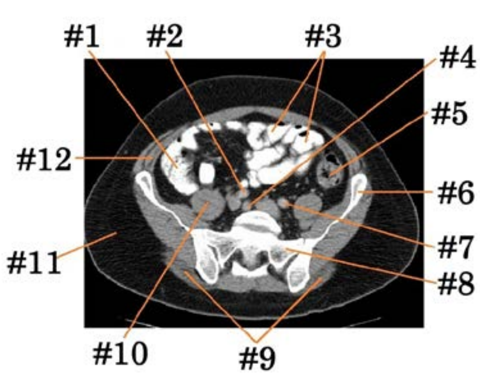
68. (614) Which number on the cross-sectional upper abdomen image identifies air in the stomach?
   a. 2.
   b. 3.
   c. 4.
   d. 6.



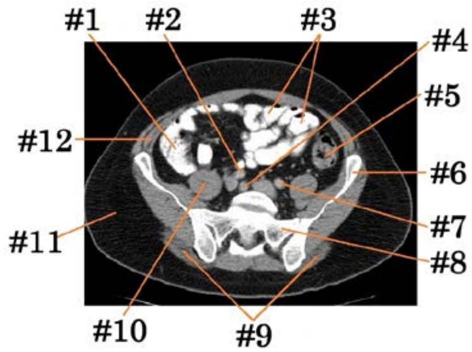
69. (614) Which number on the cross-sectional upper abdomen image identifies the spleen?
   a. 1.
   b. 4.
   c. 5.
   d. 12.



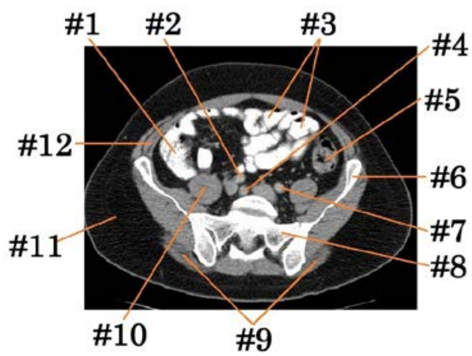
70. (614) Which number on the pelvic cross-sectional anatomy image identifies the ascending colon?
   a. 1.
   b. 3.
   c. 5.
   d. 10.



71. (614) Which number on the pelvic cross-sectional anatomy image identifies the small bowel?
    a. 1.
    b. 2.
    c. 3.
    d. 5.



72. (614) Which number on the pelvic cross-sectional anatomy image identifies the common iliac artery?
    a. 2.
    b. 4.
    c. 5.
    d. 7.



73. (615) How does the X-ray tube in a computed tomography (CT) scanner differ from a conventional X-ray tube?
    a. CT tubes use megavoltage.
    b. CT tubes require much smaller focal spots.
    c. CT tubes must tolerate enormous amounts of heat.
    d. CT tubes require less filtration to measure remnant radiation.

74. (615) What are the two types of detectors used in a computed tomography (CT) unit?
    a. Solid-state scintillation and thin-film transistor.
    b. Solid-state scintillation and gas ionization.
    c. Photochemical and thin-film transistor.
    d. Photochemical and gas ionization.

75. (615) How does the data acquisition system (DAS) of a computed tomography (CT) unit function?
    a. Measures remnant radiation.
    b. Selects the patient scanning protocol.
    c. Converts digital information into a video image.
    d. Converts electrical impulses from the detectors into digital information.

76. (616) What is a *key* component of *all* computed tomography (CT) computer systems?
    a. Detector array.
    b. Array processor.
    c. Central processing unit.
    d. Random access memory.

77. (617) Which action is *not* performed using the keyboard at the computed tomography (CT) operator's console?
    a. Tilt the gantry.
    b. Speak to the patient.
    c. Raise or lower the couch.
    d. Change the window and level settings.

78. (617) The shades of gray number that is displayed on a computed tomography (CT) image is controlled by setting the
    a. level.
    b. matrix.
    c. window.
    d. pixel pitch.

79. (617) What is used to set the density of the structures shown on an image by centering the Hounsfield scale?
    a. Level.
    b. Window.
    c. Bit depth.
    d. Matrix size.

80. (617) When an automatic contrast injector is used to inject a contrast media agent, how do you measure pressure where the contrast is injected?
    a. Milliliters per minute.
    b. Pounds per square inch.
    c. Milligrams per deciliter.
    d. Cubic centimeters per second.

81. (618) Which letter represents "with contrast" when it is written for a computed tomography (CT) exam protocol?
    a. C.
    b. S.
    c. X.
    d. Z.

82. (618) Which *common* lab test used to measure renal function has a normal range of 6 to 20 milligrams per deciliter?
    a. Serum creatinine.
    b. Blood urea nitrogen.
    c. Complete blood count.
    d. Glomerular filtration rate.

83. (618) How is the patient positioned to obtain direct coronal images of the face during a computed tomography (CT) examination?
    a. Decubitus.
    b. Lateral.
    c. Supine.
    d. Prone.

84. (619) Computed tomography (CT) accounts for 10 percent of all X-ray based procedures in regards to cumulative effective dose. Approximately how much is contributed towards the *total* medical radiation exposure to patients?
    a. One-half.
    b. One-third.
    c. Two-thirds.
    d. Three-quarters.

85. (619) Who is the *last* line of defense in protecting patients from undue or excessive radiation exposure in computed tomography (CT)?
    a. Radiologist.
    b. Primary care manager.
    c. Performing technologist.
    d. Noncommissioned officer in-charge.

86. (619) What concept(s) allow(s) you, as a technologist, to protect yourself *best* from computed tomography (CT) radiation exposure?
    a. Dose optimization.
    b. Time, distance, and shielding.
    c. Donning a personal dosimeter.
    d. As low as reasonably achievable (ALARA).

Please read the unit menu for unit 4 and continue ➔

Student Notes

Unit 4. Mammography and Bone Densitometry

4–1. Mammography 4–1
620. Benefits of mammography and breast cancer risk factors 4–1
621. Breast anatomy and physiology 4–4
4–2. Bone Densitometry 4–8
622. Bone-densitometry principles and performing common exams 4–8
623. Quality-control features 4–14

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.

4–1. 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.

620. 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.

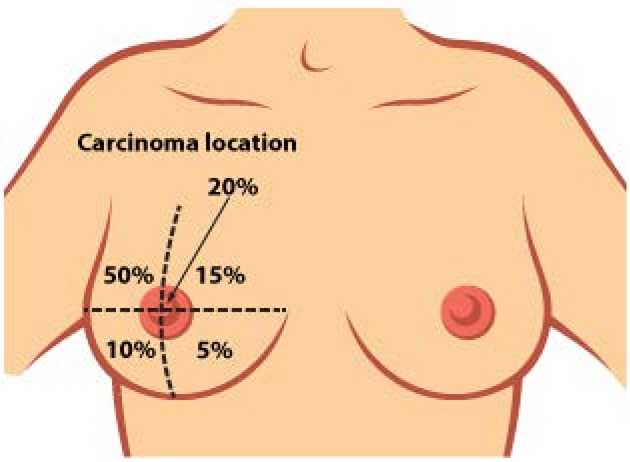


Figure 4–1. Percent of cancer incidence by location within the female breast.

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.

621. 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).

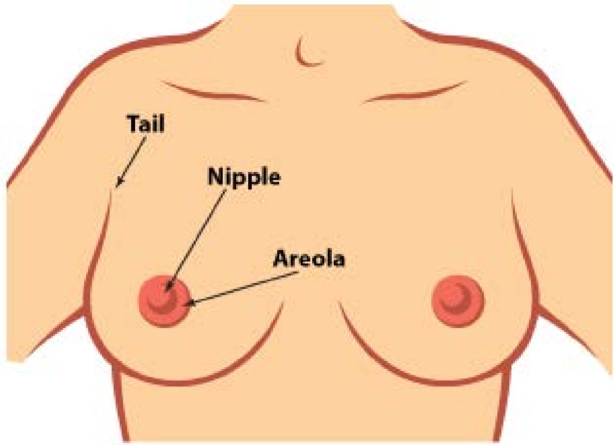


Figure 4–2. External breast landmarks.

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).

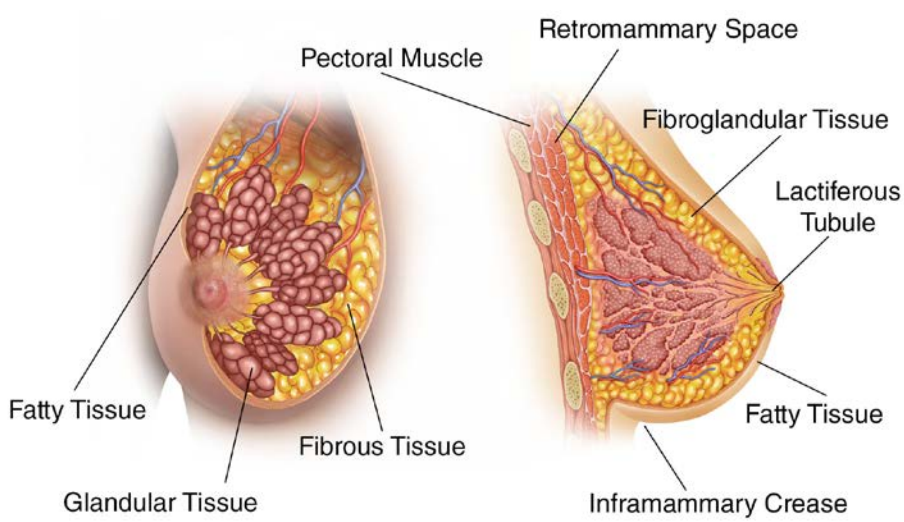


Figure 4–3. Internal breast anatomy.

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 glandualr (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.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

620. Benefits of mammography and breast cancer risk factors

1. Why is early detection of breast cancer important in improving the chances for survival?

2. How long before a breast cancer becomes palpable can mammography detect its presence?

3. What type of equipment was originally used for mammography? What was the average patient dose with this equipment?

4. What is the average gland dose per exposure to the patient when using digital mammography?

5. What is the primary goal of mammography?

6. What does mammography *not* do?

7. What is it called when a mammogram is performed on a patient who is asymptomatic of any known breast problems?

8. What is a diagnostic mammogram?

9. Who is the only medical professional that can diagnose breast cancer?

10. What is the estimated increased risk of developing breast cancer from exposure to radiation?

11. Name five of the seven factors not related to personal choice that affect a woman's chance of developing breast cancer.

12. Of the seven lifestyle-related risk factors, which two factors reduce a woman's risk of developing breast cancer?

621. Breast anatomy and physiology

1. What portion of the female breast lies in contact with the chest wall?

2. What portion of the breast is identified as the tail?

3. What are the three types of breast tissue?

4. What are the suspensory ligaments of the breast called?

5. How many lobes comprise each mammary gland?

6. What are the functional units of the mammary gland?

7. List five factors that affect the total amount of glandular tissue in the breast.

4–2. 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 radiogammetry.

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.

622. 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.

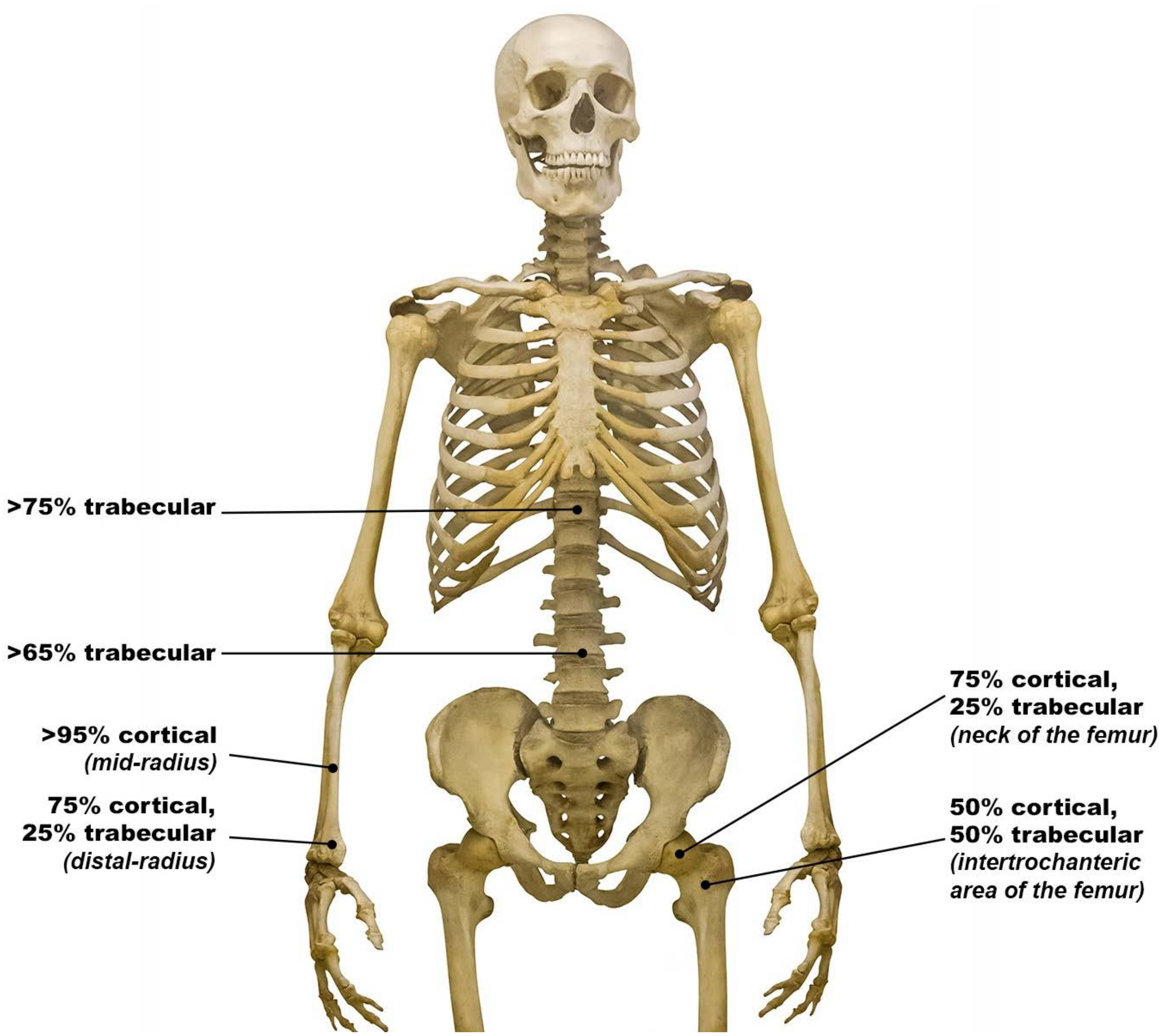


Figure 4–4. Cortical versus trabecular bone-structure percentages.

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, *radiogammetry* was widely used because it was inexpensive; however, radiogammetry 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.

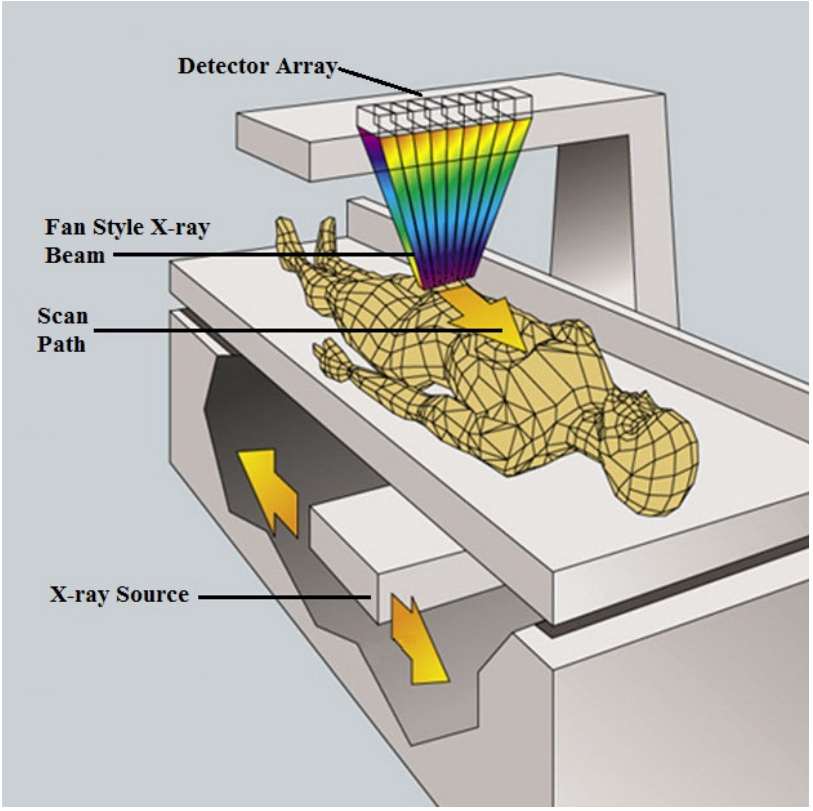


Figure 4–5. Illustrated DXA system.

Figure 4–6. 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.

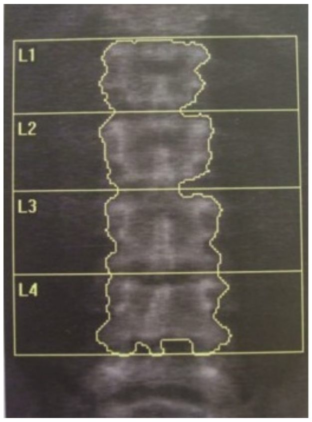


Figure 4–7. Sample L-spine DXA scan.

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.

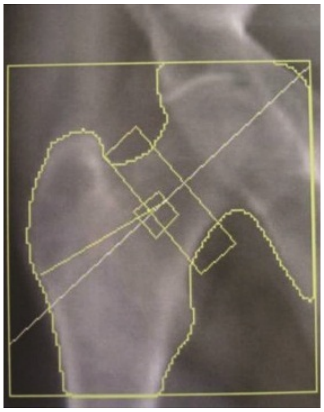


Figure 4–8. Sample hip DXA scan.

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.

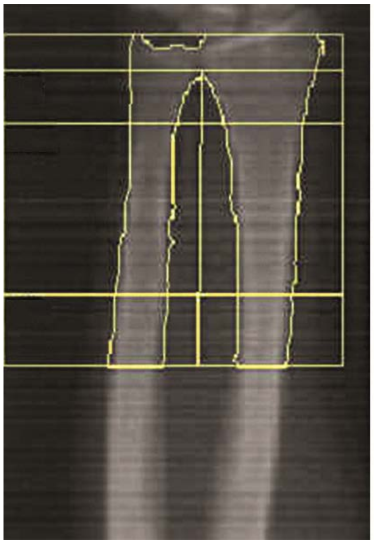


Figure 4–9. Sample distal forearm DXA scan.

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.

623. 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.

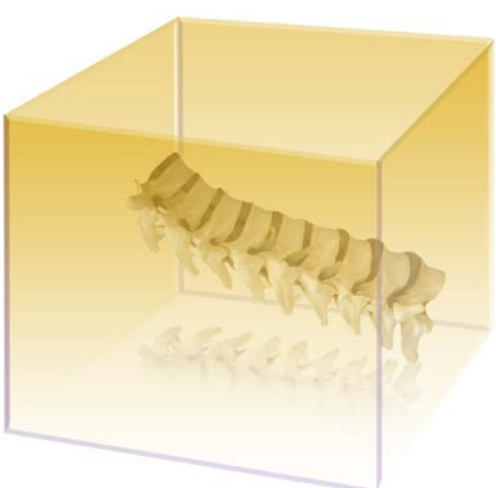


Figure 4–10. Sample DXA L-spine phantom.

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.

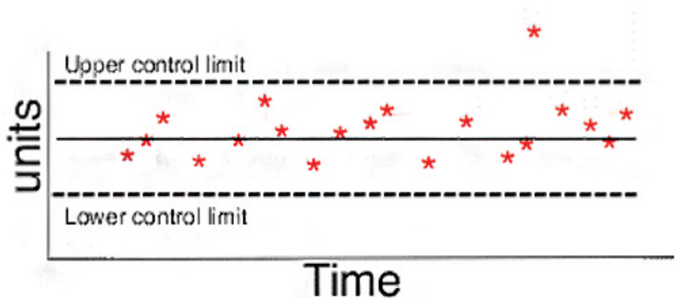


Figure 4–11. Sample Shewhart-QC chart.

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.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

622. Bone-densitometry principles and performing common exams

1. As a quantitative measurement technique, what is the primary focus of a bone-densitometry exam?

2. What is referred to as the ability of a bone-density system to calculate the true mineral value of a bony structure?

3. What structure of a bone is the dense, outermost portion of all bones?

4. What is the trabecular portion of the bone?

5. What three quantities are measured during a bone-density scan?

6. Of the two scores generated by the bone-densitometry software, which represents a comparison of BMD to individuals of the same age, gender, and ethnicity?

7. Explain the theory behind DXA technology and the formulation of T- and Z-scores by computer software.

8. What are the three most common sites for a bone-densitometry scan?

9. Why are the knees bent upward to an approximate 45°–90° angle for a DXA scan of the lumbar spine?

10. What anatomy is shown on the proximal femur scan?

11. If there is no contraindication, which forearm should be scanned? Why?

623. Quality control features

1. What are two QC applications used to monitor densitometry system specifications?

2. What is your role in the automated densitometry QC process?

3. After the QC results are displayed on the densitometry system monitor and you have read them, what is the next step in the QC process?

4. What is the preferred method for establishing the baseline parameters for the QC program to be useful?

Answers to Self-Test Questions

620

1. Because it is highly metastatic through the lymphatic system.
2. At least 2 years.
3. Standard X-ray equipment and fine grain, industrial film was used early on; it required 8–12 rads per exam.

4. Around 200 mrad or 2 mGy.
5. To detect breast cancer prior to the tumor growing to the size necessary to be palpable.
6. It does not diagnose breast cancer.
7. A screening mammography.
8. It is an exam performed on patients who have clinical evidence of possible breast problems.
9. A pathologist.
10. For every rad of exposure, a woman increases her risk of developing breast cancer 1 percent over the natural incidence.
11. Any five of the seven: gender, aging, genetics, family or personal history, race and ethnicity, dense breast tissue, and menstrual periods.
12. Physical activity and breastfeeding.

621

1. The base.
2. The portion of the breast that extends upward into the axilla.
3. Fibrous, glandular, and fatty.
4. Cooper’s ligaments.
5. 15–20.
6. Acini.
7. The patient’s age, hormonal changes, pregnancy, lactation, and menopause.

622

1. The measurement of bone mass (or density) versus structural integrity.
2. Accuracy.
3. Cortical.
4. It is the delicate, web-like material located inside the bone.
5. The BMD, BMC, and the actual area of the bone.
6. The Z-score.
7. 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 software formulates the T- and Z-scores by subtracting the amount of ionizing radiation absorbed within the soft-tissue structures from the total amount of radiation introduced to the bony structure by the two energy levels.
8. Lumbar spine, proximal femur, and forearm.
9. To reduce the curvature of the spine and open the intravertebral disc spaces.
10. The entire femoral head and acetabulum and the entire greater and lesser trochanter should be visualized.
11. The nondominate forearm because the dominate forearm tends to have a higher bone-density level.

623

1. The Shewhart-rules chart and CUSUM chart.
2. To scan the phantom, according to the manufacturer’s guidelines.
3. Document that the QC tests were completed and state the results.
4. Scan the phantom for 15–25 consecutive days, according to the manufacturer’s QC recommendations.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

87. (620) Today, the average gland dose per exposure for digital mammography is around
    a. 2 millirad.
    b. 20 millirad.
    c. 200 millirad.
    d. 600 millirad.

88. (620) If otherwise in good health, a woman should begin having annual *screening* mammograms no *later* than this age.
    a. 25.
    b. 35.
    c. 40.
    d. 50.

89. (620) Which statement concerning the risk of screening mammography is *true*?
    a. Screening mammography detects *slightly* more breast cancers than it causes.
    b. Screening mammography detects *far more* breast cancers than it could potentially cause.
    c. There is no *increased* risk of breast cancer from regular screening mammograms.
    d. There is no *data* currently available to evaluate the risk of screening mammography.

90. (621) What are the *functional* units of the mammary gland called?
    a. Acini.
    b. Lobules.
    c. Lactiferous tubules.
    d. Cooper's ligaments.

91. (621) Which type of breast is comparable to the *adolescent* breast in terms of radiographic density?
    a. Mature.
    b. Atrophic.
    c. Lactating.
    d. Menopausal.

92. (622) What is the *primary* focus of a bone densitometry exam?
    a. Measurement of bone mass.
    b. Measurement of cortical structure.
    c. Evaluation of structural integrity.
    d. Evaluation of trabecular distribution.

93. (622) This term refers to the ability of a bone density system to calculate the *true* mineral value of a bone.
    a. Competency.
    b. Accuracy.
    c. Precision.
    d. Integrity.

94. (622) Which area or structure is *not* measured by a bone density scanning system?
    a. Actual attenuation of the bone.
    b. Actual area of the bone.
    c. Bone mineral content.
    d. Bone mineral density.

95. (622) Which type of *score* number identifier represents a comparison of the patient's bone mineral density for a particular anatomical site, to that of a healthy, same gender, 30-year-old adult?
    a. M.
    b. T.
    c. X.
    d. Z.

96. (622) Which type of *score* number identifier represents a comparison of the patient's bone mineral density for a particular anatomical site to that of other individuals of the same age, gender, and ethnicity?
    a. M.
    b. T.
    c. X.
    d. Z.

97. (622) What imaging technique is the *basis* for modern bone densitometry?
    a. Radiogammetry.
    b. Photon absorptiometry.
    c. Radiographic absorptiometry.
    d. Positron emission tomography.

98. (623) What is the technologist's role in bone density equipment quality control?
    a. Scan the phantom according to the manufacturer's guidelines.
    b. Scan the phantom daily and calibrate the unit monthly.
    c. Manually plot the data points on a Shewhart chart.
    d. Interpret the findings.

99. (623) When using the Shewhart rules chart, what must happen *first* in a *useful* quality control program?
    a. Run the program.
    b. Scan the phantom daily.
    c. Establish a baseline of parameters.
    d. Calculate the average precision and standard deviation.

100. (623) What should you do if the bone density machine *fails* a quality control test?
    a. Run the program until it passes.
    b. Notify the imaging floor supervisor.
    c. Establish a new baseline set of parameters.
    d. Continue to use the machine until the test fails three consecutive days.

Glossary of Terms, Acronyms, and Abbreviations

Terms

Benign—Refers to a tumor or condition that is not life threatening or severe and is likely to respond to treatment.

C-arm—Type of mobile fluoroscopy unit that resembles the shape of a C.

Claustrophobic—A condition in which a person has a fear of enclosed or narrow places.

Contrast resolution—Refers to the ability of an imaging system to distinguish between differences in image intensity.

Luminescence—The emission of light or to produce light.

Malignant—Refers to a tumor or condition that is life threatening or severe.

Modular transfer function—Refers to the spatial frequency response of an imaging system or component thereof.

Spatial resolution—Refers to the ability of an imaging system to differentiate between tissues of similar structure and proximity.

Abbreviations and Acronyms

°	degree
2D	two-dimensional
3D	three-dimensional
ADC	analog-to-digital converter
AE	application entity
ALARA	As Low As Reasonably Achievable
ARRT	American Registry of Radiologic Technologist
BMC	bone mineral content
BMD	bone mineral density
BUN	blood urea nitrogen
CAT	computerized axial tomography
cc	cubic centimeters
CCD	charge-coupled device
CD	compact disk
CHCS	Composite Health Care System
cm	centimeters
cm^2	centimeters squared
CPU	central processing unit
CR	computed radiography
CsI	cesium iodide
C-spine	cervical spine

CT	computed tomography
$CTDI_{vol}$	volume computed tomography dose index
CUSUM	cumulative sum
DAC	digital-to-analog converter
DAS	data acquisition system
DI	Diagnostic Imaging
DICOM	digital imaging and communication in medicine
DLP	dose length product
DOD	Department of Defense
DPA	dual-photon absorptiometry
DQE	detective quantum efficiency
DR	direct radiography
DVD	digital video disk
DXA	dual-energy X-ray absorptiometry
EI	exposure index
ERCP	endoscopic retrograde cholangiopancreatography
fluoro	fluoroscopy
g	grams
g/cm^2	grams per centimeter squared
GB	gigabyte
GFR	glomerular filtration rate
GI	gastrointestinal
HIS	hospital information system
HL7	Health Level 7
HTTP	hypertext transfer protocol
HTTPS	hypertext transfer protocol secure
ICU	intensive care unit
IEC	International Electro-technical Commission
IP	internet protocol/ imaging plate
IV	intravenous
KB	kilobyte
kVp	kilovoltage peak
kV	kilovolts
L or WL	level
L1	first lumbar spine vertebrae
LAN	local area network
LCD	liquid crystal display
mA	milliamperage
mAs	milliamperage and seconds
MB	megabyte
MDCT	multidetector computed tomography

MERC	medical equipment repair center
mg	milligram
mg/dL	milligrams per deciliter
mGy	milligray
ml	milliliter
ml/min	milliliters per minute
mm	millimeter
MP	megapixel
mrad	millirad
MRI	magnetic resonance imaging
MTF	medical treatment facility
NCRP	National Committee on Radiation Protection and Measurement
NEMA	National Electrical Manufacturers Association
NIC	network interface card
NPO	nothing passed orally or nothing by mouth
OML	orbital meatal line
OR	operating room
PACS	picture archiving and communication system
PCM	primary care manager
PET	positron electron tomography
pixel	picture element
psi	pounds per square inch
QC	quality control
RA	radiographic absorptiometry
rad	radiation absorbed dose
RAID	redundant array of independent disks
RIS	radiology information system
ROI	region of interest
RT	reconstructive tomography
SD	standard deviation
sec	second
SF	standard form
SID	source-to-image distance
SPA	single-photon absorptiometry
SPECT	single-photon emission computed tomography
SQL	structured query language
SSD	source-to-skin distance
SSDE	size-specific dose estimate
SXA	single-energy X-ray absorptiometry
TB	terabyte/total storage
TEI	target exposure index

TLD	thermoluminescent dosimeter
Typos	typographical errors
VA	Veterans Administration
voxel	volume element
WAN	wide area network
WW or W	window
X-ray	X-radiation

Student Notes

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