Chapter 8

Digital Imaging

Learning Objectives

At the conclusion of this chapter, you will be able to:

- Define the key terms used in digital imaging
- List the equipment required to perform digital imaging
- Explain the computed radiography (CR) digital system
- Explain the digital radiography (DR) system
- Compare CR and DR digital systems
- Describe terms used in image processing
- Recognize the importance of using exposure technique charts with digital imaging
- Describe the processing and postprocessing of a digital image
- Explain the functions of the digital processing system
- Explain what a picture archival and communications system (PACS) is and how it is used
- Recognize the common artifacts seen in digital images
- Explain the technical considerations for everyday use of digital systems

Key Terms

analog-to-digital converter (ADC)
artifacts
backscatter radiation
brightness
charged coupled device (CCD)
complementary metal oxide semiconductor (CMOS)
computed radiography (CR)
contrast resolution
conventional radiography
CR reader
dead pixels
detector element (DEL)
DICOM
DICOM gray-scale function
digital imaging
digital radiography (DR)
direct conversion
dynamic range
edge enhancement
electronic cropping
electronic health record (EHR)
electronic medical record (EMR)
exposure index (EI)
exposure indicator number
fill factor
flat-panel detector (FPD)
histogram
image annotation
image stitching
imaging plate (IP)
indirect conversion
look-up table (LUT)
matrix
modulation transfer function (MTF)
photostimulable phosphor (PSP)
picture archival and communication system (PACS)
pixel
postprocessing
quantum mottle
radiology information system (RIS)
radiolucent
rescaling
sampling frequency
smoothing
signal-to-noise ratio (SNR)
spatial resolution window level
window width

This chapter presents an overview of the new digital imaging processing systems, **computed radiography (CR)** and digital radiography (DR). The basic definitions associated with this new area of radiology are presented.

Today, more than 90% of radiology departments are using digital systems. Therefore, it is important for the limited operator to understand the basic terminology and concepts so that these systems can be used effectively with patients.

DIGITAL IMAGING

With the old conventional processing, the image of the body part appeared on the sheet of film. The film was taken to the radiologist and placed on the illuminator for interpretation (Fig. 8.1). After interpretation, the film was stored in a paper envelope and sent to the physician or filed in a radiology file room. From this description it can be noted that there is a lot of manual work involved in the process of creating the x-ray image.

Digital imaging, by definition, is the process of acquiring images of the body using x-rays, displaying them digitally, and viewing and storing them on a computer and in computer files. Digital imaging in radiology was first used in the early 1970s with the introduction of the computed tomography (CT) scanner by Godfrey Hounsfield of England. Since then, other areas of radiology, such as conventional radiology and ultrasound, have converted to digital imaging. Most medical imaging modalities (CT, magnetic resonance imaging [MRI], ultrasound, nuclear medicine, and **conventional radiography**) produce digital images that can be sent through a computer network to numerous computers inside and outside the medical facility (Fig. 8.2). In the near future, all radiography departments will have converted to digital methods, whereas conventional screens and film, and darkrooms with mechanical processors to process films, will be obsolete. It should be noted that *digital imaging* is a general term also used outside of the radiology department. For example, nearly everyone has a digital camera, and pictures (images) are stored in a computer or flash drive. Digital imaging is what allows word files, photos, and videos to appear on the World Wide Web. YouTube and Facebook are fully digital systems.

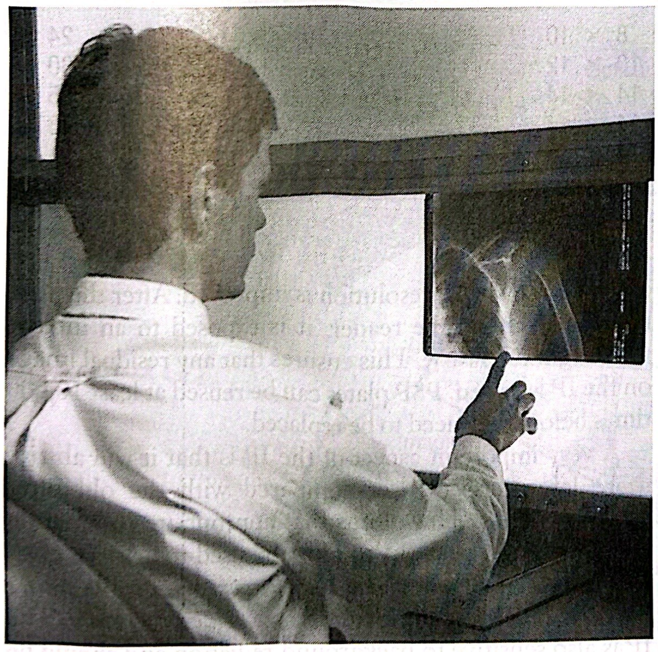

Fig. 8.1 A radiologist interpreting a shoulder x-ray image on a sheet of film using an illuminator in conventional radiology.

The terms *digital imaging* and *digital radiography* have generated much confusion over the past years as the digital world evolved in the x-ray department. Both terms are used, and very often, interchanged.

Computed Radiography

CR is one of the two types of digital imaging systems. CR was introduced in the United States in 1983 by Fuji Medical Systems of Japan. CR can be referred to as *cassette-based* digital imaging owing to the fact that the image of the body part is obtained using a cassette that contains a storage phosphor plate (Fig. 8.3A). These CR cassettes are often referred to simply as **imaging plates (IPs)**. The plate contains a **photostimulable phosphor (PSP)** that stores the latent image of the body part until it is processed. The phosphor absorbs the energy of the x-rays and, with it, the image of the body part. Most IP phosphors are made of barium fluorohalide with europium. Essentially, there are two types of IPs: a *standard-resolution IP*, which has a thick phosphor layer, and a *high-resolution IP*, which has a thin phosphor layer. High-resolution IPs have greater resolution and sharpness owing to the thinner phosphor layer. The front of the cassette containing the IP is made of a **radiolucent** material that does not absorb primary x-rays. This allows the maximum number of x-rays to reach the IP. The back side of the cassette has a lead lining to prevent **backscatter radiation** from reaching the IP. Backscatter can cause image **artifacts**.

CR cassettes come in the same sizes and shapes as traditional film cassettes (Table 8.1). The plates also contain a barcode label or barcode sticker that allows the limited operator to match the image information with the patient-identifying barcode on the examination request (see Fig. 8.3B). To process and view the image, five additional equipment components are required: a **CR reader** unit, a limited operator computer workstation, a computer system with monitors for the radiologist to view the images, a printer if images need to be printed on film, and a computer server to store the images (Fig. 8.4).

After an IP is exposed, it is inserted into the CR reader (see Fig. 8.4A). Once the plate is inside the reader, the phosphor is scanned with a laser beam. This releases the stored energy in the form of visible light (Fig. 8.5). Special

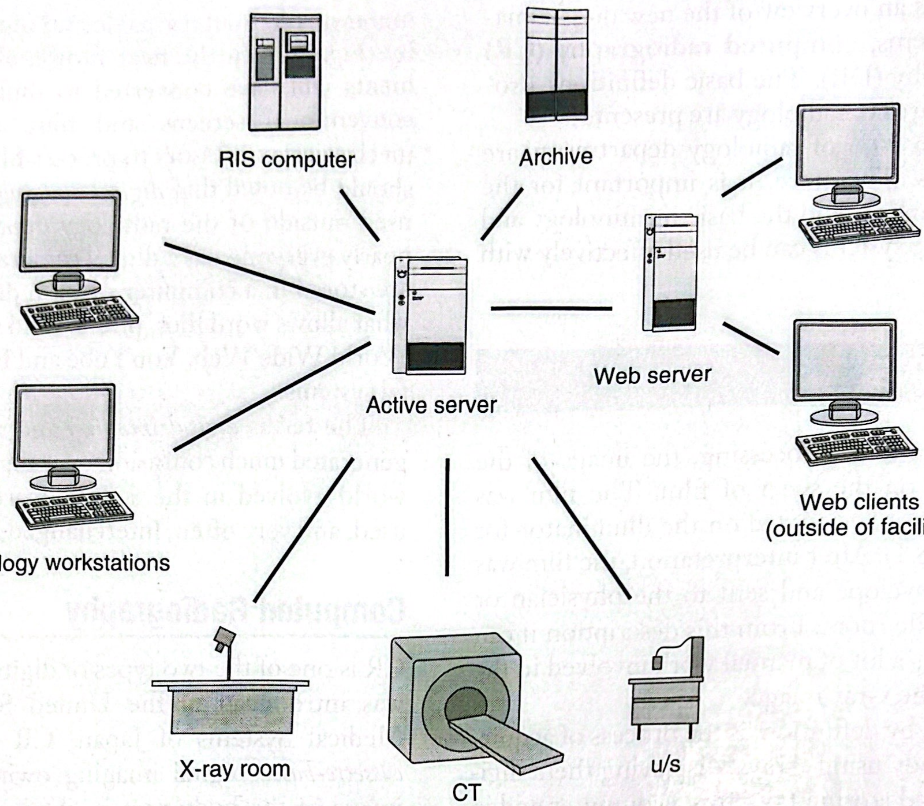

Fig. 8.2 A typical digital computer network showing the modalities feeding images to the workstations, viewing stations, servers, and archives. *CT*, Computed tomography; *RIS*, radiology information system; *u/s*, ultrasound.

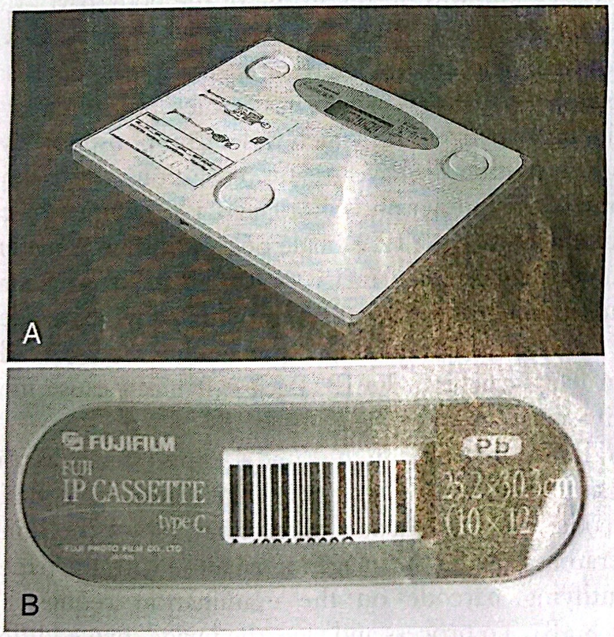

Fig. 8.3 (A) Conventional computed radiography (CR) imaging plate (IP). The plate contains a storage phosphor that stores the x-ray energy. (B) Barcode label on the CR cassette allows matching of the image with the correct patient.

electronics convert the light into an electric signal to produce the digital image of the body part on a computer screen (see Fig. 8.4B). In CR, **sampling frequency** is important. As more signal is sampled, more information is obtained and spatial resolution is improved. After the plate is scanned, inside the reader, it is exposed to an intense white light to erase it. This ensures that any residual image on the IP is erased. PSP plates can be reused at least 10,000 times before they need to be replaced.

A very important aspect of the IP is that it will absorb more low-energy scatter compared with the old film/screen cassettes. This means that appropriate collimation and kilovoltage peak (kVp) must be used to achieve optimal images. *This also makes the IP more sensitive to scatter radiation both before and after exposure to the x-ray beam.* The IP is also sensitive to background radiation and should be erased if it is not used in 48 hours; otherwise there will be fog on the image.

TABLE 8.1
Most Common Computed Radiography Plate Sizes

Inches	Centimeters
8 × 10	18 × 24
10 × 12	24 × 30
14 × 14	35 × 35
14 × 17	35 × 43
14 × 36	35 × 91

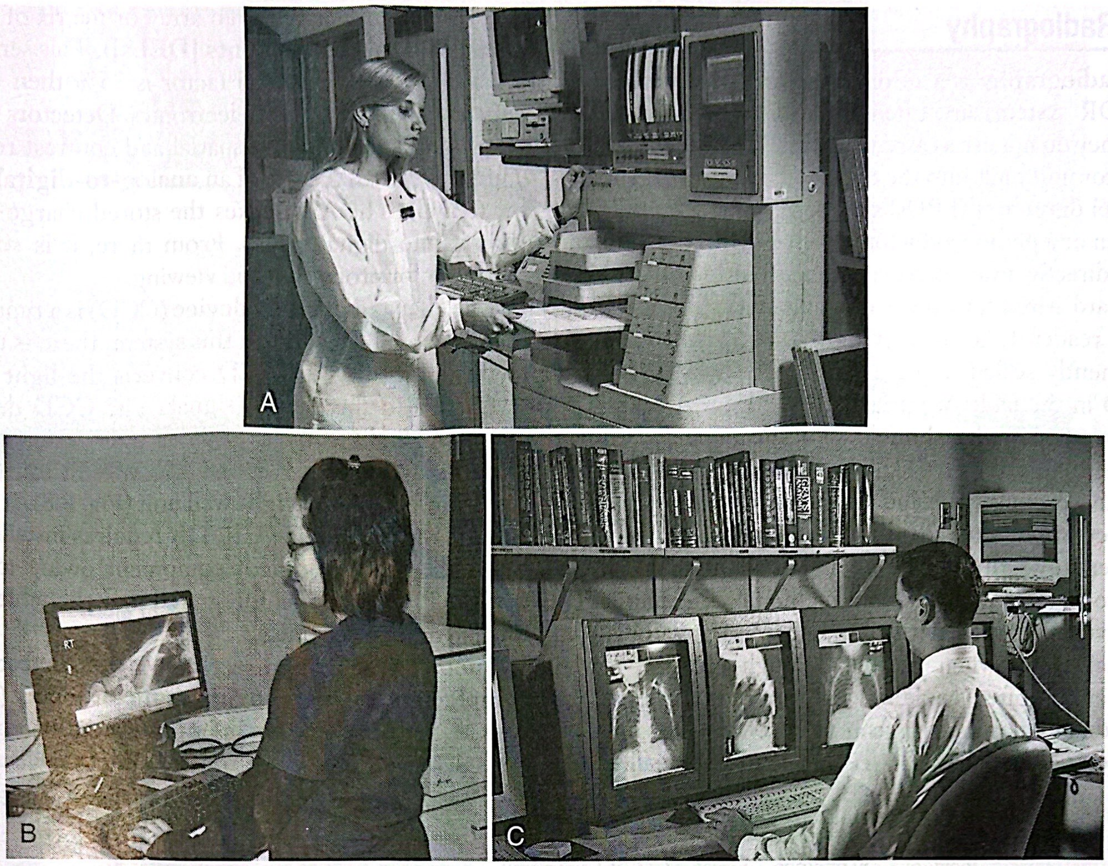

Fig. 8.4 (A) Limited operator inserting an imaging plate (IP) into the computed radiography (CR) reader for processing of the image and plate erasure. (B) The operator's computer workstation. Here the operator checks the image for quality control, adjusts the image as required, and sends it electronically to the radiologist for interpretation. (C) The radiologist at the reading station. Note that several images can be viewed at one time. Images are retrieved from the department server for reading.

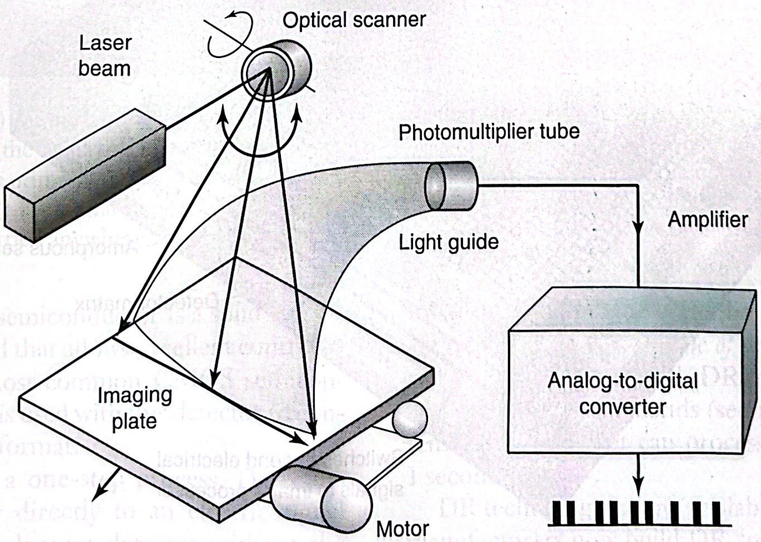

Fig. 8.5 A look inside the computed radiography (CR) reader. A laser beam scans the CR imaging plate (IP) and releases the stored energy as visible light. A photomultiplier tube converts the light to an electric signal. A converter creates the digital image, which is then sent to the computer system.

Digital Radiography

Digital radiography is a second type of digital imaging system. DR systems are often referred to as *cassetteless* because they do not use a cassette with an IP. Instead there is a detector unit built into the table and upright wall unit. **Flat-panel detectors** (FPDs) consist of either a scintillation screen or a photoconductor, which converts the x-ray photons directly into electrical signals. With DR, the FPD is hard wired into the x-ray table and upright unit and a CR reader device is not required. For protection, it is permanently sealed inside a rigid protective housing. The FPD in the table or upright unit is 43 × 43 centimeters to accommodate horizontal and transverse body part projections. DR systems can be divided into two categories: indirect conversion and direct conversion systems.

Indirect conversion DR is a two-step process in which the x-ray energy is first converted into light and then converted into an electric signal. This method uses a scintillator to convert the x-ray energy into light. A scintillator is a device that glows when hit by the high-energy x-ray photons, and is often made of cesium iodide. A photodiode made of amorphous silicon then converts the light into an electric signal (Fig. 8.6A). The amorphous silicon collects electric charges as an array or matrix of pixel size elements (**detector elements [DELs]**). This sensing area has a **fill factor**. If the fill factor is 75% then the other 25% would be covered by electronics. Detectors with high fill factors present higher spatial and contrast resolution. This occurs with the use of an **analog-to-digital converter (ADC)**. The ADC takes the stored charge and converts it into digital values. From there, it is sent to the computer for processing and viewing.

The **charged coupled device** (CCD) is a type of indirect conversion detector. In this system, there is no photodiode and instead the CCD converts the light from the scintillator to the electric signal. The CCD device uses optics and light and therefore is often referred to as a CCD camera. The FPD or CCD is built into the x-ray table (Fig. 8.7A) or upright wall unit (Fig. 8.8). It is important to note that, unlike CR, DR requires installation of a new radiography room of equipment owing to the fact that the FPD system is integrated into the table, generator, and other electronics.

Another type of indirect conversion detector is the **complementary metal oxide semiconductor (CMOS).** CMOS detectors convert light into electrons very similar to CCD technology. With CMOS, the electrons are

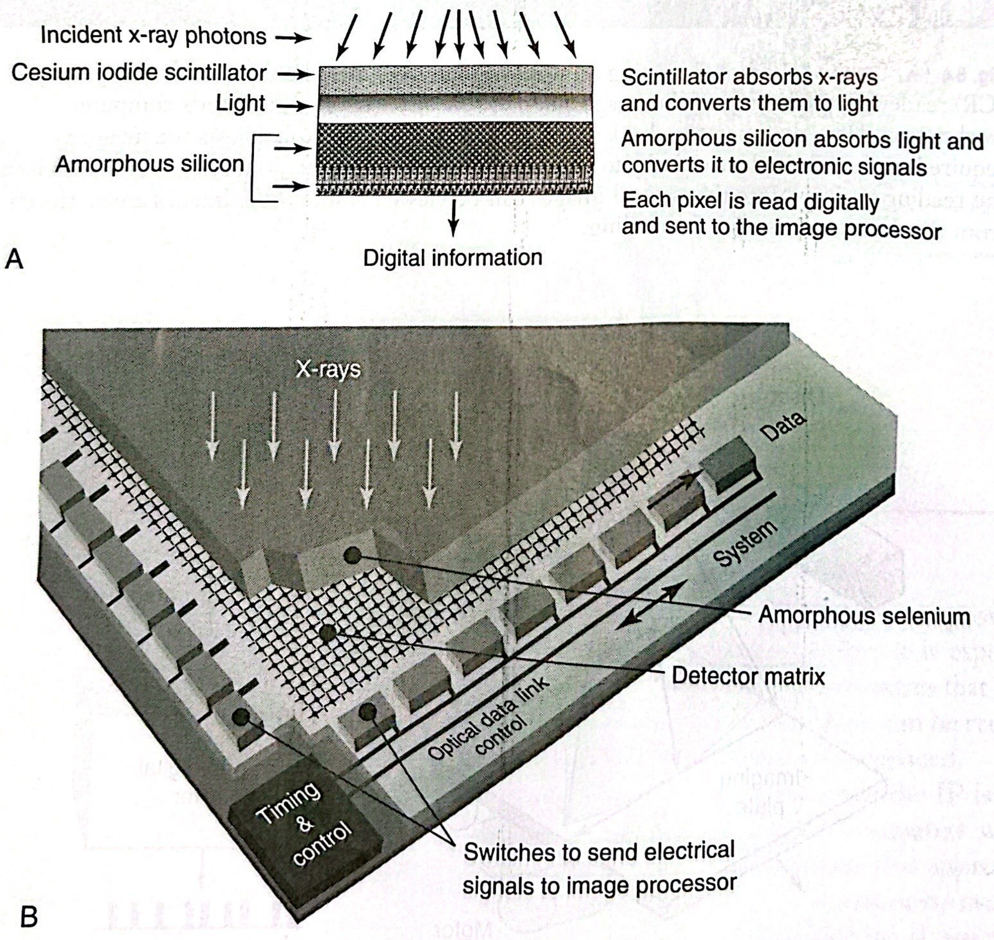

Fig. 8.6 (A) Cross-sectional drawing of an indirect conversion detector showing the scintillator, the light given off, and the amorphous silicon layer that converts the light into the electric signal. (B) Flat-panel detector in a direct conversion system in which the x-ray energy is converted directly to an electric signal. Amorphous selenium layer is shown.

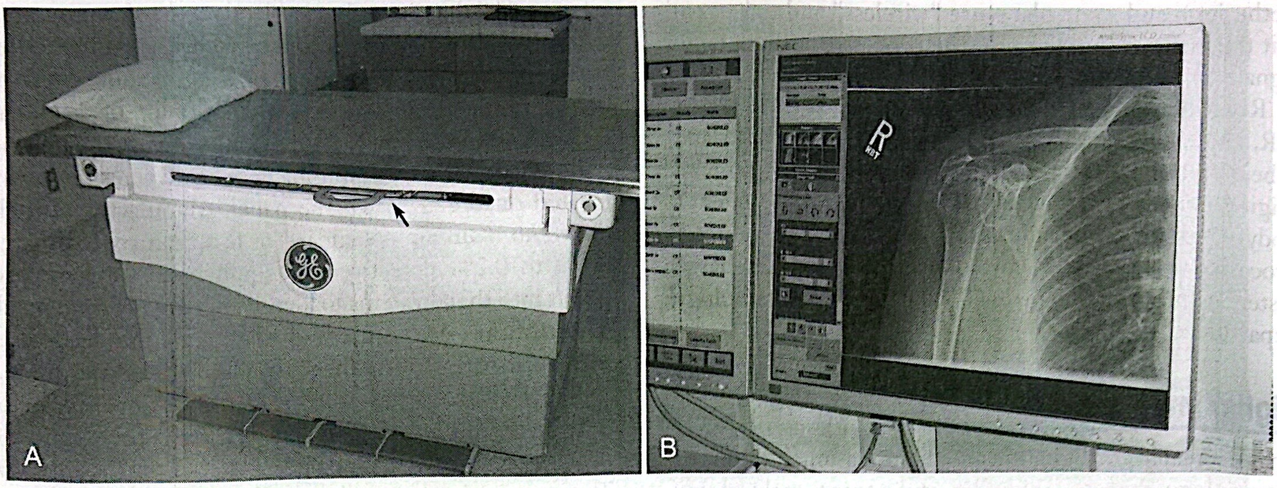

Fig. 8.7 (A) Digital radiography x-ray table. The flat-panel detector unit is built into the table *(arrow)*. There is no Bucky tray for either a conventional film cassette or a computed radiography (CR) imaging plate (IP). (B) The image is displayed on the monitor in the x-ray room in 3 to 5 seconds for viewing.

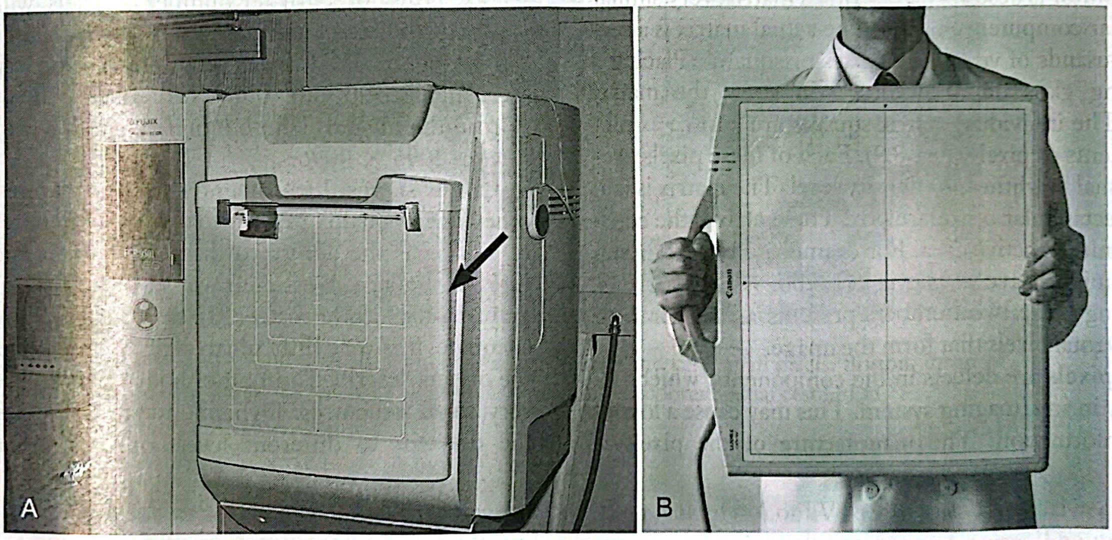

Fig. 8.8 (A) An upright or wall-mounted digital radiography unit. The flat-panel detector is built into the front of the unit *(arrow)*. This unit is used for radiography of upright chests and abdomens primarily but can be used for any x-ray projection that is done in the upright position. (B) A digital radiography (DR) cassette containing a flat-panel detector. These plates can be carried anywhere for obtaining fast images.

stored in capacitors. The semiconductor is a solid chemical element or a compound that allows excellent control of electrical current. The most common CMOS semiconductor is silicon. An ADC is used with this detector to convert the image into digital format.

Direct conversion is a one-step process. Detectors convert the x-ray energy directly to an electric signal through an amorphous selenium detector without the light conversion (see Fig. 8.6B). DR images, especially those from direct conversion detectors, are available within seconds of making the exposure, whereas with CR the plate has to be manually inserted into the reader unit for processing before it can be viewed. *The ability to see x-ray images very fast is one of several major advantages of CR and DR systems.* With DR, images can be processed and seen in 3 to 5 seconds (see Fig. 8.7B). The best systems on the market can process an image in as little as 1 second.

DR technology is now available in cassette form. Many manufacturers now build DR "plates" that have the FPD built into the cassette (see Fig. 8.8B). These DR plates can be used to take x-rays on patients in wheelchairs, on carts, and outside the department using a mobile x-ray machine. Some DR plates are connected to the processor via a cord (tethering), and some plates are "wireless" and can transmit the image information to the processor using a radio signal.

Regardless of the type of digital imaging system, CR or DR, the x-ray generator, the overhead tube crane and tube, and the patient table and upright wall unit remain. Digital imaging starts when the x-rays exit the patient's body. With digital imaging, the x-ray image is produced, processed, viewed, and stored within a computer-based system, which provides many efficiencies for the radiology department.

Digital Images

Images created by digital means require a much different terminology than the old film and screen technology. Limited operators should become familiar with this new terminology because it is used every day in the production of digital images.

Matrix and **pixel** are digital terms used to describe the viewing monitor and the image. The digital image as seen on the monitor is described as having a matrix, very similar to a regular computer monitor. The actual matrix is a series of thousands of very small boxes or squares. Placing a magnifying glass on a monitor will show the matrix squares. The individual matrix squares are known as picture elements or pixels (Fig. 8.9). Each of these pixels presents a visual brightness or density level. The matrix is laid out in a rectangular or square box. The matrix is the computer monitor's active area. For example, a typical digital monitor might have a matrix of 2000 × 2500 pixels. Multiplying these two numbers presents a monitor with 5,000,000 total pixels that form the image.

Dead pixels are defects in the components, which is a possibility in any imaging system. This may cause a loss of patient information. The manufacture of the pixels is so complex that it is inevitable that the detector array will suffer some damage. Dust, scratches, and interactions between materials can occur, resulting in some defective pixels. These pixels may be malfunctioning or dead, that is, not functioning at all. As the detector ages, the number of dead pixels increases but may not be detected if they are located on the edges of the panel. Manufacturers make efforts to maintain a standard of less than approximately 0.1% to 0.2% defective pixels and build software programs into their systems to identify and isolate dead pixels. The software uses a method to "fill in" the dead pixels with information using the surrounding pixels as a guide.

Spatial resolution is a critical image quality factor. A basic definition of spatial resolution is the amount of detail or sharpness of an image as seen on the monitor. The matrix size has a direct effect on spatial resolution. *The larger the matrix and the smaller the pixels, the greater the spatial resolution.* Therefore, a 1000 × 1000 matrix (1,000,000 pixels) in a 20-inch monitor will present greater resolution than a 512 × 512 matrix (262,144 pixels) in that same 20-inch monitor. Fig. 8.10 illustrates that smaller size pixels, or a greater number of pixels, will produce images with better resolution than larger pixels. Monitors can be purchased with different resolution capabilities. Very high-resolution monitors are used by the radiologist to read the images. These monitors can have a matrix as large as 4096 × 4096.

Contrast resolution and **dynamic range** are two other image-quality factors that work together. Contrast resolution is the ability to distinguish anatomical structures of similar subject contrast, such as liver–spleen and gray matter–white matter. If contrast resolution is not adequate, it is very difficult to see the difference between the organs described and other body structures, especially very small structures. Dynamic range is the response of the detector to different levels of radiation exposure.

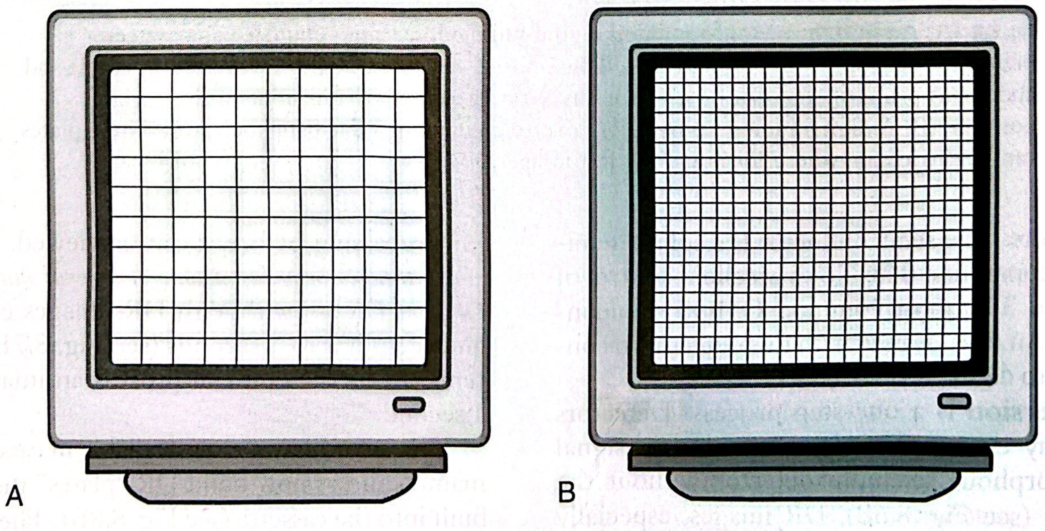

Fig. 8.9 A computer monitor's matrix and pixels shown. (A) Monitor with a 10 × 10 matrix and 100 pixels. (B) Monitor with a 20 × 20 matrix and 400 pixels. An image on the B monitor would display greater spatial resolution because of the larger matrix and smaller size of the pixels.

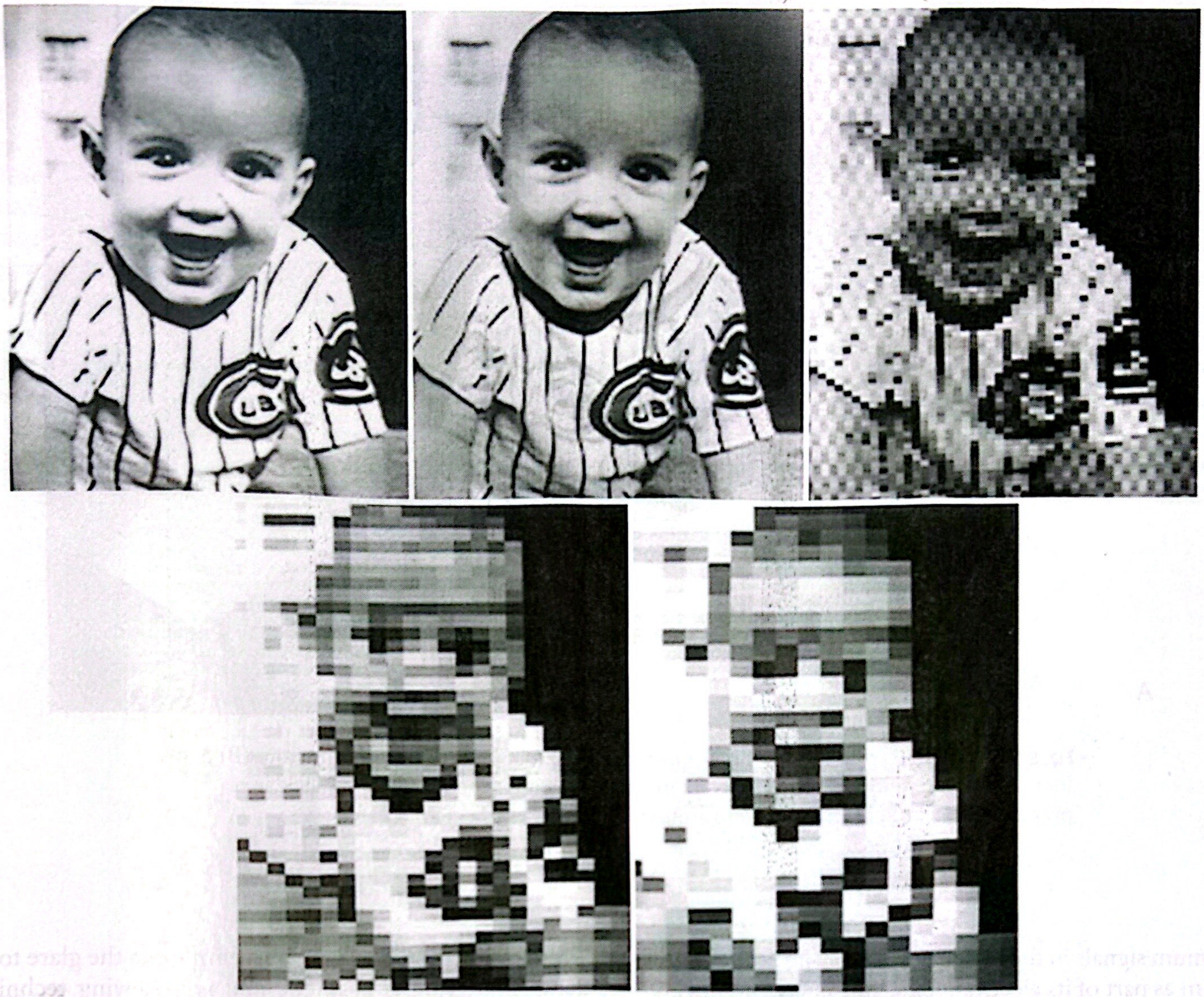

Fig. 8.10 Top image of child made with a large matrix and very small pixels. Bottom image made with smaller matrix and larger pixels resulting in poorer spatial resolution.

A digital image can be produced with a wider range of exposures. Because of this response, overexposures and underexposures may not need to be repeated. However, a technique chart should still be used to determine the correct exposure and not just set a "range" exposure for a given body part. Both CR and DR detectors are capable of producing a much wider gray scale in the image. Digital imaging systems are capable of producing better contrast resolution and a wider dynamic range than the old film/screen systems. Contrast resolution and gray scale of any image are manipulated by adjusting the window described in the next section.

Signal-to-noise ratio (SNR) describes the ability of the digital system to convert the x-ray input electric signal into a useful radiographic image. *Signal* refers to the useful information in the image. *Noise* refers to the amount of information that is not useful. Noise can be caused by **quantum mottle** or inherent electrical noise. Quantum mottle occurs when there are not enough photons in the detectors to provide a high-quality image, which is usually the result of mA or kVp set to low. The goal in digital imaging is to reduce the amount of noise. The more signal that is present, the less noise, and the higher the quality of the image. When there is a high SNR, or low system noise, the greatest amount of information is captured. When the SNR is poor, contrast resolution is directly affected.

In addition to the SNR, the **modulation transfer function (MTF)** plays a role in the efficiency of the system. MTF is used to measure the capacity or accuracy of the digital detector to pass its spatial resolution characteristics to the final image. An MTF of 0 represents no signal and therefore no image. An MTF of 1.0 would represent a body part image perfectly.

FUNCTIONS OF THE PROCESSING SYSTEM

When a digital image is processed a **histogram** is created. The histogram is basically a graph of the minimum and

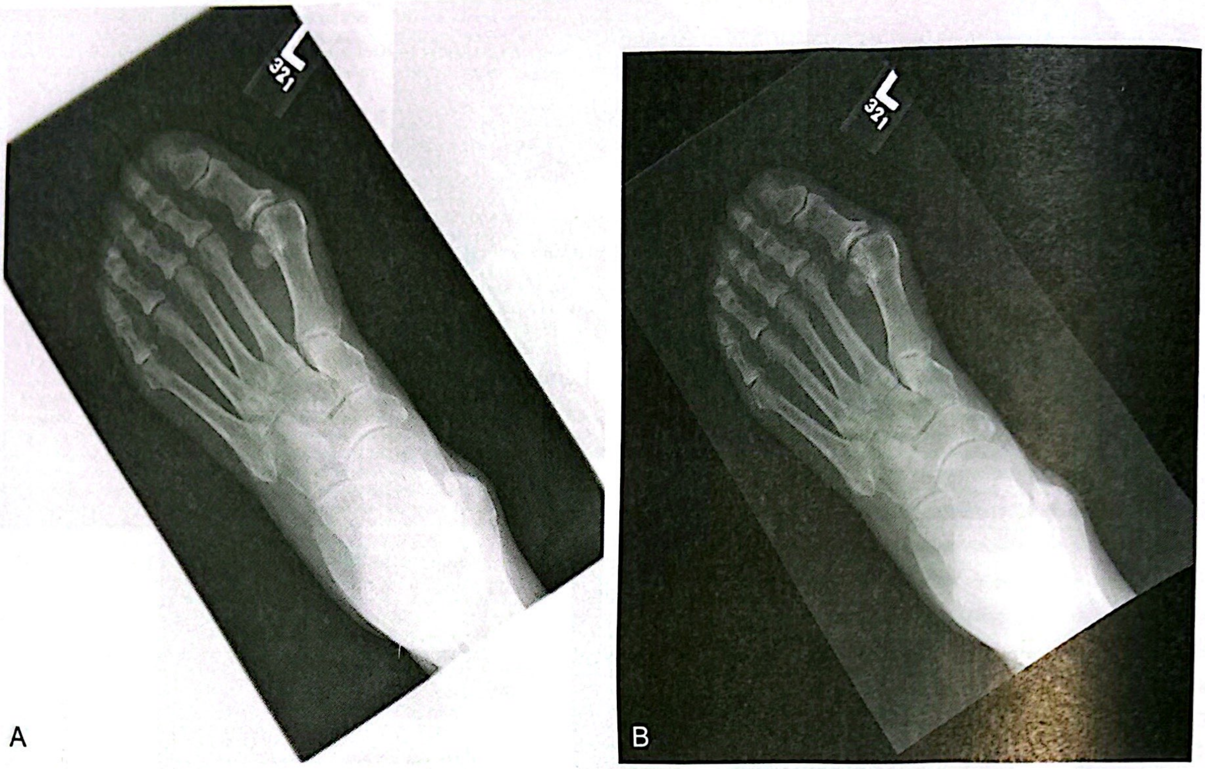

Fig. 8.11 Electronic cropping. (A) Anteroposterior (AP) foot with proper collimation. (B) Same foot with collimation and masking. Note masking surrounds the image with black area preventing bright light from showing around the image.

maximum signals in the image. Each x-ray image has a histogram as part of its electronic file. The operator does not view this histogram directly; however, when the contrast or brightness of the image is adjusted, the histogram is adjusted. A **look-up table (LUT)** is used along with the histogram. The LUT is a file of stored images for each projection. These LUT files are referenced during processing. The LUT is used as a base image reference when adjustments are made on an image.

Image Manipulation

The most common image processing parameters are those for brightness and contrast. **Window level** controls the density in the image. In digital imaging the word **brightness** is used in place of density. **Window width** controls the contrast in the image. The limited operator or physician can manipulate both of the controls, width and level, by simply clicking on the mouse (see Fig. 8.4B and C).

Electronic Cropping

When proper collimation is used there is a clear area around the collimated image. This clear or white area presents excess white light, which can interfere with viewing and interpretation (Fig. 8.11). **Electronic cropping,** also known as *masking* or *shuttering*, is used to blacken out the white collimation borders. This eliminates the glare to the eyes. Shuttering is aesthetic and is a viewing technique only. Many systems perform electronic masking automatically. Cropping can be applied manually by the operator. In these cases, cropping margins are selected and positioned by the operator as required to improve image appearance. It should never be used to mask poor collimation practices. For example, if there was wide, or open, collimation of the body part, scatter is introduced and contrast decreased. The image quality will be reduced even though the cropping did not show the larger collimated area. All body parts should be collimated in the usual way when using digital systems. Electronic cropping is not a substitute for pre-exposure collimation. The American Society of Radiologic Technologists (ASRT) has taken a strong position against the use of electronic cropping when done inappropriately. For DR, in which there is no cassette to automatically set the collimator via a microswitch, standardized collimation settings are now stated in positioning textbooks.[a,b]

[a] Long BW, Hall-Rollins J, Smith BJ: *Merrill's atlas of radiographic positioning and procedures*, St. Louis, 2015, Elsevier.

[b] Long BW, Hall-Rollins J, Smith BJ: *Merrill's pocket guide to radiography*, St. Louis, 2015, Elsevier.

Image Stitching

When anatomy or the area of interest is too large to fit on one IR, multiple images can be "stitched" together using a special computer program, a technique called **image stitching**. This is used most often when doing full-spine posteroanterior (PA) projection images for scoliosis. Imaging the full spine requires a long IR plate. In digital imaging, a special plate consisting of two interlocked 14 × 17-inch cassettes in a 14 × 34-inch plate is used. Image stitching software automatically merges the two, or with some systems three, images together. One image will appear on the viewing monitor (Fig. 8.12).

Image Annotation

Many times, information other than standard identification must be added to the image. **Image annotation** allows the limited operator to add text that is useful to have on the image. This can include information such as time, exposure technique, or patient position. In many digital software systems there is a preset selection of annotation items to choose from, or else the operator can manually insert these into the image. *Annotation should never be used to place a right (R) or left (L) marker on the image.* Identification markers should be placed directly on the image receptor (IR) or tabletop. This is a medicolegal

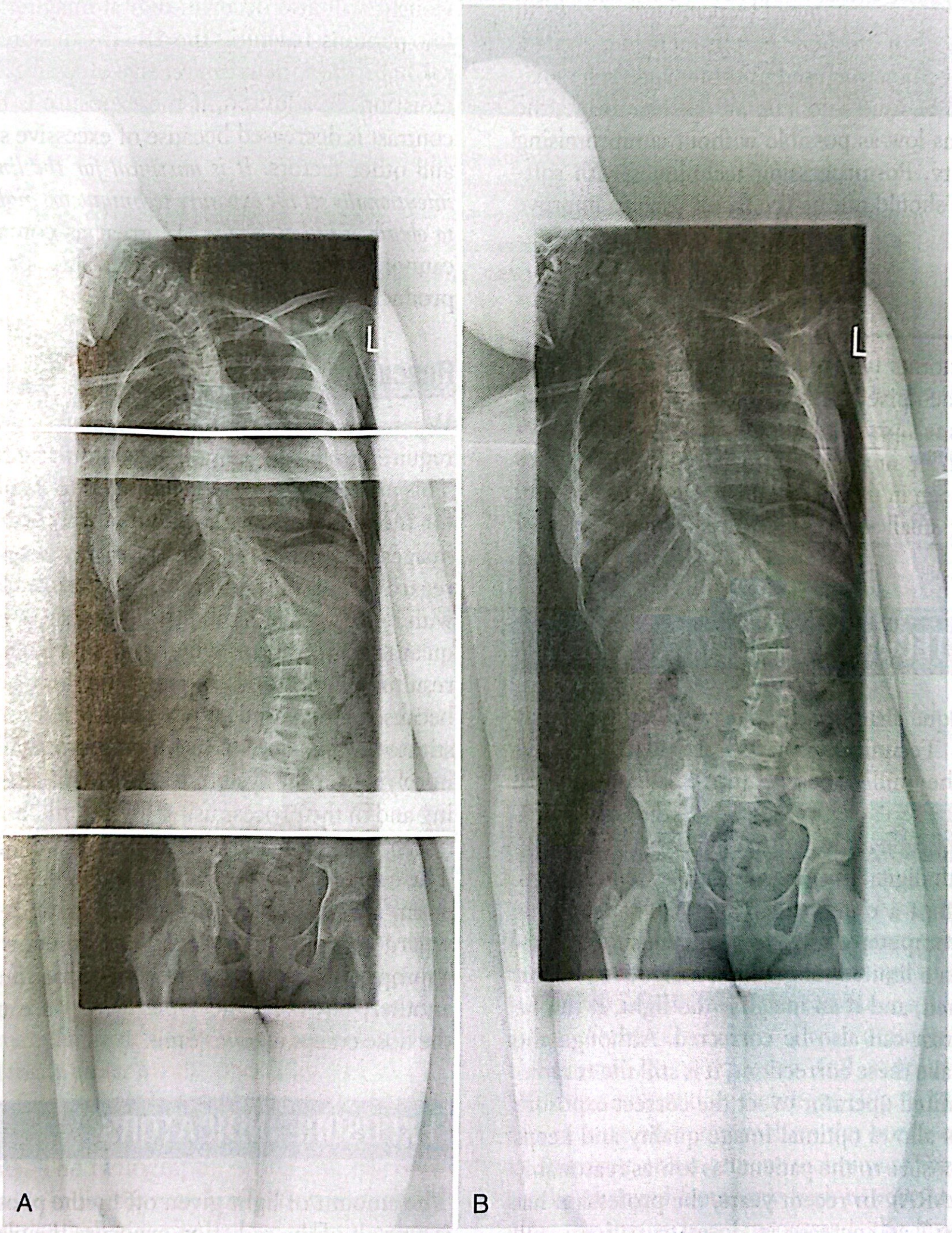

Fig. 8.12 Image stitching. (A) Posteroanterior (PA) projection of spine made with three exposures. (B) All three images joined together by image stitching.

issue. Right or left side errors can easily be made when annotation is used in place of lead markers.

Edge Enhancement

Edge enhancement is a processing technique in which images can be made sharper and have greatly increased contrast; however, it does introduce some noise. This is done by the computer software using various algorithms. A high-pass filter can scan the image's digital file and remove information that is not useful in the image. Edge enhancement can aid the radiologist when interpreting an x-ray examination; however, it can result in the loss of small detail. It is important for the operator to realize that the information content of a digital image is still totally dependent on the correct exposure technical factors. The appropriate exposure technique of kVp and mAs must still be set on the generator, the body part properly penetrated, and appropriate collimation used. Although enough radiation dose should be used to obtain an optimal image, the dose should be as low as possible without compromising the image quality. Postprocessing techniques with software algorithms should not be the factor used to improve image quality.

Smoothing

Smoothing is another type of processing technique. With this technique each pixel's frequency is averaged with the surrounding tissue's pixel values. This is done to remove noise, which can be bothersome to the radiologist. Less contrast is also seen in the image. This technique is useful in viewing very small structures and the fine details of bone.

EXPOSURE TECHNIQUE CHARTS

Exposure technique charts must be used with digital imaging systems. Technique charts are described in Chapter 10. The milliamperage (mA), kVp, exposure time, and automatic exposure control (AEC) selections that were used for each body part in conventional imaging must be used with digital imaging. The IR systems in digital imaging prompt a much wider dynamic range. This means that the computer can correct for exposure technique errors within a limited range. If an image is too dark, it can be lightened, and if an image is too light, it can be darkened. Contrast can also be corrected. Although the computer can make these corrections, it is still the responsibility of the limited operator to set the correct exposure techniques. This allows optimal image quality and keeps the radiation exposure to the patient "as low as reasonably achievable" (ALARA). In recent years, the profession has seen "dose creep," an increase in doses to patients and operators, because of inappropriately increasing the exposure technique in an effort to avoid a repeat examination. In addition, state laws and the Joint Commission require that exposure technique charts be available in the x-ray room for reference to each x-ray projection performed. Therefore, although the computer and software systems may be able to correct for overexposure and underexposure, this should not be seen as a reason to set broad exposure factors. Use of an exposure technique chart is more critical with digital systems. An exact kVp and mAs must be set for each body part.

One of the most important aspects of setting the exposure technique using digital imaging is correctness of the kVp chosen to penetrate the body part. If the kVp is too low and underpenetration occurs, a poor-quality image will be produced, as shown in Fig. 8.13, and a repeat will have to be done. This will result in additional exposure to the patient and to the limited operator. Quantum mottle, described previously, will also occur in digital imaging if there are too few photons reaching the IR. If exposure factors are set too high, the patient can receive excessive and unnecessary radiation. In addition, if the exposure is too high, image contrast is decreased because of excessive scatter radiation and other factors. *It is unethical for the limited operator to intentionally set the exposure technique too high to avoid having to obtain a repeat image.* As great as computers are, they cannot make excessive overexposure or underexposure produce an optimal image.

Rescaling

When the x-ray exposure is greater or less than what is required to produce an image, automatic rescaling occurs. This processing system is designed to display all the pixels for the area of interest. Automatic **rescaling** means that images are produced with *uniform density and contrast*, regardless of the amount of exposure. Problems occur with rescaling when too little exposure is used, resulting in quantum mottle, or when too much exposure is used, resulting in loss of contrast and loss of distinct edges because of increased scatter radiation. Rescaling is no substitute for appropriate technical factors. There is a danger in relying on the system to "fix" an image through rescaling and in the process using higher milliamperage seconds (mAs) values than necessary to avoid quantum mottle. The term *dose creep* is widely used to explain this phenomenon. It refers to the use of automatic rescaling without regard to appropriate exposure amount. What may be appropriate for one patient may be too much exposure for another; however, the same factors are used. Therefore the dose creeps up over time.

EXPOSURE INDICATORS

The amount of light given off by the phosphors in the IP is a result of the radiation exposure the plate has received. The light is converted into a signal that is used to calculate the **exposure indicator number**. Some refer to this as the

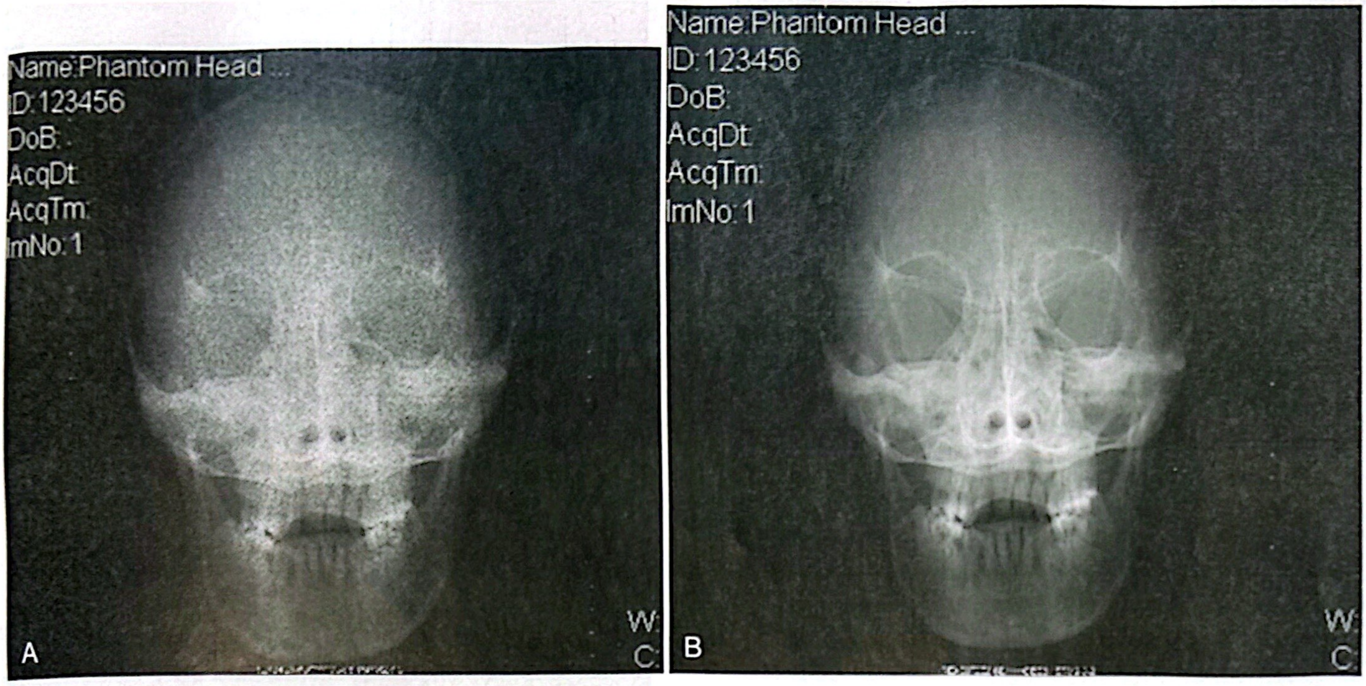

Fig. 8.13 Computed radiography images showing the effect of underpenetration. (A) Anteroposterior projection of the skull underpenetrated at 58 kVp. The computer was unable to create a diagnostic image because not enough x-rays reached the detector. Quantum mottle, or noise, is evident. (B) Same projection correctly penetrated at 85 kVp. Use of the correct kilovoltage is critical when using digital systems.

TABLE 8.2
Recommended Exposure Indicator Values

Company	Overexposure	Underexposure	Adult: Nongrid/Grid	Distal Limbs Nongrid
Carestream	>2500	<1600 tabletop; <1800 Bucky	1800–2100	2200–2400
Agfa	>2.9	<2.1	2.1–2.3	2.4–2.6
Fuji	<100	>250 tabletop; >400 Bucky	200–300	75–125

exposure index. The total signal is not a measure of the dose to the patient but indicates how much radiation was absorbed in the phosphors, which gives only an idea of what the patient received. *The base exposure indicator number for all manufacturers' systems designates the middle of the detector operating range*. Unfortunately, the exposure indicator numbers are not standardized among the different manufacturers of digital systems and, in fact, they can vary widely (Table 8.2). The exposure indicator should be checked on every image. Fortunately, most departments have only one manufacturer's system, so understanding these numbers is made easier for the operator.

Because manufacturers differ in the way exposure is numerically represented, it can be difficult to calculate exposure amounts. The radiography profession has been calling for exposure indicator standardization for several years. Standardization will give the limited operator more confidence in adjusting technical factors while following the ALARA principle. Limited operators should use their vendor's proprietary exposure indices for reference to the correct exposure.

POSTPROCESSING

Another important component of digital imaging is **postprocessing** because a repeat exposure may not be necessary. With postprocessing, any image of a body part can be further adjusted with the computer software to visualize areas of interest better. Two common postprocessing techniques are subtraction and contrast enhancement. With the subtraction technique (Fig. 8.14), the computer can remove anatomy such as the bones or organs. With the contrast enhancement technique (Fig. 8.15), contrast can be changed from very high to very low; however, the more an image is postprocessed, the less information is transferred to the physician. Therefore, manipulation of the image should be kept to a minimum.

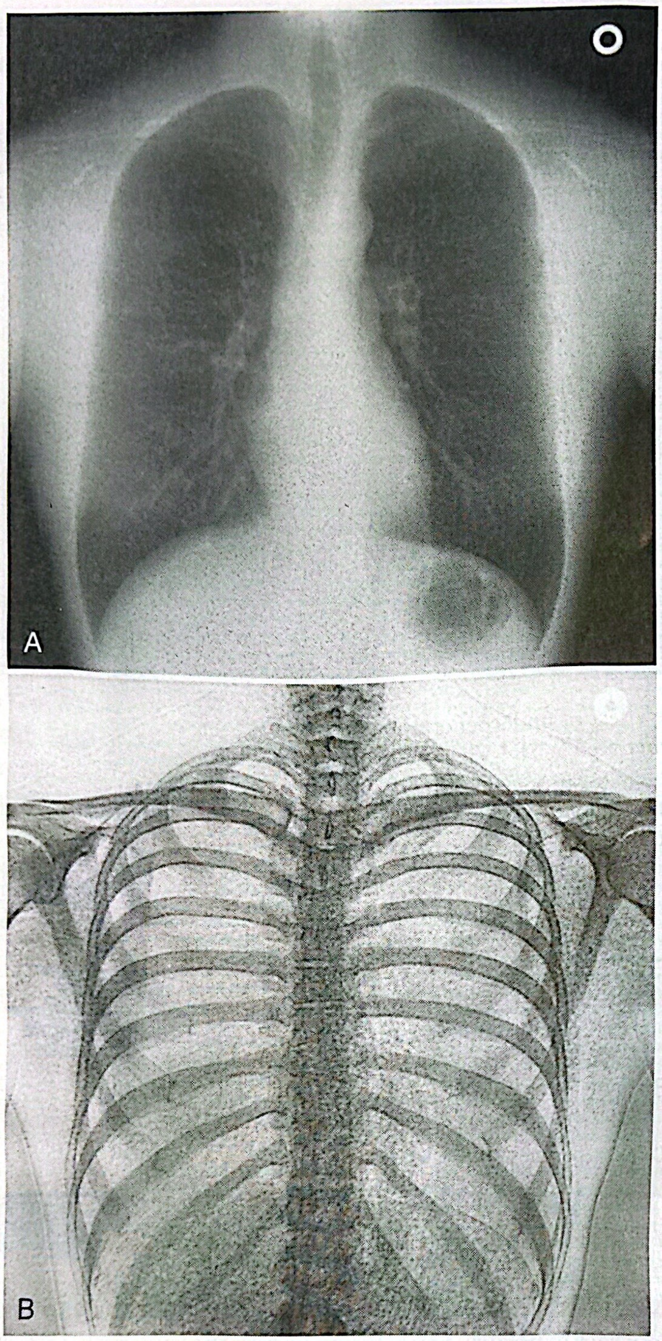

Fig. 8.14 Postprocessing subtraction technique. (A) Ribs are removed to only show the lungs. (B) Lungs and soft tissue are removed to show only the bony areas.

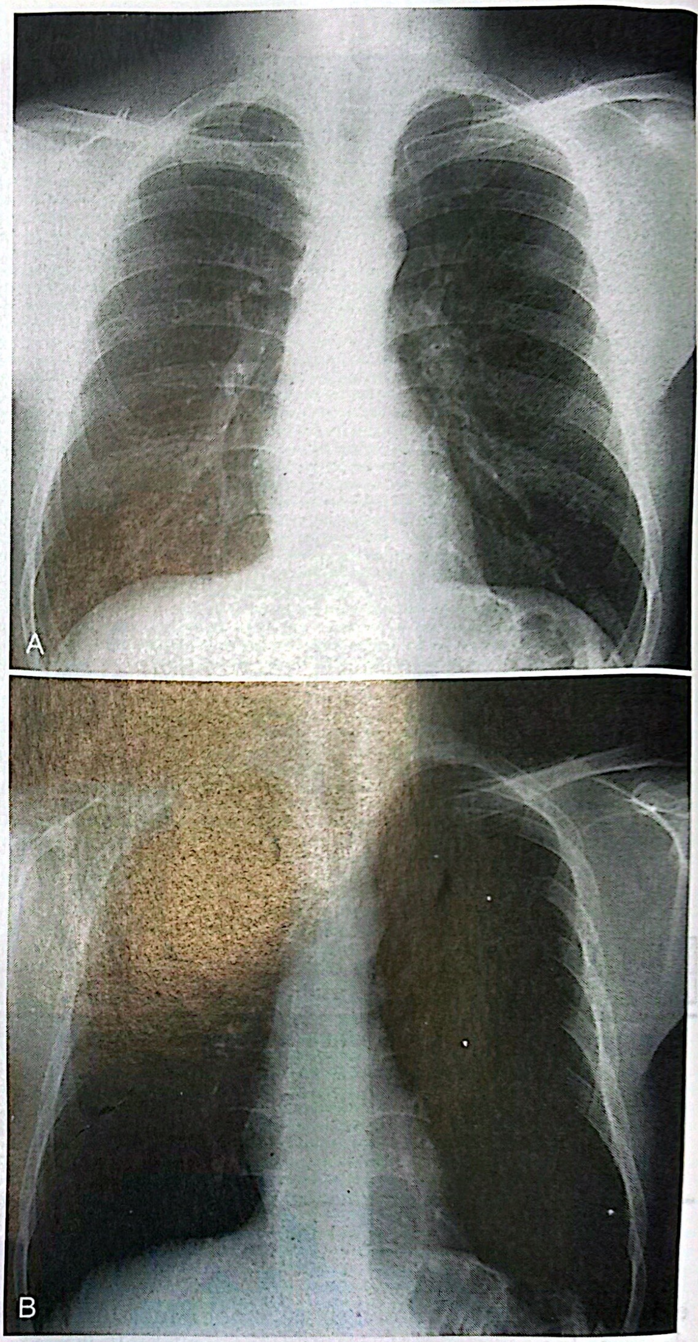

Fig. 8.15 Postprocessing contrast enhancement technique. (A) This chest image shows the standard long scale of contrast for the lungs. Note that the trachea and bones of the shoulder do not show. (B) Contrast adjusted to display a short scale of contrast. Note how the trachea and bones of the shoulder are now displayed.

Digital Imaging and Communications in Medicine

Digital imaging and communications in medicine **(DICOM)** is a universally accepted standard for exchanging medical radiographic images within the institution and in the many areas where the images are viewed. In addition, the DICOM system allows physicians and others to view x-ray images made on different manufacturers' systems in a "cooperative" computer environment. For example, images made with a Fuji system can be read with an Agfa or Carestream system. Changes are made annually to the DICOM software, and limited operators should watch for bulletins with these updates.

One of the more important functions of the DICOM software is that it specifies a standardized display function for consistent display of gray-scale images. This is important because the scale of densities shown on an image in the original system, and a diagnosis made on that system, must be able to be duplicated exactly in a competitor's system. The **DICOM gray-scale function** provides methods for calibrating a particular viewing monitor display system for the purpose of presenting images consistently on different display monitors and printers.

Informatics in medical imaging is closely tied together. Each patient has an **electronic medical record (EMR)** or sometimes it is referred to as the **electronic health record (EHR)**. In radiology, a specific **radiology information system (RIS)** is tied to these records for reports of the patients x-ray examinations.

ARTIFACTS

CR and DR systems produce unique artifact patterns in digital imaging. Generally, an artifact is considered an *error* on the image. Some of the more common artifacts are described below.

- *Quantum mottle* is caused by an inadequate exposure technique. This can be caused by either low mAs or low kVp (Fig. 8.16).
- *Moiré pattern*. This artifact occurs when the grid lines are not aligned with the laser scanning frequency of the CR reader (Fig. 8.17).
- *Light spots* are usually caused by dust or other foreign material on the IP. *CR phosphor* plates can be cleaned, but this must be done carefully according to the manufacturer's recommendations to avoid permanent damage.
- *White line* artifacts appear along the length of travel on the image due to dust on the light guide.
- *Histogram analysis error* may be caused by any of the following: improper collimation, improper technique, beam alignment error, scatter, and extreme subject density differences.
- *Phantom or ghost images* may appear as a result of incomplete IP erasure. This artifact requires troubleshooting of both the CR plate preparation system and the display systems. Extreme overexposure may require two erasure cycles to completely remove the image (Fig. 8.18).
- *Scratches or tears* are permanent artifacts caused by damage to CR plates. Replacement of CR plates is expensive, but it is the only solution because these artifacts cannot be repaired (Fig. 8.19).
- *Extraneous line patterns* are linear lines caused by noise in the image reader electronics. They can run lengthwise or crosswise (Fig. 8.20).

Fig. 8.17 Moiré pattern artifact caused by incorrect grid alignment with laser scan direction.

Fig. 8.16 Grainy appearance artifact of the bones. Quantum mottle appeared because of insufficient exposure to the IP.

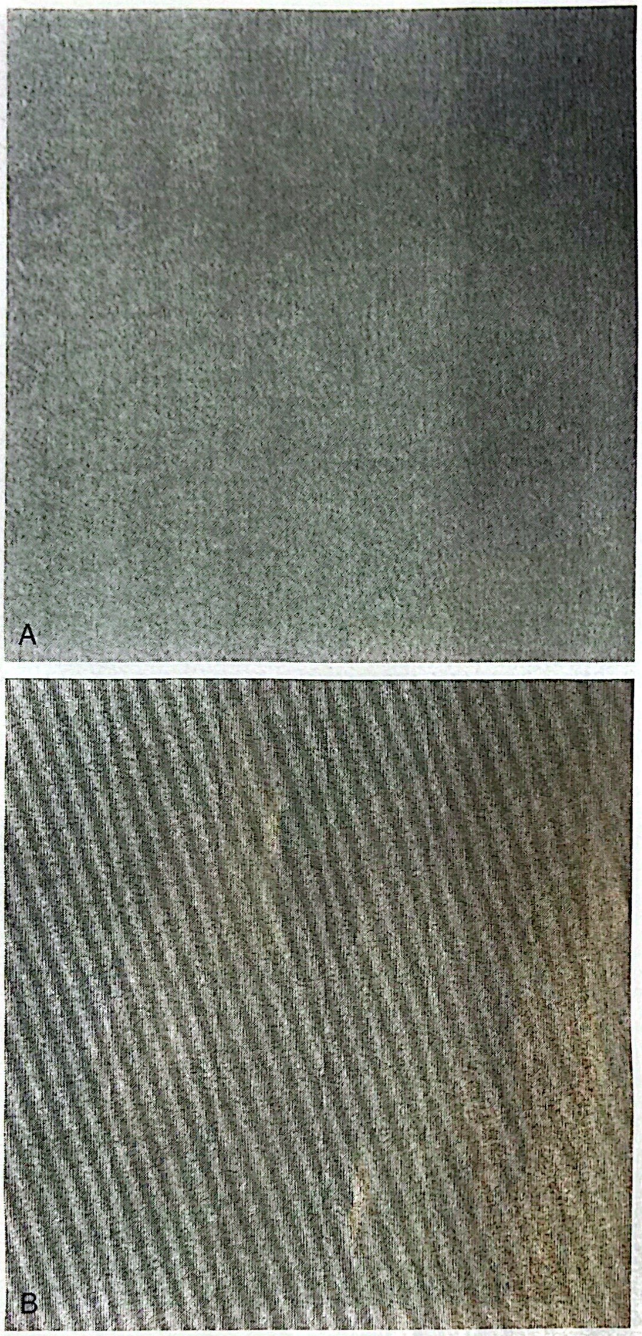

Fig. 8.18 (A and B) Phantom or ghost image artifacts. These can occur from many sources including double-exposed imaging plates and scatter radiation. The actual artifact can appear as though it is in the patient's body, leading to incorrect diagnosis.

- *Fogging* from background or scatter radiation is caused by the CR plates being much more sensitive than the former film.

PICTURE ARCHIVAL AND COMMUNICATION SYSTEMS

In a typical radiology department, thousands of x-ray images can be processed in a given day. Before digital

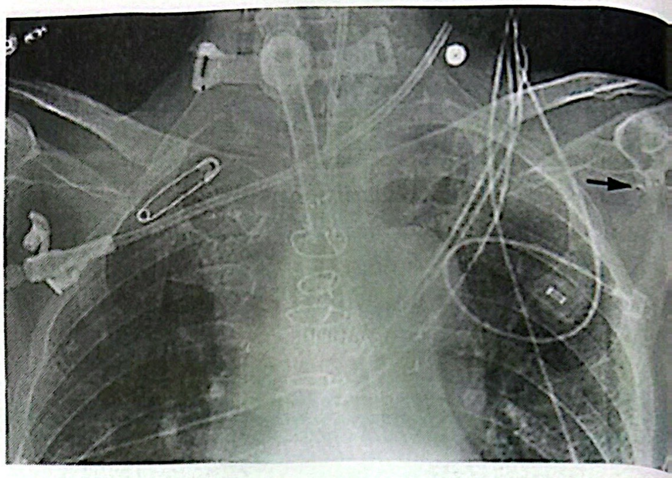

Fig. 8.19 Scratch artifacts *(arrow)* are typically permanent because they occur inside the IR plate and in the phosphor.

Fig. 8.20 Extraneous line pattern artifacts. These are typically caused by the CR reader device and malfunctioning electronics.

imaging, these images were on film and stored in envelopes in large file rooms. With digital imaging, the images are totally contained within computer systems; therefore a system is required to view and file them. The image management system used in radiology departments is called a *PACS*. *PACS* is short for **picture archival and communication system**. The system consists of an extensive networked group of computers, servers, and archives (Fig. 8.21). A PACS will contain all the digital images that are produced in the department, including CT, MRI, ultrasound, and nuclear medicine images. This extensive computer system allows multiple users inside and outside the department to view images. A PACS typically is specially designed for the hospital or clinic depending on factors such as the volume of patients, the number of radiologist reading stations, the number of outside department physician viewing stations, and so on. The software with the PACS system must conform to DICOM standards.

TECHNICAL CONSIDERATIONS FOR EVERYDAY USE

Attention to detail is very important when using digital imaging systems. This section addresses the technical considerations that are different from those in conventional radiography.

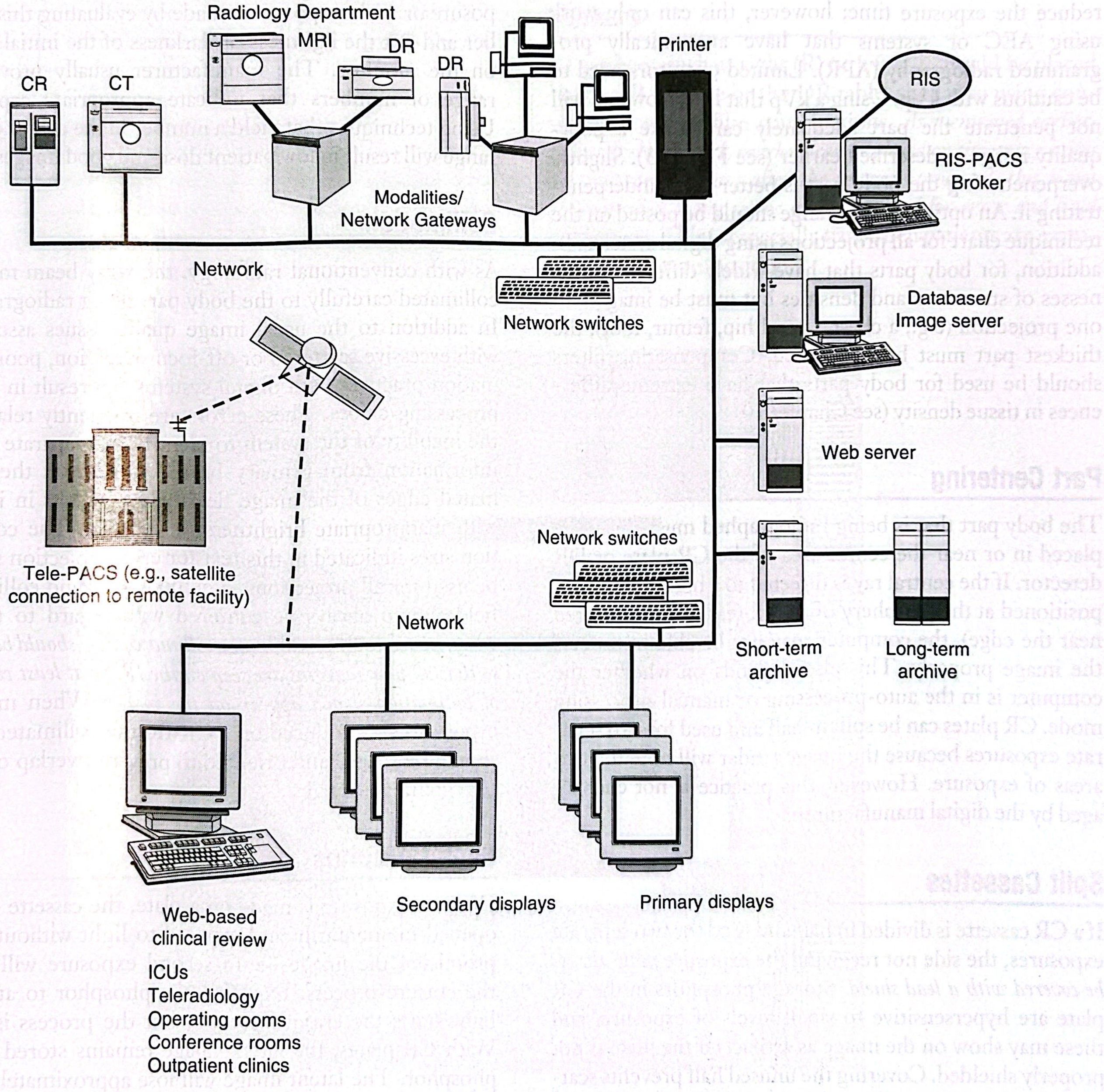

Fig. 8.21 Schematic showing a picture archival and communications system *(PACS)* network. *CR*, Computed radiography; *CT*, computed tomography; *DR*, digital radiography; *ICU*, intensive care unit; *MRI*, magnetic resonance imaging; *RIS*, radiology information system.

Patient ID

Every image, including digital images, must include four items of information: the patient's name or institution ID for a given patient, a birth date or institution ID specific for a given patient, the date of the examination, and the name and location of the x-ray facility.

Kilovoltage

Owing to the wider dynamic range of digital systems, a higher kVp setting may be acceptable for radiography projections that are done using the Bucky and a grid. The kVp may be increased as much as 10 kVp with little effect on contrast. This will help reduce radiation exposure to the patient because a higher kVp will penetrate better and reduce the exposure time; however, this can only work using AEC or systems that have anatomically programmed radiography (APR). Limited operators need to be cautious with kVp. Using a kVp that is too low and will not penetrate the part adequately can create a poor-quality image as described earlier (see Fig. 8.13). Slightly overpenetrating the body part is better than underpenetrating it. An optimum kVp range should be posted on the technique chart for all projections using digital systems. In addition, for body parts that have widely different thicknesses of structures and densities but must be imaged on one projection (e.g., a chest, lateral hip, femur, foot), the thickest part must be penetrated. Compensating filters should be used for body parts that have extreme differences in tissue density (see Chapter 10).

Part Centering

The body part that is being radiographed must always be placed in or near the center area of the CR plate or DR detector. If the central ray is directed to a body part that is positioned at the periphery of the IR (e.g., a finger placed near the edge), the computer may not be able to process the image properly. This also depends on whether the computer is in the auto-processing or manual-processing mode. CR plates can be split in half and used for two separate exposures because the image reader will note the two areas of exposure. However, this practice is not encouraged by the digital manufacturers.

Split Cassettes

If a CR cassette is divided in half and used for two separate exposures, the side not receiving the exposure *must always be covered with a lead shield.* Storage phosphors in the CR plate are hypersensitive to small levels of exposure, and these may show on the image as artifacts if the plate is not properly shielded. Covering the unused half prevents scatter radiation from reaching the unexposed side of the CR plate. Although this technique was practiced in conventional radiography, it is more critical with CR. Depending on the specific technical factors used, if shielding is inadequate, the images may not appear at all, may contain artifacts, or may display other image-processing failures. In addition, technical factors and body part thickness for the two exposures must be relatively close to each other.

Overexposure and Underexposure

A light or dark image on the display monitor may not indicate that the body part was underexposed or overexposed with x-rays as in conventional radiography. A wide array of computer-related factors can cause a light or dark image when digital processing is used. Digital images are often processed with unique numbers, described earlier as *exposure indicator numbers*, which indicate the amount of the exposure reaching the plate. The determination of overexposure or underexposure is made by evaluating this number and not the lightness or darkness of the initial image on the monitor. The manufacturer usually provides a range of numbers that indicate appropriate exposure. Using techniques that yield a number in the center of that range will result in low patient dose and good images.

Collimation

As with conventional radiology, the x-ray beam must be collimated carefully to the body part being radiographed. In addition to the usual image quality issues associated with excessive scattered or off-focus radiation, poor collimation practices with digital systems can result in digital processing errors. These errors are frequently related to the inability of the system to identify and separate image information from primary beam exposure at the collimated edges of the image field, which results in images with inappropriate brightness or contrast. The collimation sizes indicated in this text for each projection should be used for all projections. The body part and collimated field should always be centered with regard to the IR when possible. If possible, *the collimated field should be placed so that all four margins are seen on the IR, or at least two sides of collimation should appear on the image.* When multiple exposures are produced on a CR IR, the collimated fields should be spaced and oriented to prevent overlap of adjacent collimated edges.

Open Cassettes

Once an exposure is made on a plate, the cassette can be opened momentarily and exposed to light without compromising the image—a 15-second exposure will begin the erasure process. Exposing the phosphor to ambient light starts the erasure process, but the process is slow. With CR plates, the latent image remains stored in the phosphor. The latent image will lose approximately 25% of its energy in 8 hours. All exposures on CR plates should be processed immediately. The cassette is not designed to be light-tight but is designed to protect the IP from dust, scratches, and other damage. This is different from conventional radiography, in which the film inside the cassette is ruined even if momentarily exposed to light.

Grids

The IRs used in DR systems are much more sensitive to scatter radiation. Controlling scatter is a critical consideration in optimizing image quality when using digital imaging systems. Some projections may require a grid if the kVp is above a certain level. For example, one manufacturer requires that a grid be used for any exposure above 90 kVp. This consideration is particularly important in mobile radiography, in which many projections are done without a grid. The common problems associated with grids will occur with digital systems—grid cutoff and moiré artifacts. With digital systems, examination routines may need to be reevaluated to determine the need for a grid.

Display Monitor Quality Assurance

The viewing monitor is often the weakest link in the digital imaging chain. The monitor has a direct effect on the quality of the image that is viewed. The American College of Radiology (ACR) suggests that the monitor is checked for quality at daily, monthly, and quarterly time frames. The main quality control tools are the Society of Motion Pictures and Television Engineers (SMPTE) and American Association of Physicists in Medicine (AAPM) test patterns (Fig. 8.22). These patterns are in the computer software and can be retrieved to perform the tests. The most important monitor tests include:

- Viewing surface and airflow
- Image quality and appearance using a test pattern
- Geometric distortion
- Luminance, reflection, noise, and glare
- Resolution

In most instances, these QC tests of the viewing monitor will be performed by trained QC radiologic technologists or a physicist.

Markers

ID markers, such as right (R) or left (L), should be placed on the CR cassette or the DR table, similar to using conventional screen/film combinations. *As mentioned earlier, although the R and L markers can be placed on the image using the computer software after the image is processed, this is not recommended owing to the great potential for error and legal implications.* This is especially true when patients are examined in the prone position.

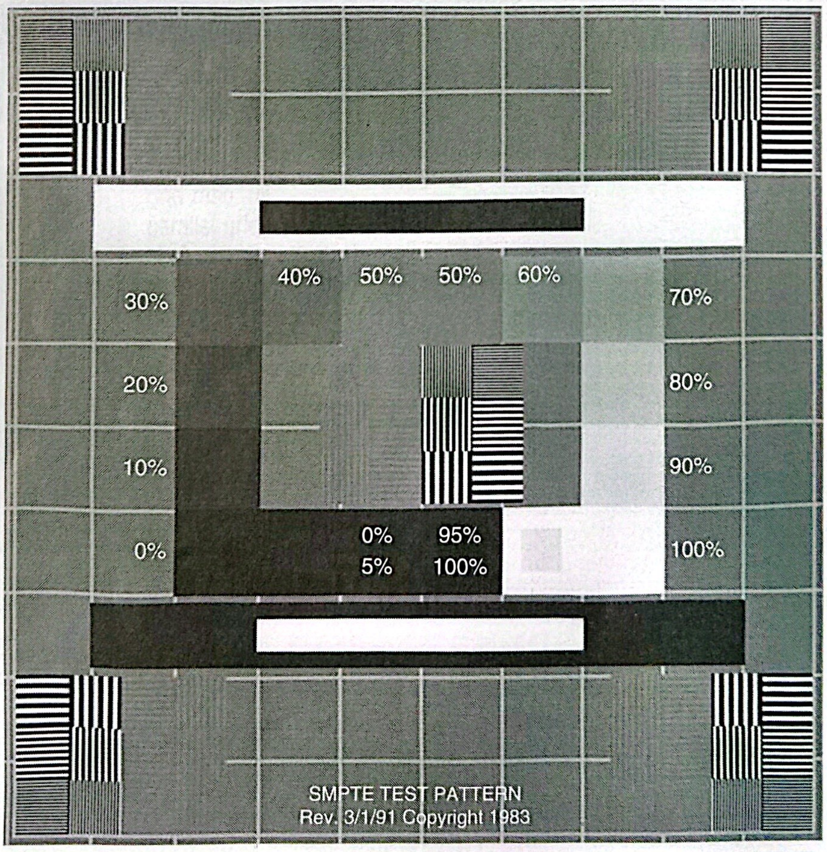

Fig. 8.22 Society of Motion Pictures and Television Engineers test pattern, as seen on a monitor, used to check viewing monitor performance including distortion, luminance, noise, contrast, and resolution.

SUMMARY

The new radiography systems—CR and DR—were introduced in this chapter. New terminology associated with these systems was also presented. The differences between these new digital processing systems and conventional radiography screens and film are important to understand and are brought out in the discussions. The unique differences between the IR used in CR and in DR are presented. The importance of using exposure technique charts and practicing the ALARA concept is discussed because there can be a greater likelihood of overexposing patients when using digital systems. Because film is not used in digital systems, and the storage of x-ray images is on computer servers, the picture archival and communication systems used in DR are discussed. When using digital systems, the limited operator has to change many of his or her daily technical considerations. This chapter presented all of the technical considerations that are different when using digital systems. Technical items such as the kVp, part centering, splitting cassettes, overexposure and underexposure, collimation, grid use, and ID markers were all discussed.