Chapter 4

IMAGE DISPLAY

> *Key Terms:* display monitors • digital-to-analog converters • window width • window level • window center • gray scale • display processor • region of interest • Hounsfield measurement • standard deviation • distance measurement • image annotation • reference image • image magnification • multiple image display • histogram • advanced display functions • multiplanar reformatting • three-dimensional reformatting

In the first two phases of image creation information is collected from the passage of x-ray photons through an object, converted into a usable format, and used to reconstruct densities in cross-sectional slices. The last phase in the creation of the CT image is that of display. Image display includes all of the system components necessary to convert the digital data created from the reconstruction process to electrical signals needed by the CT display monitor. The display system also includes the ability to display patient information and scan protocol data, and provides many graphic aids designed to assist in image interpretation.

DISPLAY MONITORS

An output device allows the information stored in computer memory to be displayed. The device used to display CT images is generally a black-and-white or color monitor. The display device is usually either a cathode-ray tube (CRT) or some form of flat panel such as a TFT LCD (thin-film transistor, liquid crystal display). The monitor consists of the display device, circuitry to generate an image from electronic signals sent by the computer, and an enclosure. The CRT monitor included in many CT systems is basically a standard television set with some modifications that improve image resolution. CRT monitors are heavier, bulkier, hotter, and less durable than the newer LCD monitors. In addition, LCD monitors produce higher luminance and higher spatial resolutions (see Chapter 9 for additional comparisons). Although newer monitors that support digital input signal are growing in popularity outside of medicine, they are not currently included in CT systems. It is a common misconception that all computer monitors are digital. Because the monitors used in CT work with analog signals, it is necessary to convert the digital signal from the computer's memory back to an analog format. Digital-to-analog converters (DAC) accomplish this task.

> **BOX 4–1 Key Concept**
>
> Digital-to-analog converters change the digital signal from the computer memory back to an analog format so that the image can be displayed on the monitor.

Standard, cross-sectional images are nearly always displayed in gray scale. Non-image data, such as text fields that include patient information or scan parameters can be displayed in color.

CAMERAS

In some instances the images are transferred to film. The camera is an output device that transfers the image from the monitor to the film. The camera used may be a multiformat camera, although most CT systems today include a laser camera. Multiformat cameras transfer the image displayed on the monitor to film. Laser cameras bypass the image on the display monitor and transfer data directly from the computer, bypassing the video system entirely, thereby significantly improving image quality. The film used in CT consists of a single emulsion that is sensitive to either the light-emission spectrum of the video screen phosphor (for the multiformat camera) or to the laser beam light.

WINDOW SETTINGS

The way an image is viewed on the computer monitor can be adjusted by changing the window width and window levels. At certain window settings, a slice of the thorax shows the lung parenchyma (Fig. 4-1A). At another setting, the same slice shows mediastinal detail and no longer displays the lung parenchyma (Fig. 4-1B). Many studies, such as those of the thorax, require each image to be viewed at two or more different window settings.

This section provides a technical explanation of window width and window levels. Although there are some guidelines for window settings, a substantial factor is personal preference. In the past, when a technologist's responsibilities included producing hard-copy film for the radiologist's interpretation, the subjective nature of window settings presented substantial challenges. Ideally, windows should be set so that the radiologist responsible for interpretation is satisfied. In practice, it was often impossible for a technologist to know which physician would be responsible for interpreting any given examination. Therefore, it was common practice for each imaging department to have established window settings for filming each type of examination. It was well worth the radiologists' time to work closely with technologists in developing filming protocols to ensure that all parties understood exactly how the image is best displayed. It was also essential that technologists be allowed discretion in selecting window settings, because factors such as patient size and body composition have a pronounced effect. Optimal images cannot be achieved with standardized window widths and levels that do not consider influencing factors.

It is now common practice for radiologists to view studies from a computer workstation, thereby allowing them the freedom to adjust the window settings as they prefer. Although the creation of hard copies is no longer standard procedure for every examination, it is no less important today that technologists understand the impact of window settings. Obviously, technologists must appropriately view images as they are being created. In addition, there continue to be situations in which filmed images are still needed. One example is when a surgeon would like to refer to specific cross-sectional images during the course of an operation. In situations such as these, old-fashioned, polyester-based film is still the most practical method of viewing images. It is also important that the window be set correctly when images are saved onto a compact disk in a static format (these images are often called "screen-shots" because they capture the image exactly as is seen on the screen and do not allow for any further manipulation).

Gray Scale

In an ideal world, the image would be displayed with a different shade of gray for each Hounsfield unit represented. However, although there are more than 2,000 different Hounsfield values, the monitor can display only

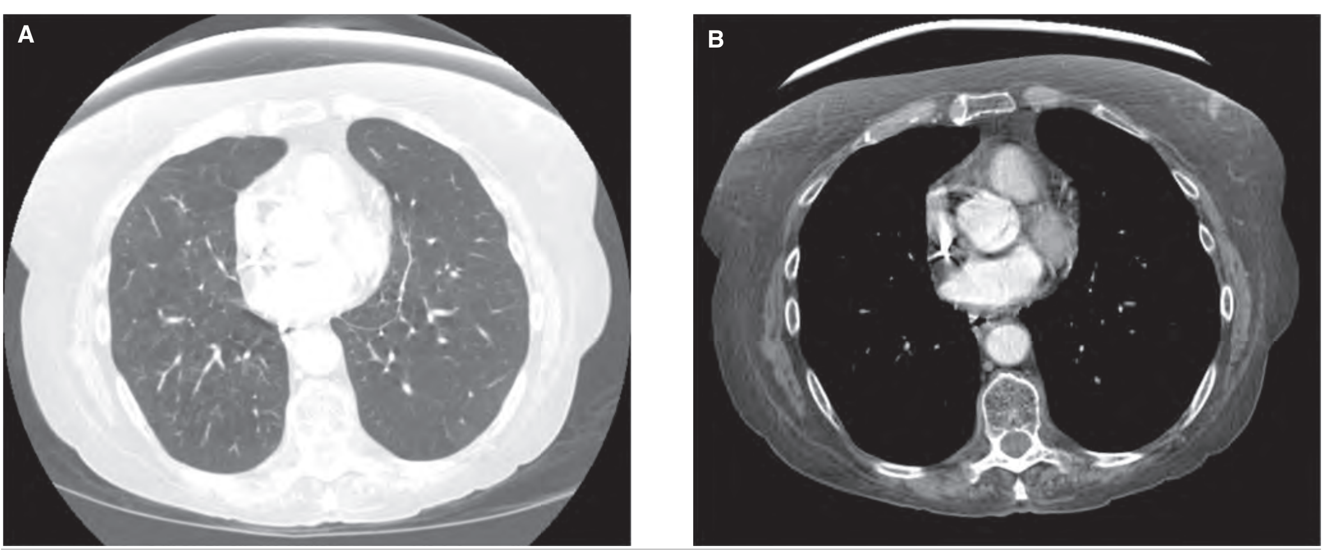

FIGURE 4-1 The effect of window settings on image appearance. A. This lung window provides good lung detail, but the mediastinum is completely white. B. The same slice displayed in a soft-tissue window provides good mediastinal detail, but the lungs are completely black.

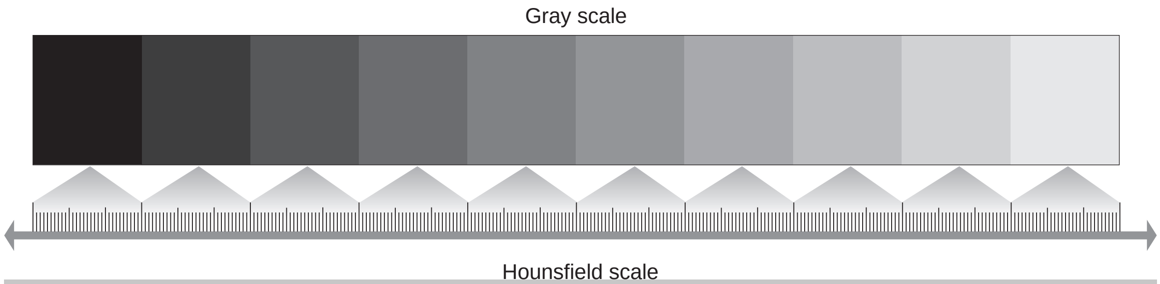

FIGURE 4-2 The display processor assigns a group of Hounsfield unit to each shade of gray. In this simplified illustration, 10 different shades are available to display the 300 Hounsfield units in the window width.

256 shades of gray. Even more limiting, the human eye can differentiate only a fraction of those shades–typically fewer than 40. As a general rule, the human eye cannot appreciate contrast differences of less than about 10%, whereas CT scanners can easily demonstrate differences of less than 1%. To overcome these inherent limitations, a gray scale is used in image display. In this system a display processor assigns a certain number of Hounsfield units (HU) to each level of gray. The number of Hounsfield units assigned to each level of gray is determined by the window width.

BOX 4–2 Key Concept

The gray scale is used to display CT images. This system assigns a certain number of Hounsfield units to each shade of gray.

As was explained in Chapter 1, the Hounsfield scale assigns 0 to the density of water. Correspondingly, −1,000 HU represents air and 1,000 HU represents a dense material such as bone. Values higher than 2,000 HU represent very dense materials, such as metallic dental fillings. By convention, the gray scale assigns higher HU values lighter shades of gray, whereas lower values are represented by darker shades.

Window Width

The window width determines the number of Hounsfield units represented on a specific image. The software assigns shades of gray to CT numbers that fall within the range selected. All values higher than the selected range appear white, and any value lower than the range appears black. By increasing the window width, usually referred to as "widening the width," more numbers are assigned to each shade of gray.

BOX 4–3 Key Concept

The window width determines the quantity of Hounsfield units represented as shades of gray on a specific image.

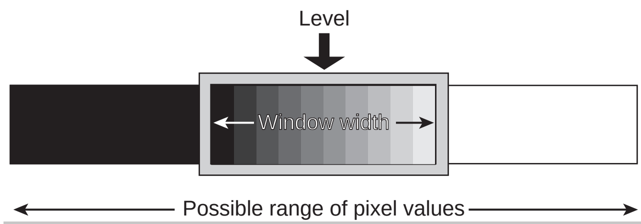

FIGURE 4-3 Window width assigns the quantity of pixel values to the gray scale. Window level determines the center pixel value in the gray scale.

Using a simplified scenario to demonstrate gray scale and window width, assume that we have 10 shades of gray available. We have selected 300 as our window width. Therefore, only 300 (of the more than 2,000 possible density values in our scale) will be represented on the image as a shade of gray. All others will be either black or white. In this example, 30 different Hounsfield units will be grouped together and represented by each shade of gray in the image (Fig. 4-2).

If the window width is set at 300, which 300 Hounsfield values, from all those possible, will be shown? Now that we have selected the *quantity* of Hounsfield units to be displayed by selecting the window width, we now need to determine the *range* of values to display.

Window Level

The window level selects the center CT value of the window width (Fig. 4-3). The terms window level and window center are often used interchangeably. The window level selects which Hounsfield numbers are displayed on the image.

BOX 4–4 Key Concept

The window level selects which Hounsfield values are displayed as shades of gray.

Answering the question posed in the previous paragraph, the particular Hounsfield units to be included in our image are entirely dependent on the window level selected. If 0 is chosen as the window level, the Hounsfield values that are represented as a shade of gray on this image will range from −150 to 150 (Fig. 4-4).

Now assume the width stays unchanged at 300, but the center is moved to 200. Determining the range of Hounsfield values requires only simple arithmetic. First, divide the window width in half. Next, subtract the quotient from the window level to determine the lower limit of the range, and add the quotient to the window level to determine the upper limit. The new range of Hounsfield numbers to be included in the gray scale is from 50 to 350 (Fig. 4-5).

Suggestions for Setting Window Width and Level

The software assigns shades of gray to CT numbers that fall within the range selected. All values higher than the selected range (in the current example, 350) will appear white, and any value lower than 50 will appear black (Fig. 4-6). If we increase the window width, a wider range of values will be included in the grayscale range; more values will be assigned to each shade of gray (Fig. 4-7).

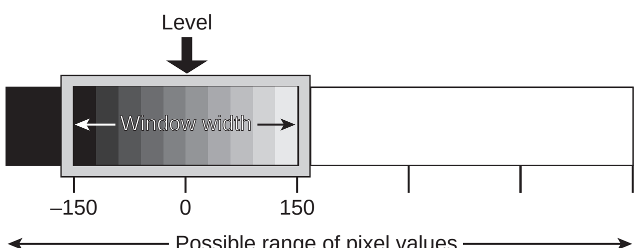

FIGURE 4-4 If the window width is 300 and 0 is chosen as the window level, the Hounsfield values that are represented as a shade of gray on this image will range from –150 to 150.

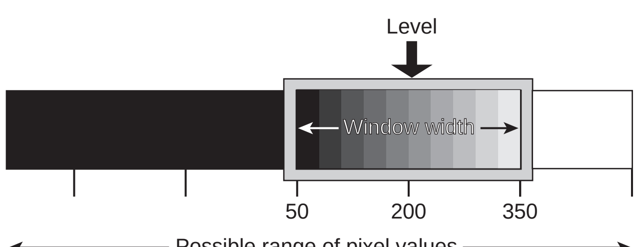

FIGURE 4-5 The width stays unchanged at 300, but the center is moved to 200. The new range of Hounsfield numbers to be included in the gray scale is from 50 to 350. Determining the range of Hounsfield values requires only simple arithmetic. First, divide the window width in half. Next, subtract the quotient from the window level to determine the lower limit of the range, and add the quotient to the window level to determine the upper limit.

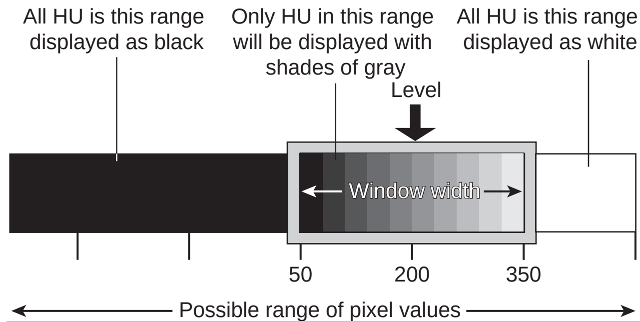

FIGURE 4-6 The software assigns shades of gray to CT numbers that fall within the range selected. All values higher than the selected range (in the current example, 350) will appear white, and any value lower than 50 will appear black.

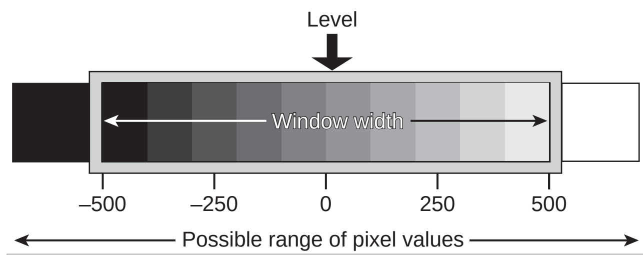

FIGURE 4-7 Widening the window width will include a wider range of values by placing more Hounsfield units into each shade of gray.

BOX 4–5 Key Concept

All values higher than those in the selected range will appear white on the image. All values lower than those in the selected range will appear black on the image.

The window level should be set at a point that is roughly the same value as the average attenuation number of the tissue of interest. For example, a window level setting that is intended to display lung parenchyma will be approximately −600 because air-filled lung tissue measures around −600 HU. The manipulation of window width and window level to optimize image contrast is referred to as windowing.

BOX 4–6 Key Concept

The window level should be set at a point that is roughly the same value as the average attenuation number of the tissue of interest.

In general, wide window widths (500–2,000 HU) are best for imaging tissue types that vary greatly, when the goal is to see all of the various tissues on one image. For example, in lung imaging, it is necessary to see low-density lung parenchyma as well as high-density, contrast-enhanced vascular structures. Wider window widths

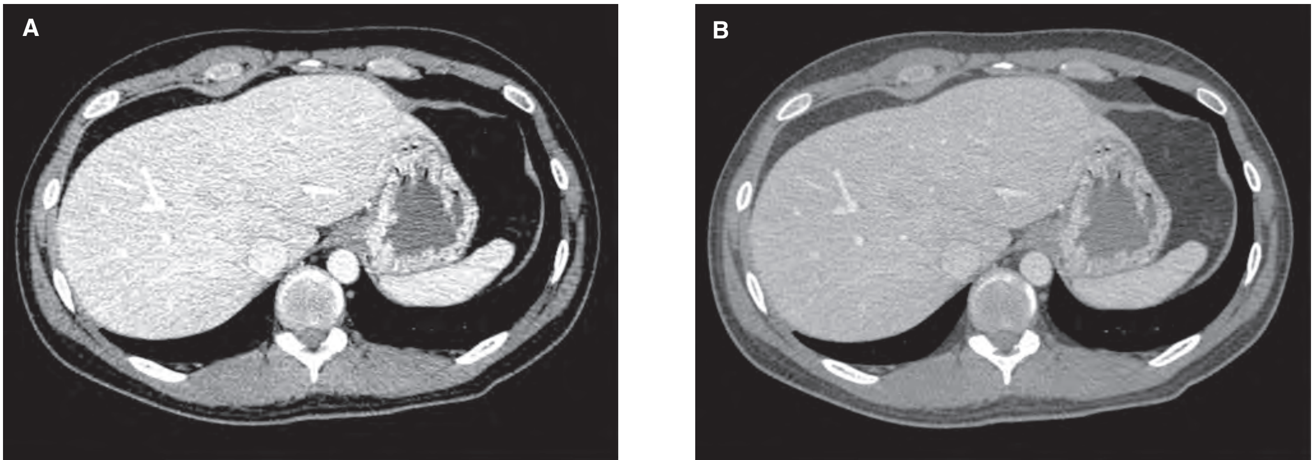

FIGURE 4-8 A. Image of the liver displayed with the department's "standard" window settings. B. Same cross-sectional slice is displayed with the window setting adjusted to better suit the patient.

encompass greater anatomic diversity, but subtle density discrimination is lost.

Because wider window width settings decrease image contrast, they suppress the display of noise on an image. For this reason, it is common practice to widen the window width when patients are obese or when there are metallic artifacts.

Tissue types with similar densities should be displayed in a lower, or narrow, window width (50–500 HU). This approach is best in the brain, in which there is not as much variation in CT numbers. The values can be spread out over the available gray scale so that two tissues with only a small density difference will be assigned separate shades and can therefore be differentiated by the viewer. Because narrow widths provide greater density discrimination and contrast, using a narrow width when displaying the brain makes it possible to differentiate the white and gray matter of the brain.

Often systems provide the option of recording two different window settings, superimposed on one another, in a single image. This technique is known as dual window setting, or double window setting. Because many professionals find the superimposition of images to be confusing and distracting, the technique is infrequently used.

Table 4-1 provides some typical window settings for various examinations.

Clinical Application Box 4-1

Window settings

Most facilities have a few window settings programmed into their CT systems. These are typically labeled with terms such as lung, abdomen, bone, and brain. Although these settings will not provide the optimal window setting for viewing all images in the various categories, they do provide an excellent starting point. For example, Figure 4-8A at the level of the liver is displayed with the department's programmed window setting: width 350, level 50. However, because of the patient's obesity, the image appears both grainy and light. Notice the improvement in Figure 4-8B, the same cross-sectional slice with the window width adjusted to 400 and the level lowered to 30.

Similarly, Figure 4-9A is an image of the neck displayed at the programmed window setting, width 300, level 50. Notice the diminished appearance of the streak artifact in Figure 4-9B when the window width is widened to 500.

IMAGE DISPLAY OPTIONS

Region of Interest

A display function available on all scanners is that of defining an area on the image. This area is referred to as the region of interest (ROI). An ROI is most often circular, but may be elliptic, square, or rectangular, or may be custom drawn by the operator. Defining the size, shape, and location of the ROI is the first step in many display and measurement functions. Image magnification, obtaining an averaged Hounsfield measurement, and acquiring the standard deviation all demand defining an ROI.

BOX 4–7 Key Concept

Region of interest: an area on the image defined by the operator. Defining a region of interest is the first step in a number of image display and measurement functions.

Hounsfield Measurements and Standard Deviation

Hounsfield measurement is one of several valuable tools that aid in image interpretation. However, because

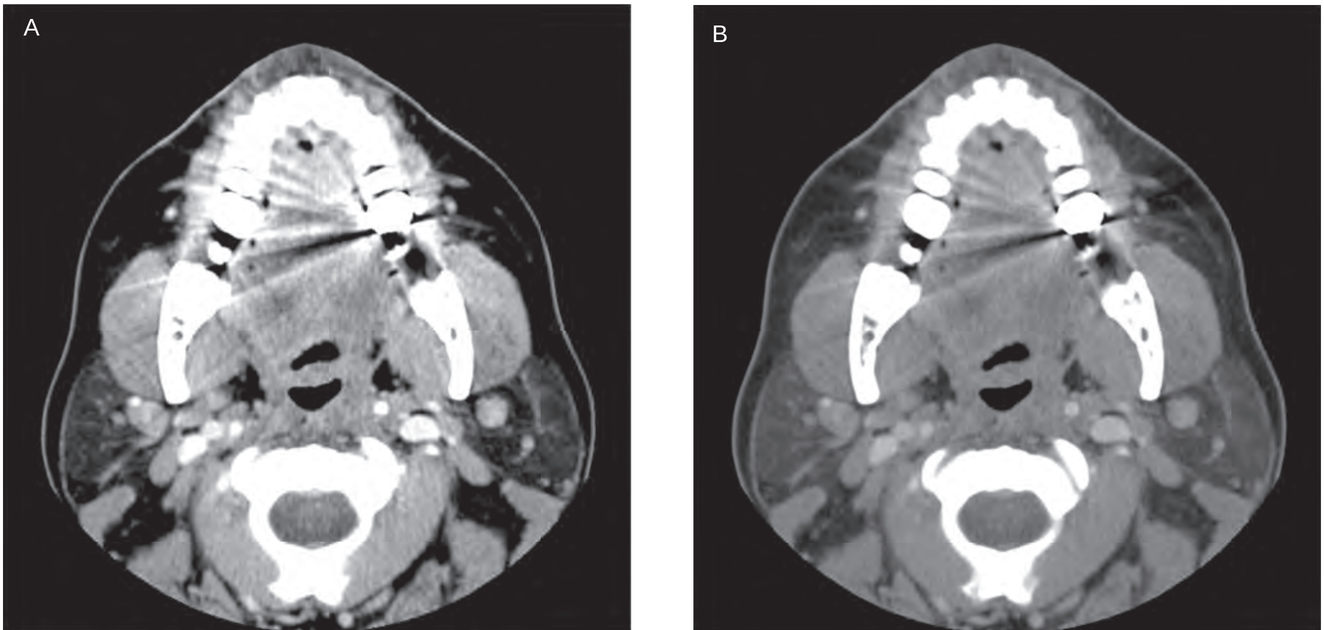

FIGURE 4-9 A. Image of the upper neck displayed with the department's "standard" window setting. B. Window width is adjusted to reduce the appearance of streak artifact caused from dental fillings.

TABLE 4-1 Typical Window Settings for Common CT Examinations

Examination	Width	Level
Head		
Posterior fossa	150	40
Brain	100	30
Temporal bone	2,800	600
Neck		
	250	30
Chest		
Mediastinum	350	50
Lung	1,500	−600
Abdomen		
Soft tissue	350	50
Liver (high contrast)	150	30
Pelvis		
Soft tissue	400	50
Bone	1,800	400
Spine		
Soft tissue	250	50
Bone	1,800	400

measurements may be negatively affected by volume averaging or image noise, caution should be used when Hounsfield values are used in the diagnosis of disease.

On most systems, a cursor (+) placed over an area reads out a measurement of that area. If a cursor is used, it is essential to understand that the subsequent measurement is only for the pixel covered by the cursor. If an ROI is first placed over an area, the reading is the average for all of the pixels within the ROI. If the ROI is accurately placed within the area of the suspected lesion, the averaged value is probably more accurate than the single-pixel reading.

A cursor measurement is effective when used as a rapid method of evaluating the density of a specific structure on an image. For example, if a cursor is placed over a known vascular area, such as the aorta, on the first image taken after the initiation of contrast media, this measure indicates whether the anatomy is actually contrast enhanced. If the measurement is 70 HU (indicating unenhanced blood) instead of the expected higher value of contrast-enhanced blood (90–160 HU), then a number of steps could be taken before the examination is continued. These steps may include checking the injection site for intravenous infiltration, checking the tubing for kinks or poor connections, and increasing the delay between injection and the start of scanning because the contrast material has not reached the desired areas of the anatomy. Injection techniques are discussed in Chapter 13.

ROI measurement should be used whenever the values will be considered in formulating a diagnosis. When an area is used, in addition to the averaged Hounsfield value of the pixels within the ROI, a standard deviation reading is given. This reading indicates the amount of CT number variance within the ROI. For example, if an area of interest has a Hounsfield value of 5 and the standard deviation is 0, what is known about the region? This standard deviation shows that there is no variation within the ROI; therefore, every pixel within the region has the value of 5 HU. If the standard deviation is not 0, but 20, all of the pixels within the ROI do not have an identical reading of 5 HU. The higher the standard deviation, the greater the variation among pixels within the region.[1] The standard deviation does not indicate the levels of the individual pixels. Factors that produce high standard deviation are 1) mixed attenuation

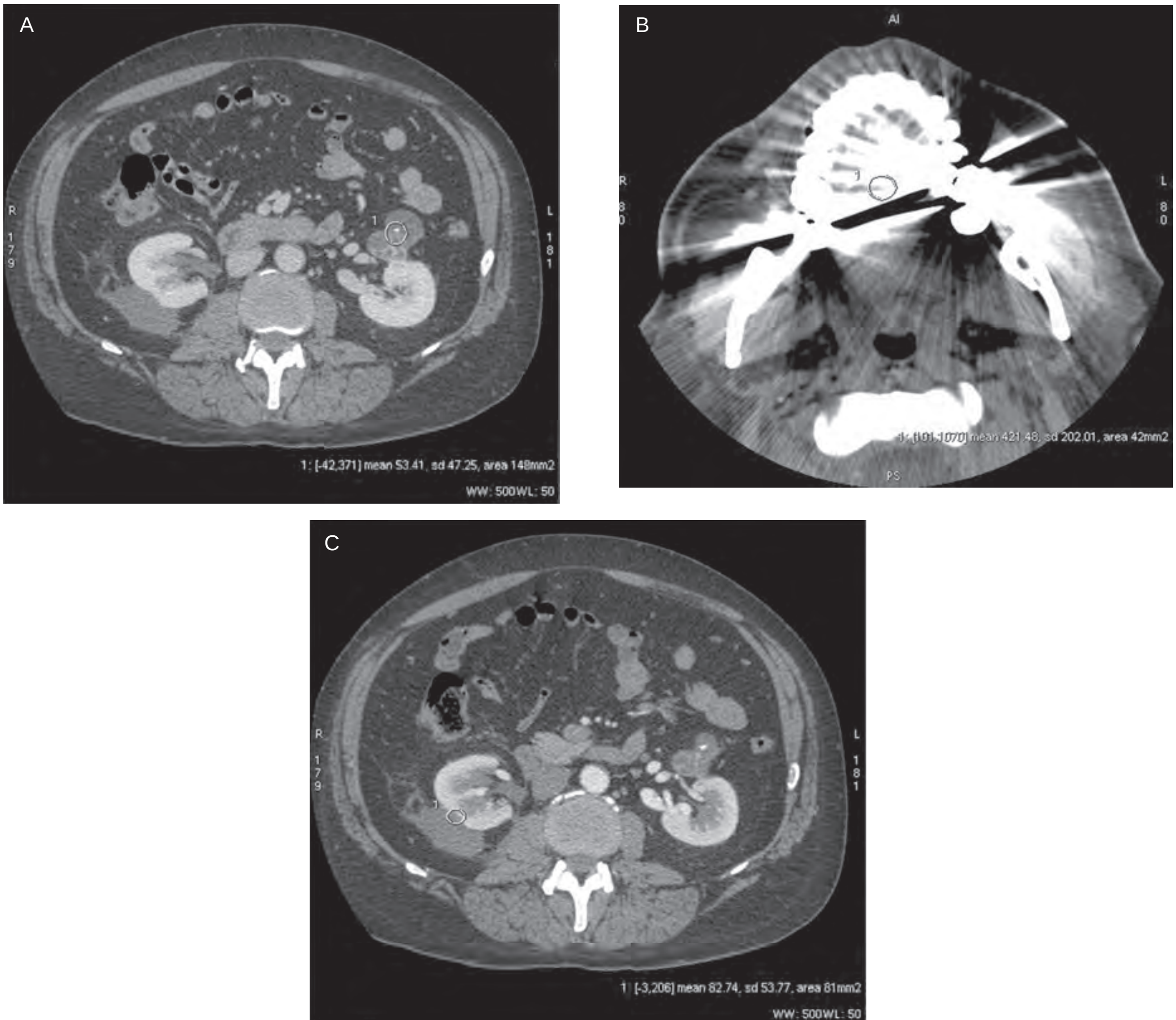

FIGURE 4-10 Factors that produce high standard deviations are mixed attenuation tissue with the ROI (e.g., calcium flecks within an organ A); an ROI that includes a streak artifact (B); and an ROI that is not inside the margins of the object being measured (C).

tissue within the ROI (Fig. 4-10A; e.g., calcium flecks within an organ); 2) an ROI that includes a streak artifact (Fig. 4-10B); and 3) an ROI that is not inside the margins of the object being measured (Fig. 4-10C; e.g., kidney cyst measured with an inappropriately large ROI that includes a section of the adjacent renal calyx, which is averaged in with the cyst). In the last two instances, the high standard deviation also reflects an inaccurate Hounsfield measurement.

[1]The standard deviation is the most widely used statistical measure of the spread or dispersion of a set of data. It is the positive square root of the variance. The standard deviation, like the variance, measures dispersion about the mean as center. However, the standard deviation has the same unit of measurement as the observation, whereas the unit of variance is the square of the unit of the observation. The standard deviation is always greater than or equal to zero. It is zero when all observations have the same value; this value is thus the mean, and so the dispersion is zero. The standard deviation increases as the dispersion increases (Mosteller FR, et al. Probability with Statistical Application, 2nd ed. 1970).

BOX 4–8 Key Concept

The amount of CT number variance within the region of interest is indicated by the standard deviation.

Distance Measurements

All CT systems allow distance measurements. This feature is helpful in reporting the size of the abnormality. It is also essential for the placement of a biopsy needle or drainage apparatus. The system calculates the distance between two deposited points in either centimeters or millimeters. Additionally, CT systems calculate the degree of angulation of the measurement line from the horizontal or vertical plane. A grid can also be placed over an entire image.

All CT images have a scale placed alongside the image for size reference. This feature allows a ruler to be placed along the scale, then subsequently placed along an area of diseased tissue in the patient. The CT distance scale is used in the same way as a scale of miles in a map key.

Image Annotation

Typical information that appears on each image includes facility name, patient name, identification number, date, slice number and thickness, pitch, table location, measurement scale, gray scale, and right and left indicators. Often other information is displayed as well. Optional information includes the addition of contrast enhancement and all scan parameter selections.

Software allows the operator to annotate specific images with words, phrases, arrows, or other markers. Whenever computer software is used to alter the position of an image, an explanatory annotation is recommended. An example is recording a sinus study. If sinus studies are typically obtained in a coronal position, with the patient lying prone, and a specific study must be done with the patient reversed in the supine coronal position, images are often reversed for filming. It is important to note this change to prevent any potential misdiagnoses because fluid appears to be floating to the top.

Reference Image

The reference image function displays the slice lines in corresponding locations on the scout image. This feature aids in localizing slices according to anatomic landmarks (Fig. 4-11).

Image Magnification

It is important to differentiate between image magnification and decreasing the field of view size. A decrease in display field of view increases the size of the displayed image. The result of both functions is an image that appears larger than the original. In each case, relevant clinical data may be easier to see because of the enlargement. However, image magnification uses only image data and does not improve resolution; it simply makes the existing image larger. In spite of this drawback, in many instances, simply magnifying the image data is appropriate. An example is the display of suspected abnormalities for measurement. Image magnification does not adversely affect the accuracy of Hounsfield unit or distance measurement. In fact, because magnifying the image may clarify the margins of the abnormality, allowing for more accurate cursor placement, measurement accuracy may improve.

BOX 4–9 Key Concept

Image magnification is NOT the same as decreasing the display field of view.

Image magnification should not be used when the image displayed on the monitor appears too small. This problem results from inappropriate DFOV size selection, and it should be corrected by using the raw data to reconstruct the entire study in the correct DFOV size. Image

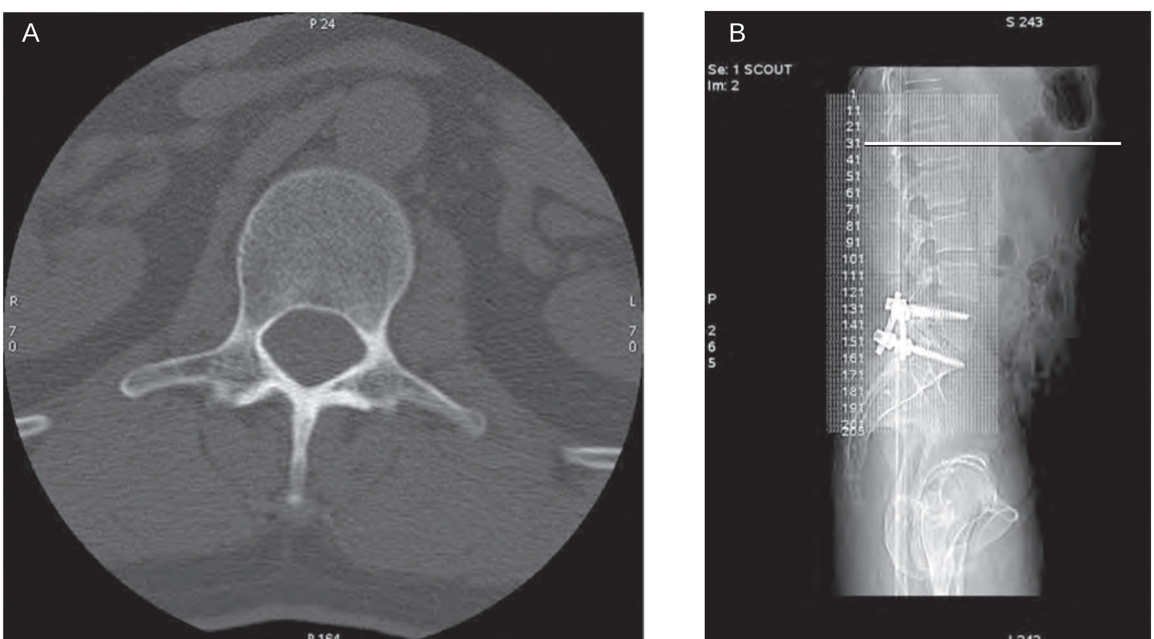

FIGURE 4-11 A reference image can help pinpoint the location of a cross-sectional slice. A. It is difficult to determine which lumbar vertebra is depicted in the cross-sectional image labeled as slice 36. Identifying slice 36 on the reference image (B) allows the viewer to determine that the cross-sectional image depicts the first lumbar vertebra.

resolution is improved if the image is enlarged using the raw data. However, if the raw data are not available, a less attractive alternative is to magnify each image in the study.

In summary, magnification is a useful tool that should be used on isolated images within a study. Magnification allows relevant clinical detail to be more easily seen and more accurately measured. However, magnification has inherent limitations and should not be used as an alternative to correct display field selection.

Multiple Image Display

The multiple image display function allows more than one image to be displayed in a single frame. It is often used as a method of saving film, particularly when copies are requested by the referring physician. The format (i.e., four images per frame, six images per frame) often varies with the manufacturer.

Histogram

A histogram is a graphical display showing how frequently a range of CT number occurs within an ROI (Fig. 4-12).

Advanced Display Functions

Conventional CT studies consist of several contiguous, typically axial images that are perpendicular to the long axis of the body. In many situations an alternative imaging plane may provide valuable information. In most cases, it is not possible to position the patient within the gantry in a way that will allow the direct imaging of other planes. This limitation of CT can be overcome by image manipulation commonly referred to as multiplanar reformatting (MPR). This technique, along with three-dimensional (3D) reformatting, will be discussed in detail in Chapter 8.

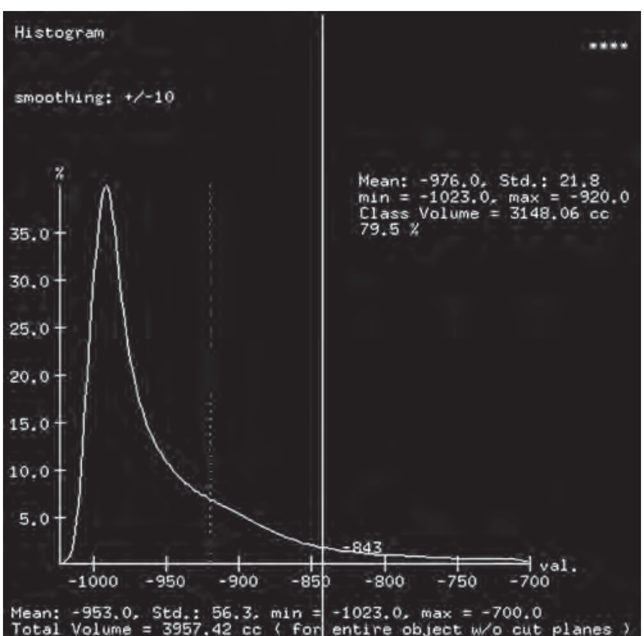

FIGURE 4-12 The appearance and frequency of a range of CT numbers within a region of interest are displayed on a histogram.

SUMMARY

The display functions are the final step in creating the CT image. Analog monitors display the CT image. Therefore, the digital signal from the computer's memory must be converted back to an analog format.

Changing the window width broadens or narrows the range of visible CT numbers. Window width and window level determine which aspects of an image are displayed as shades of gray. The shade of gray that is assigned to a specific anatomic structure is related to the structure's beam attenuation. Higher Hounsfield values are represented by lighter shades of gray. The window width selects the range of Hounsfield units for a particular image, and the window level determines the center Hounsfield unit in this range. In general, the window level is set at roughly the same level as the Hounsfield value of the tissue of interest. Optimal window settings are highly subjective, and they vary dramatically within the field. Published window widths and centers are intended to serve as guidelines only. Patient conditions as well as personal preference make considerable adjustment necessary.

CT systems offer a variety of functions that allow images to be manipulated to facilitate diagnosis. Defining an ROI is the first step in many measurement and display functions. Hounsfield measurement, standard deviation, and distance measurement may offer valuable diagnostic information.

It is important to annotate images with any information that may not be immediately apparent. Examples of such annotation include "Images in this study have been flipped, top to bottom" and "Delayed image: 15 minute post contrast injection."

The technologist must understand the difference between image magnification and decreasing the display field of view size and use each function appropriately.

Review Questions

1. Why is a gray scale necessary to display CT images?
2. What does the window width determine?
3. What happens to pixel values that are higher or lower than the range selected by the window width?
4. Provide an example of an area of anatomy that is best imaged with a wide window width. What is an area that is best visualized by a narrow width?
5. What does window level select?
6. When is it helpful to magnify a CT image?
7. What does a high standard deviation indicate?