CT Basics: Image Quality
Module 6

1. **Title Slide**
   Module 6: Image Quality

2. **License Agreement**

3. **Objectives**
   After completing this module, you’ll be able to:
   1) Discuss factors that affect image quality in CT.
   2) Explain the methodology used to define image quality in CT.
   3) Identify CT image artifacts.
   4) List factors that influence artifacts.
   5) Identify the tests associated with a quality control program.

4. **Image Quality**
   As in diagnostic radiography and mammography, image quality is a balance between certain selectable factors and the radiation dose to the patient. Quality is especially important consideration because a poor quality image has to be repeated, doubling the dose to the patient.
   
   This module looks at the major factors that determine the quality of a CT image, other factors that influence quality and the need for a quality control program in computed tomography. The module concludes with a brief overview of several tests that can be conducted to ensure consistent image quality in CT departments.

5. **Evaluating Image Quality**
   Several factors determine image quality in computed tomography. The quality of a CT image can be measured by examining contrast resolution, linearity, the noise found in the image, the uniformity of the image, as well as the spatial and temporal resolution.

6. **Contrast Resolution**
   Contrast resolution is the ability to image adjacent tissues that have similar mass density and effective atomic density. In other words, contrast resolution is the ability to distinguish between similar tissues. Examples of areas that have similar tissue densities are the liver/spleen interface, and gray and white matter of the brain. CT has superior contrast resolution because narrow x-ray beam collimation reduces scatter radiation.
   
   Contrast resolution can be improved by using a smaller field of view, thicker slices, a smaller matrix size, larger pixel size, a higher milliampere seconds (mAs) or a low-pass filter.

7. **Linearity**
   CT linearity refers to assigning the correct Hounsfield unit to a specific material being scanned. CT mean values are calculated for a particular reference material as measured using a phantom. After the phantom is scanned, the resulting CT numbers are compared to linear attenuation coefficients for the object. These phantom tests determine the CT numbers for water and other known materials.
The CT numbers are then plotted using the attenuation coefficient of the phantom materials, and the results indicate if the CT machine is within tolerance. For example, water should always equal 0 and bone should equal 1000. Linearity can be tested daily by performing quality control, or QC, tests using a phantom.

8. **Noise**
   When a CT image appears grainy or speckled, it is referred to as a noisy image. Noise occurs because an insufficient number of photons reach the detectors. Increased noise degrades the contrast resolution of the image. Reconstruction filters and selectable technical factors can affect the amount of noise in the image.
   Noise is reduced by increasing the mAs, slice thickness or pixel size. Each of these parameters affects the total amount of photons that reach the detectors. If more photons are detected, the noise is less apparent.

9. **Uniformity**
   Uniformity is the ability of the CT scanner to assign the same Hounsfield number to the same tissue each time. When imaging a test object made of a uniform material, the value for each pixel represented in the image should be the same Hounsfield number. This uniformity should remain consistent over the entire field of view. Uniformity standardizes the appearance of a CT scan for a large patient and the appearance of the same scan for a small patient.
   When scanning different-sized patients, the anatomical structures in the resulting images should have the same Hounsfield unit number. For instance, scans of the livers in both a large and a small patient should have relatively the same Hounsfield number. A cupping artifact is created when the Hounsfield numbers are not accurate for consistent material because of beam divergence.
   Beam hardening causes the Hounsfield numbers to be lower toward the middle of a uniform test object, and these inconsistent Hounsfield numbers produce the cupping artifact.

10. **Spatial Resolution**
    Spatial resolution describes the degree of blurring in an image. It represents the ability to discriminate objects of varying density, a small distance apart, against a uniform background. Spatial resolution is a measure of how small an object can be imaged using CT. CT is a superior imaging modality for spatial resolution because it is able to differentiate tissue with density differences of less than 0.5%.
    In comparison, conventional radiography cannot differentiate densities less than 10%. Spatial resolution is often represented by the point spread function, or PSF, and the line spread function, or LSF. PSF describes the lack of sharpness that occurs when a point in the object being scanned is not represented as a true point on the image. LSF describes the “unsharpness” of an imaging system in terms of breaking down an object into its frequency components.
    Spatial resolution can be improved by using thin slice thicknesses, an image matrix with a small pixel size, reconstruction filters such as high-frequency convolution filter and a small detector size.

11. **Temporal Resolution**
    Temporal resolution refers to the ability of the scanner to image moving objects effectively. Temporal resolution is often associated with cardiac imaging, where the goal is to image a beating heart effectively. Currently, only dual 64-slice CT scanners and 128-slice CT machines are capable of this type of imaging. These machines have rotating speeds of 0.3 to 0.4 seconds per gantry rotation and are capable of imaging the entire heart in a single rotation.
    A dynamic volume 320-slice scanner also is commercially available. This scanner does not have a helical/spiral scanning profile, but rather incorporates a two-dimensional detector that has field
coverage of 160 mm, which is an improvement from the 128-mm coverage of a 256-slice scanner. Even at these increased rates of speed, it may not be possible to capture a beating heart without motion. Therefore, other methods are used to improve temporal resolution.

One approach is reconstruction algorithms that incorporate partial projection data for image reconstruction. The technique, called the half-scan algorithm, improves temporal resolution by 40%. This algorithm uses a $180^\circ$ projection data set and a fan angle. In addition to the algorithm, the data set is acquired during certain heart cycles, for instance, during the rest cycle or the R wave.

12. Practice Question
13. Practice Question
14. Factors Influencing Image Quality
   Many factors influence image quality in computed tomography. CT technologists can control some of these factors, such as selectable scan parameters and viewing conditions, while other aspects, such as beam geometry and image receptor type, are not directly under their control. In the following section, we’ll explore variables that affect image quality and suggest ways to improve image quality where appropriate.

15. Focal Spot Size
   The focal spot, or target, is the area on the anode that the electrons strike and create x-radiation. In third generation CT scanners, the focal spot is related to spatial resolution. The smaller the focal spot, the better the spatial resolution. The focal spot size on the anode is rectangular because the anode angle is approximately $8^\circ$ to $17^\circ$.

   CT technologists usually only have the option of choosing a small or large focal spot size on multislice CT scanners. A disadvantage of selecting a small focal spot size is that it can increase tube heating on the anode. Greater heat can result in tubes needing to be replaced more often or, ultimately, tube failure.

16. Beam Geometry
   Beam geometry refers to the path the x-ray beam takes once it leaves the x-ray tube, passes through the patient and strikes the detectors. Beam geometry varies among the generations of CT scanners. For example, first generation CT scanners used parallel beam geometry, second generation scanners employed the fan beam geometry and third generation CT scanners used an even wider fan beam.

   The more detector rows a CT scanner has, the wider the x-ray beam geometry needs to be. However, a wider x-ray beam produces more scattered radiation. Modern CT scanners use what is described as cone-beam geometry. The cone beam is found in multislice CT scanners and uses a wider x-ray beam to cover multiple detector rows.

   In general, the more scattered radiation created during the examination, the lower the quality of the resulting image. CT scanners compensate for increased scatter by using postpatient collimators to absorb scattered radiation and specialized algorithms that digitally reduce the effects of scatter on the final image.

17. Image Receptor
   Just as the type of image receptor affects image quality in radiography, the image receptor also affects the image quality in computed tomography. The detectors, which are the image receptors in CT,
may be either gas or scintillation detectors. Modern CT scanners more often use scintillation detectors because they need less recalibration, are more efficient and are less noisy.

Regardless of the type of detector, image quality can be affected by the size of the detector, the concentration of detectors in a specific space and the detector’s ability to efficiently convert image data and reset for the next acquisition.

18. **Subject Contrast**

One influencing factor not under the control of the CT technologist is subject contrast. Subject contrast is determined by the body habitus of the patient and the anatomy of interest. Large patients produce more scatter radiation and require increased technical factors to penetrate anatomy, which also increases scatter and degrades the image.

Very large patients may produce out-of-field artifacts because their entire anatomy cannot fit within the scan field of view. The anatomy of interest also can affect the image quality. For example, a CT scan of the abdomen produces more scattered radiation than the same-sized chest CT scan because of the increased tissue in the abdomen. Modern CT scanners control scattered radiation to some extent through the use of postpatient collimators and specific reconstruction algorithms.

19. **Viewing Conditions**

The viewing conditions where the CT images are interpreted can affect the quality of the images. Because images are displayed on computer monitors in a black-and-white scale, work areas and radiologist viewing rooms should be dimly lit. Low-light rooms provide the optimal environment to view or read CT scans. Conditions that hamper image viewing include lighted areas such as rooms with fluorescent lighting.

20. **Selectable Factors**

The CT technologist can select several scan factors that affect image quality in a positive or negative way depending on the setting. Most settings are predetermined by the manufacturer or adjusted by the technologist based on a predetermined protocol. One of the most important actions a technologist can take to improve image quality and reduce patient dose is to follow departmental protocols. These protocols have been designed by radiologists, CT technologists and medical physicists to produce the best quality image with the lowest possible dose to the patient.

21. **mA and Scan Time**

The milliamperage, or mA, controls the quantity of x-rays per scan. The mA is a measurement of the current of x-ray photons across the x-ray tube. Computed tomography mA settings are typically relatively high at approximately 200 mAs. A high mA setting is used to reduce image noise.

Increasing the scan time also can increase the number of x-ray photons the x-ray tube produces. This option results in less image noise but at the expense of increased patient dose. The CT technologist needs to carefully consider the outcome of increased dose to the patient if a higher mAs is used.

22. **Scan Field of View (SFOV)**

Scan field of view is a parameter set by the CT technologist that determines where the projection data is collected for the given anatomy. Therefore, the scan field of view establishes which detectors are activated during the scan and the size of the resulting pixels. Anatomy should always be within the scan field of view because, otherwise, out-of-field artifacts will occur.
23. **Display Field of View (DFOV)**

The display field of view also is referred to as the reconstruction field of view. The display field of view is always equal to or smaller then the scan field of view. A smaller field of view displays a larger area of anatomy on the monitor. The field of view can affect image noise and resolution.

For example, displaying a larger field of view results in less noticeable noise in the image. A smaller display field of view shows the image larger with smaller-sized pixels, and a larger display field of view shows the image smaller with larger-sized pixels.

24. **Slice Thickness and Spacing**

Slice thickness in CT determines the anatomical coverage. Thicker slices cover more anatomy, while thinner slices result in less anatomy covered. The thinner the slice, the more noise that is noticeable on the image because fewer photons are available when scanning a thinner slice.

Scanning with thinner slices improves partial volume averaging, however, because the computer does not have to estimate the size and type of anatomy missed when using thick slices. For example, suppose we scan the same area using different slice thicknesses. The first exam scans 30 mm of tissue using 1-mm slices, which produces 30 slices.

The second exam scans the same 30-mm area using 5-mm slices. This scan produces a total of 6 slices. The first scan of 30 slices yields better image quality but at an increased patient dose. Spacing is an important quality consideration in helical scans with multislice CT equipment. In these scanning procedures, the gantry completes one revolution around the patient, and then the table is moved forward, or indexed, to the next location.

The movement of the table can be either contiguous, which means the table movement is equal to slice thickness; overlapped, which is when the table increment is less than the slice thickness; or gapped, which means the table movement is greater than the slice thickness. The best image quality is achieved when the slices overlap and no anatomy is missed, although patient dose is higher with this type of scan.

25. **Filters**

Filters are part of image reconstruction. A convolution filter, or kernel, is applied to the raw data to remove blurring and artifacts. Kernels, or algorithms, allow the viewer to see the scan in a variety of window settings. The most common algorithms are used routinely for chest CT scans. These algorithms reconstruct the image in both a soft tissue window that allows optimal viewing of the mediastinum and a lung window that permits further evaluation of lung tissue.

26. **kVp**

Kilovolt peak, or kVp, often is referred to as the quality of the x-ray beam. The CT technologist can control the energy level of the x-ray beam by adjusting the kVp. Typical kVp settings in CT are 100, 120 and 140. The kVp used in CT is considerably higher than conventional radiography because anatomy is imaged rapidly. Changing the energy level of the x-ray beam affects both the x-ray penetration of the patient and image quality.

The kVp controls the contrast of the image. As kVp increases, less absorption occurs. The higher the kVp, the lower the image contrast. Increasing the kVp results in more x-rays emitted with a higher energy and therefore greater ability to penetrate tissue. This increase in kVp results in an increase of scatter radiation and less image contrast.

27. **Preset Options**

CT machines have preset options that optimize window width and window level settings. The window width controls the contrast of the image and describes a range of CT numbers represented on a
gray scale. The window level determines where the range extends on the gray scale. These preset options, sometimes referred to as organ mode, are algorithms that can display the scan in multiple settings such as a bone or soft tissue window. Manufacturers install CT machines with standard presets, but individual clinics can customize selections to meet the needs of the radiologist or institution.

28. Practice Question

29. Practice Question

30. Artifacts
   Artifacts due to positioning or technical errors can severely degrade image quality. Because artifacts are so harmful to the final image, this section of the module examines several of the most common artifacts found in CT along with their causes. It is important for a CT technologist to identify artifacts when they occur so that equipment can be repaired quickly and put back into service. A keen eye for artifacts reduces the need for repeat examinations, ensures that schedules are maintained and, most importantly, reduces the possibility of misdiagnosis.

31. Beam Hardening Artifacts
   An x-ray beam with too much beam hardening produces broad streak artifacts on a CT image. Both the quantity of the x-rays, measured in mAs, and quality of the x-rays, measured as kVp, affect beam hardness. When lower-energy photons are absorbed by the patient and higher-energy photons pass through the body, the average power of the remaining photons increases and the beam becomes harder.

   An increase in kVp also results in an increase in the energy of the x-ray beam and a harder beam. Attenuation is determined by both the amount and density of tissue the beam penetrates, and various areas of the body attenuate the beam differently because the human body is not uniform. For example, beam attenuation is greater in thicker areas. Since this is the case, there is less beam hardening at the periphery of the body compared with the middle of the body. Beam hardening also depends on patient size and the type of anatomy the beam encounters. In CT the beam is attenuated at different rates when it passes through interfaces such as bone and soft tissue.

   Beam hardening is particularly apparent in areas of the skull between the petrous portions and the brain, appearing as a streak artifact in a CT scan of the head. Beam hardening also is affected by CT contrast agents.

32. Partial Volume Averaging Artifacts
   Partial volume averaging occurs when similar tissue types share the same voxel, and therefore, the tissues are averaged as one Hounsfield unit. This can result in a miscalculation of the CT numbers, which ultimately can lead to misdiagnosis. Partial volume averaging artifacts can be reduced by scanning with thin slices. Thinner slices allow each tissue type to be accurately represented by specific linear coefficient numbers.

   Scanning with thin slices leads to increased patient dose, but image quality is better because the correct Hounsfield unit numbers representing each tissue are displayed. Sometimes partial volume averaging is hard to determine because the array processor compensates for the miscalculation by averaging the two tissues types.

   If there’s concern about the effects of partial volume averaging, then the CT technologist should repeat the scan over a particular area of interest using a slice thickness of 1 mm and an overlap technique. This method lessens the effects of partial volume averaging. Another technique to correct for
partial volume artifacts is to use a specific computer algorithm. The algorithm compensates for inaccuracies that sometimes appear in the CT image as bands or streaks.

33. **Motion Artifacts**

Motion artifacts often appear as ghosting on the image. The image has fuzzy edges that do not define the anatomical borders correctly. This artifact diminishes the ability of the radiologist to accurately interpret the CT exam. Patient motion artifacts are caused by both voluntary and involuntary movement.

The patient can directly control voluntary motion, such as moving their arms and legs; however, involuntary motion, such as peristalsis or cardiac movement, cannot be directly controlled by the patient. Patient communication is the most effective way of managing voluntary movement. It is important to explain the procedure and the importance of remaining still to the patient.

In addition, the examination should be performed as quickly as possible, especially if contrast is used. The CT technologist should make the patient as comfortable as possible so that little effort is required to stay in the recommended position. For example, positioning devices such as lumbar supports and pillows under raised arms allow the patient to remain still during the exam.

Techniques such as cardiac triggering are used to reduce involuntary movement during CT scanning. Cardiac triggering reduces heart motion by scanning prospectively and retrospectively. Prospective imaging synchronizes the cardiac cycle using an electrocardiograph (ECG) signal. The scan is triggered during diastole when the heart is at rest.

Diastole occurs during the R-peak wave of the ECG cycle. Prospective gating reduces radiation dose to the patient by initiating the scan during a specific part of the cardiac cycle, but the technique requires the patient to have a relatively regular heartbeat. If the patient presents with an irregular heartbeat, prospective gating is not recommended. Retrospective gating is used for patients who are not able to hold their breath or patients with irregular heart rates.

For this technique, the entire anatomy is scanned. After the patient leaves the exam room, the computer uses only the images acquired during diastole. This technique increases radiation exposure to the patient compared with prospective gating because much of the acquired data are not used.

When the technologist holds a patient still, this increases the dose to the technologist or any medical staff who is holding the patient, so it is not recommended as a standard procedure. Fortunately, with the use of multislice CT, scans are increasingly faster, and as a result motion artifacts are greatly reduced.

34. **Metal Artifacts**

Metal objects in or on the patient’s body or clothing during the scan cause this type of artifact. The source of metal can be prosthetic implants, dental work, jewelry, zippers, snaps, stents and clips implanted during surgery, or metal fragments left by injury or bullets. Metal artifacts appear on the CT image as a streak emanating from the object.

As x-rays pass through a metal object in the body, the x-ray beam is attenuated differently because metals have higher atomic numbers than the atomic numbers associated with the human body. The artifact can be more or less severe depending on the atomic number of the metal, the geometry of the object and amount of metal present.

The metal object appears radiopaque, or white, on the image, greatly degrading image quality and sometimes making the image nondiagnostic. To reduce metal artifacts, the CT technologist should remove all metal from the patient if possible. Some scanners have a metal artifact reduction software program that greatly reduces the effect of the artifact.

Although software programs can compensate for this artifact, none are completely effective in removing the streak artifact associated with metal in the body.
35. **Equipment Artifacts**
   When impurities are present in the x-ray tube of a CT scanner, a short circuit can occur causing tube arcing. Tube arcing usually results from extended tube usage. There are two types of arcing: inside the tube and outside the tube. Inside tube arcing happens when the voltage arcs to minute particles of tungsten within the tube. Outside tube arcing occurs in the oil in the tube housing.
   
   The voltage can arc to impurities such as water, gas or even air bubbles within the housing. Both types of arcing are potentially dangerous, and if they occur, the CT technologist should stop the scan immediately and call the service engineer. Artifacts appear as an obvious band across the entire image or as an overall degradation of the image.
   
   Both arcing types also can cause complete tube failure. The reformatted coronal CT image displayed on this page shows a band of increased noise over the bottom portion of the image due to tube arcing. The best way to avoid tube arcing is to replace the x-ray tube on a routine schedule. Tube life spans are determined by the number of hours of operation, and tubes should be replaced long before tube arcing occurs.

36. **Ring Artifacts**
   Ring artifacts usually are seen only with third generation CT scanners. The artifacts are the result of faulty detectors. They appear over the anatomical region as concentric rings that radiate from the center of the image. Faulty detector elements generate a miscalculated pixel result that cause the rings to appear. This type of artifact is rarely seen today because current detector elements are of superior quality.
   
   Ring artifacts also can be caused by a faulty digital acquisition system. The incorrect reading is produced during the back projection process. Correcting ring artifacts is not under the CT technologist’s control. A service engineer must replace the faulty detector or digital acquisition system channels.

37. **Cone Beam Artifacts**
   Cone beam artifacts are associated with the cone beam geometry configuration of the multislice CT scanner. Artifacts, which can be high or low frequency, arise from insufficient projection samples. Low-frequency artifacts appear as shadowing on the image and usually are corrected by using interpolation. Interpolation is a mathematical technique that estimates the values of a function from known values on either side.
   
   High-frequency artifacts are caused by the abrupt longitudinal changes of the body. These types of artifacts are more difficult to address and are usually corrected by using specific algorithms. An example of this artifact are streaks from the vertebrae on a chest CT scan. To eliminate these streaks, an additional line or scan sometimes is acquired to create more data to complete the volumetric reconstruction.
   
   This compensation adds more time to the scan and delivers additional dose to the patient. The technologist usually is unaware when cone beam artifacts occur, so they are difficult to recognize. If image quality is degraded, a service engineer should be notified.

38. **Edge Gradient Artifacts**
   Edge gradient artifacts appear as streaks that originate from body structures that vary in tissue density. Examples of areas of variable densities are bone and soft tissue interfaces, such as the petrous ridges in the skull and the mastoid air cells. Air and contrast media also can cause edge gradient artifacts. The CT system has difficulty imaging structures with different densities within a single pixel or voxel.
   
   During the reconstruction process, areas that have density differences often are seen as one object and assigned a single Hounsfield number. This results in inaccurate CT numbers. An algorithm
usually helps compensate for these differences. High-pass filters can enhance the edge of structures by diminishing the blur usually associated with these areas, although the use of a high-pass filter results in increased noise on the image.

Edge gradient artifacts also can be reduced by using thinner slices, increased data sampling rates and detectors with small apertures.

39. **Out-of-Field Artifacts**

Out-of-field artifacts occur when the attenuated x-ray beam from areas outside the scan is not recorded. Anatomy that falls outside the scan box can block detectors and attenuate photons, contributing to beam hardening. Misrepresented CT numbers are present in the final image, causing streak artifacts that can appear throughout the image.

The severity of out-of-field artifacts depends on the size and density of anatomy that falls outside the scan box. A common example of this artifact occurs when a patient cannot raise his or her arms during a chest CT exam. The patient’s arms are outside the area being scanned or scan box. Another example involves patients who are obese.

These patients often have anatomy outside the described scan box that causes streaking and scattered radiation. The best way to avoid out-of-field artifacts is to make sure that the anatomy being scanned is within the scan field of view.

40. **Practice Question**

41. **Practice Question**

42. **Quality Control Programs in CT**

A quality control program periodically tests the performance of a CT scanner and compares the results with a set standard. The goal of QC in computed tomography is to produce consistently high quality scans that do not differ among facilities. Quality scans provide the radiologist with the best possible images from which to base a diagnosis, result in fewer callbacks and ultimately contribute to better patient care.

QC programs ensure that the CT machine is operating at an optimal level. If the machine isn’t functioning correctly, then certain steps need to be taken to bring the performance up to the set standard. Manufacturers recommend certain QC protocols, but facilities also set their own standards. QC programs are run daily, monthly and annually, depending on the test performed.

The QC test involves the use of a phantom, which provides timely information for prompt interpretation. The equipment manufacturer usually provides software to record the results so that individual interpretation is no longer necessary. In addition to the daily QC tests performed by the CT staff, most manufacturers require a physicist to perform annual tests.

QC programs have been promoted by professional societies such as the American College of Radiology, or ACR. The ACR has established QC standards in various imaging modalities. Because the ionizing radiation used by CT equipment can be potentially harmful to patients, implementing safety standards is important for public safety.

Successful QC programs ensure that high performance standards are maintained for patient safety. For a QC program to be effective, it should:

1) Define the objective or desired result.
2) Record the quantitative results, so that if performance is suboptimal, the service engineer can be notified immediately.
3) Consist of tests that are easy to follow and quick to perform by the technologist and engineer.
43. **Principles of Quality Control Testing**

Regular QC testing is important to ensure accurate results. Some tests are performed daily, and in certain cases the CT scanner’s software prompts the technologist to perform the test. For example, a CT scanner manufactured by Siemens requires a twice daily QC test called a “Checkup.” A pop-up appears on the computer screen every 12 hours, reminding the technologist to perform the 6-minute test.

Test results are recorded in the CT database so that manual bookkeeping is no longer necessary. The service engineer performs other QC tests that are needed less frequently. QC tests that require more time usually are performed during annual preventive maintenance. The information collected from these QC tests is recorded in the CT scanner’s database and checked against the performance of other CT equipment in the manufacturer’s database.

The facility is notified about the results in the preventive maintenance record. If the QC tests indicate suboptimal performance, the machine shuts off automatically until the service engineer has addressed the problem. Because individuals no longer record much of the QC data, the need for manual bookkeeping has become almost obsolete.

Information is recorded in the local database and used for direct interpretation. If the machine is not performing optimally, the service engineer can access previous QC tests to accurately diagnose the problem. Next, we’ll examine some common QC tests performed by CT technologists, quality control technologists or medical physicists.

Remember, however, that your facility may perform any number of tests based on facility preference, type of equipment, equipment manufacturer and your facility’s accreditation. The QC tests described in the following examples use an ACR phantom for the most part; however, in some cases another specialized phantom may be employed. It’s very important to follow accepted protocols and use the prescribed techniques.

In addition, all QC tests described in this section apply to a multislice CT scanner. When performing QC tests on multislice CT scanners, manuals often use the term “Nmax.” This acronym stands for “maximum number of axial images able to be acquired simultaneously in one rotation.” For example, a 16-slice CT scanner acquires 16 slices during one rotation of the tube. However, only the center slice location is used for the QC test. Also, the CT technologist must distinguish between helical and axial slices for each QC protocol.

44. **Phantom Setup**

To begin the setup, place the phantom in the head cradle, and line up the laser lights on the scribed lines that correspond to the center lines on the phantom. The lines represent the sagittal, coronal and axial planes of the phantom. Proper alignment ensures the most accurate QC test results. Once aligned, zero the table and record the table location.

It helps to use the zero location as a reference when repeating multiple QC tests at one session. Tape can be used to hold the phantom in the desired position throughout the QC tests.

45. **CT Number Calibration Test**

The phantom displayed in this image is an example of a phantom used in the CT number calibration test. It contains several items that mimic the CT numbers found in normal human anatomy. Once the phantom is positioned correctly:

1) Select the adult abdomen technique, axial mode and a display field of view of 21 cm or greater.
2) Scan the phantom.
3) Place a 200-mm region of interest in the center of each circle represented in the image. Each circle is designed to mimic bone, water, acrylic, air and a polyethylene material.
4) Record the individual mean values for each circle.
5) Set the window width at 400 and of the window level at 0.
6) Repeat multiple axial images using different kVp settings but keeping all other parameters the same.

This test should be performed at installation and daily thereafter. Both water and air should be compared daily. The acceptable limits for air are plus or minus 1000. The acceptable limits for water are plus or minus 3 from zero.

This image shows the four circles that should be represented on the phantom. When scrolling through the images, the image with the BBs indicates the image where the region of interest measurements were taken.

46. **Standard Deviation of the CT Number in Water**

A water-filled phantom is typically a cylindrical-shaped plastic container filled with water. To measure the standard deviation of the CT number, scan the phantom and record the region of interest at the center of the phantom. This test is performed at scanner installation and daily thereafter, using the manufacturer’s phantom. Ideally, the CT number for water is 0. The acceptable range of CT numbers is typically 2 to 7 Hounsfield units from 0.

The test establishes a range of CT numbers for each specific CT machine, and then a typical number is determined for the scanner when its performance level is optimal. For instance, if the scanner consistently measures plus or minus 3 from 0, then this range is the standard for that specific CT machine. The service engineer should be notified if the CT number increases or decreases from the set standard.

The greater the increase from the standard, the noisier the image appears and the poorer the low-contrast resolution. If this occurs, the CT machine must be recalibrated. Variables that affect the CT number include kV and mA, slice width, the placement of the region of interest, reconstruction algorithm and scan duration. When these variables can be repeated accurately each day, a set standard can be established.

47. **High-contrast Resolution**

The high-contrast resolution test is performed using a plastic phantom with a square-hole pattern drilled into the plastic. Measuring 15 x 15 mm and varying in depth, each hole contains a bar resolution pattern of 4, 5, 6, 7, 8, 9, 10 or 12 line pairs per centimeter. Scan the phantom and count the number of squares in which line pairs can be seen. The more squares with identifiable line pairs, the better the contrast resolution of the CT scanner.

For example, the image on this page shows a high-contrast resolution test. Line pairs appear in just four of the squares. Most modern multislice CT scanners can resolve holes slightly smaller than 1 mm. Increased contrast resolution allows more anatomy to be displayed on the images. This test should be performed at the time of installation and biannually thereafter.

48. **Low-contrast Resolution**

Low-contrast resolution describes the CT scanner’s ability to discriminate tissue densities that have very similar CT numbers. CT has superior low-contrast capabilities compared with plain-film radiography. The primary factor that affects low-contrast resolution is image noise. Decreasing image noise increases low-contrast resolution.

As noise increases, the edge definition of anatomy is diminished, and therefore it’s more difficult to differentiate anatomy with similar tissue densities. A special plastic phantom is used to test the low-contrast resolution capabilities of a CT scanner. The phantom has multiple holes that decrease in diameter.
The holes typically are filled with water, methanol or sucrose so that their Hounsfield numbers are close to the number for plastic, about a 0.5% to 0.6% difference. The test should display approximately 50% of the drilled holes. If fewer than half of the holes are represented, it indicates a decrease in low-contrast resolution. Modern multislice CT scanners can discriminate objects as small as 3 mm and with density differences of 0.5% or less.

Scan the phantom using an adult abdomen technique. Repeat the test using an adult head technique. Scan using a display field of view of 21 cm or larger. Choose a scan reconstruction interval of 5 mm with a window width and window level set at 100. Record the smallest set of holes that can be visualized using multiple techniques.

This test should be performed at the time of installation and biannually thereafter. A baseline for techniques is necessary because adjustments in technique can drastically change the outcome. For instance, decreasing the mA can increase noise on the image, and therefore, fewer holes are visualized and low-contrast resolution is decreased. The service engineer or department physicist usually determines the optimal techniques to perform the test.

49. Distance-measuring Device Accuracy

A specific plastic phantom with a pattern of small holes spaced 1 cm apart is scanned to evaluate the accuracy of the distance-measuring device in the CT scanner software. These holes measure image distortion. After obtaining an axial image, measure the distance between the holes at the edge of the phantom image. Repeat this technique, moving toward the middle of the phantom until you’ve measured all hole relationships.

The distance between the holes on the phantom image should accurately represent the actual distance on the phantom. If there is a discrepancy of 2 mm or greater, notify the service engineer. A possible cause for discrepancies greater than 2 mm is a miscalibrated reconstruction algorithm. This test should be performed at the time of installation and annually thereafter.

50. Video Monitor Distortion

For this test, a Society of Motion Picture and Television Engineers, also known as SMPTE, or a similar manufacturer’s pattern is displayed on the liquid crystal display (LCD) monitor used to read the CT images. Monitors used by CT technologists usually are not tested for accuracy. The pattern is brought up on the monitor and compared to a set standard.

A SMPTE pattern shows distortion, but not uniformity. The intricate patterns are compared according to the lines visible and edge definition. The test also can measure light on the LCD monitor. The measurement is expressed as candelas per meter squared, which is the standard unit of luminance.

Another part of the video distortion test is to evaluate the ambient light in the reading room. This measurement is taken using a lux meter and determines if the reading room has too much ambient light that could degrade image quality. The physicist usually performs this test as part of annual QC.

51. CT Number Flatness

The CT number flatness test determines the uniformity of CT numbers throughout the image. Images that do not show a great deal of variation are considered to be a flat image. After scanning a water phantom, place multiple regions of interest, or ROIs, at various locations on the axial image. Ultimately, the region of interest should measure zero when placed anywhere on the phantom.

The ROIs should not deviate more than 5 points from the average ROI number recorded at different locations. If the ROI recorded at the center of the image is high and the ROI recorded at the edge of the image is low, the image shows capping. Conversely, if the ROI recorded at the center of the image is low, and the ROI recorded at the edge of the image is high, the image exhibits cupping.
Capping and cupping are usually a result of beam hardening. For example, if the beam energy is low at the edge of the phantom, but harder at the center of the phantom, capping occurs. Some CT manufacturers have software that compensates for beam hardening; however, in some cases the software overcorrects or underestimates the problem, so a service engineer should be notified when this test is outside acceptable limits.

52. **Hard Copy Output**

This test is performed on a printed film and checks the accuracy of printed images. The image is a gray-scale stepped pattern and is referred to as a SMPTE pattern. After the image is displayed on the monitor, adjust the contrast so that 95% of the squares are displayed and can be separated visually. Then locate the 5% patch inside the 0% patch that appears almost black. Assess the printed image to determine if it displays the same visibility when shown on a view box.

The SMPTE image should display the 5% and 95% patches each time the image is printed. If these patches are not visible, the hard copy printer settings should be checked. If this does not correct the problem, a service engineer should check the film processing. Another device that could cause the problem is the camera. The video monitor, laser or light device also could be faulty and produce unreliable film quality. This test should be performed at the time of installation and annually thereafter.

53. **Localization Device Accuracy**

The location and accuracy test is conducted to ensure that the CT scanner is capable of localizing a specific area within the scan field. The test phantom is simply a solid plastic phantom with two holes drilled into it. The holes are drilled at 90° to each other to form an “X”; however, the drilled holes do not meet in that one passes slightly above the other. The phantom is placed in the scanner so that the drilled holes are 45° to the plane of the scan.

The localization light is centered at the point where the two drilled holes intersect. A single scan is then performed. Once the scan is completed and the image is reconstructed, both drilled holes should be visible and ideally are located next to each other, as shown on this page. If the holes do not appear next to each other or are not visible at all, contact a service engineer. This test should be performed at the time of installation and annually thereafter.

54. **CT Couch Indexing**

The CT couch indexing test determines how accurately the patient table moves during the CT scan. Place an x-ray film on top of the CT table, and load 100 pounds or more of weight on top of the film to simulate a patient. Take a series of exposures 10 mm apart. Use the smallest slice width available, that is, a slice width of less than 5 mm.

After the series of exposures, the x-ray film will have multiple bands exposed 10 mm apart. Measure the distance between each exposed band. This measurement determines how far the couch moves between each exposure. The distance between the centers of each exposed band to the next exposed band should equal 10 mm. If 10 exposures were taken, then the area between the bands should be 90 mm from the first to the last exposed band.

If the distance between the bands differs more than 1 mm, then the couch movement is not accurate and a service engineer should be notified. This test should be performed at the time of installation and annually thereafter.

55. **CT Couch Backlash**

The CT couch backlash test determines the ability of the patient table to return to its original position after the conclusion of the scan. Using a ruler, find the zero point on the couch. Mark that
location with two pieces of tape, placing one piece of tape on the part of the table that moves and the other piece of tape on the base of the table that doesn’t move.

Mark each piece of tape with lines that match up at the zero point. Place a 100-pound object on the table to simulate a patient. Start a CT scan sequence so that the couch moves into the gantry approximately 150 to 300 mm at 10- to 20-mm increments. Then zero the table. The couch should return to the original position, with the two lines matching up. A discrepancy between the two marks indicates a backlash of the patient couch.

Repeat this procedure, moving the bed in the opposite direction. Multiple tests should result in the couch returning to the original position and the two lines matching up opposite each other. If the returned position has a discrepancy of 1 mm or more, a service engineer should be notified. Table backlash can occur because the gears and belts used to drive the couch aren’t operating properly, or faulty sensors don’t correctly record the position of the couch.

The service engineer is usually able to diagnose the problem and resolve couch backlash. This test should be performed at installation and annually thereafter.

56. **Light Field Accuracy**

This test is used to determine the accuracy of the laser positioning light. Position a single piece of film inside a presealed paper envelope on the couch so that it is centered in the gantry. Turn on the centering lights or laser beam. Using a sharp object, poke two holes through the protective cover of the package, directly over the centering light. One hole should be near the left edge and the other hole should be near the right edge.

Both of the holes will be visible after the x-ray film is exposed. Set the slice width to the minimum width. The patient couch is then moved into the gantry and a single exposure is made using an adult abdomen technique. After the film is developed, the small holes poked through the paper should be located directly on the CT scan’s exposed area. If the holes are more than 2 mm from the exposed area, a service engineer should be called. This test should be performed at installation and annually thereafter.

57. **Slice Width**

This test is performed to ensure that the width of the slice selected on the operator’s console is the same thickness as what the CT scanner actually produces on a finished image. The test uses a phantom with a wire or hole that is angled at 45°, similar to the phantom used in the localization device accuracy test. Using an adult abdomen technique, perform a series of three scans using multiple slice widths, such as 0.75 to 5 mm.

After the scan is completed, use the distance measuring device located on the operator’s console to measure the length of the hole or wire. The beam width should equal the measured hole distance. For a slice thickness of 7 mm or more, the measured hole should be between 9 mm and 5 mm. Smaller slice widths may have greater variations; for example, a 2-mm slice width that measures 4 mm falls within acceptable limits. This test should be performed at installation and annually thereafter.

58. **Radiation Leakage and Scatter**

As its name suggests, this test measures the amount of radiation leakage and scattered radiation during the scanning process. Using a Geiger counter or ion chamber dosimeter, scan a head phantom. Place the radiation detector where you want to take a reading. A CT technologist or physicist is present during the scan. Take a complete measurement during the entire sequence of a CT head exam.
Repeat this procedure using different room locations, trying to simulate where a technologist might stand during a CT exam. The measurement determines the amount of radiation that a person receives for a particular location and specific scan. There are no acceptable limits for the scatter test; limitations for annual radiation exposure should guide the technologist’s actions.

If the exposure rate is higher than 25 mR per scan (milliroentgen/scan), it’s likely a problem with collimation or x-ray tube shielding, requiring a service engineer to diagnose the problem. These types of problems could also result in increased dose to the patient. This test should be performed at installation and annually thereafter.

59. **Measurements by Physicists**

To ensure that the quality of CT scans always remains at optimal levels, medical physicists measure and test various factors at least annually. Although a CT technologist doesn’t perform or interpret these tests, it’s important for technologists to understand the physicist’s measurements in order to observe daily image quality. Any change in image quality should be reported to the medical physicist for additional testing.

In addition, CT technologists need to work closely with a medical physicist during the measurement process. Even though the medical physicist or quality control technologist may be performing the test, the CT technologist will need to perform several of the scans and provide additional assistance.

CT technologists are responsible for interacting with the medical physicist in their department to determine which tests are conducted and which parameters they should watch closely.

60. **Practice Question**

61. **Practice Question**

62. **Conclusion**

The information presented in this learning module just scratches the surface of image quality in computed tomography. For additional information on image quality, check with your supervisor, medical physicist or the American Association of Physicists in Medicine at [www.aapm.org](http://www.aapm.org).

AAPM Report #1 titled “Phantoms for Performance Evaluation and Quality Assurance of CT Scanners” and report #39 “Specification and Acceptance Testing of Computed Tomography Scanners” are especially helpful.

63. **Acknowledgements**

64. **Bibliography**


65. **Objectives**