Image Noise

Noise

Noise in computed tomography is an ***unwanted change in pixel values in an otherwise homogeneous image***. Often noise is defined loosely as the ***grainy appearance on cross-sectional imaging***.

Noise in CT is measured via the ***signal to noise ratio (SNR)***; comparing the level of desired ***signal (photons) to the level of background noise*** (***pixels deviating from normal***). The ***higher the ratio, the less noise is present in the image***.

Noise in a cross-sectional image will ***equal a decrease in the picture quality and inadvertently will hinder the contrast resolution***.

CT numbers of a particular substance such as water ***are not uniform but rather fluctuate***. For water, the CT numbers will fluctuate around an ***average of 0*** (by convention). These random ***fluctuations in the CT number of a uniform material appear as graininess on a CT image***. The degree of r***andom fluctuations depends on the number of X-ray photons that contribute to the formation of a CT image***. CT noise, therefore, is associated with the number of X-rays contributing to each detector measurement. ***The more X-rays used to generate an image, the smaller the amount of image noise***. Thus, to understand how each CT technique factor affects image noise, one must imagine the affect of this technique on the number of X-rays reaching detector to form the image.

Factors affect image noise

In r***adiography***, image noise is related to ***the numbers of X-ray photons contributing to each small area of the image*** (e.g., to each pixel of a digital radiograph). In CT, ***X-rays contribute to detector measurements and not to individual pixels***. CT image noise is thus ***associated with the number of X-rays contributing to each detector measurement***.

To understand how CT technique affects noise, one should imagine how each factor in the technique affects the number of detected X-rays. Examples are as follows and illustrated in table (1):

- tube current
- scan time
- slice thickness
- tube voltage
- patient size

Tube ***current in mA is directly proportional to the number of X-rays reaching the detector***. Therefore, ***increasing mA will decrease image noise***.

Scan time is also ***directly proportional to the X-ray number and thus as scan time increases, image noise decreases.***

Scan time and tube current are considered together and measured as mAs (milli-amperes-sec).

Table (1) :The affect of various CT conditions on image noise

Factor	Affect on CT image noise
Increasing Tube current (mA)	Decrease
Increasing scan time	Decrease
Increasing slice thickness	Decrease
Increasing tube voltage (KeV)	Decrease
Increasing patient size	Increase

Slice thickness changes the beam width entering the detectors. Thus increasing slice thickness results in increasing the beam width which in turn ***increases the number of X-rays*** proportionately. ***Increased slice thickness decreases image noise***.

Increasing tube voltage (keV) increases the energy of the generated X-rays and thus, ***more X-rays will penetrate the patient and reach the detectors***.

Increasing keV decreases image noise. ***Decreasing KeV will increase image noise*** (less penetrated X-rays) and will brighten the contrast.

Patient factors may also contribute to image noise. That is, the ***larger the patient, the more attenuation of X-rays and thus, less of these X-rays will reach the detectors***. ***Increasing patient size results in more image noise*** due to less X-rays reaching the detectors to form the CT image.

Figure (1) shows examples of noise in scans of uniform phantoms using standard and higher-resolution (bone) filters and with standard and very low values for mAs.

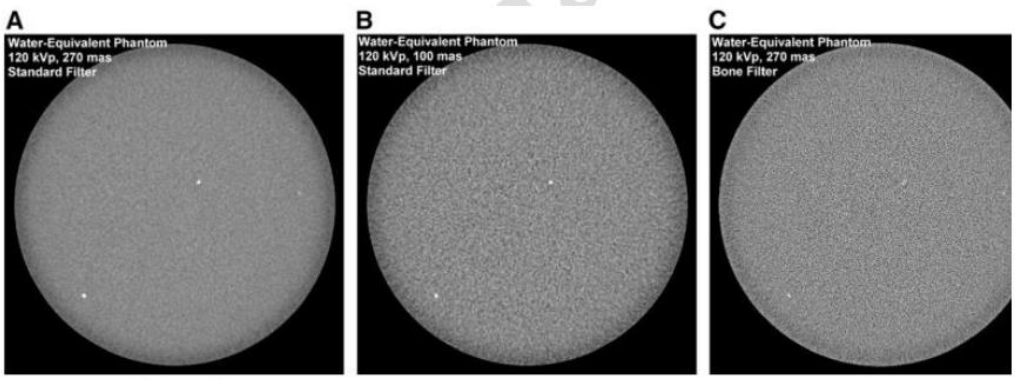

Figure (1): CT image noise depends on number of X-ray photons contributing to image. (A and B) Comparison of noise from scans using 270 mAs (typical clinical value) and 100 mAs. (C) Appearance of image noise is strongly affected by reconstruction filter; sharp filter such as bone also sharpens (enhances) appearance of noise.

Image Artifacts

Artifacts may be ***defined as any structure that is seen on an image but is not representative of the actual anatomy***.

Artifacts can ***degrade image quality***, affect the ***perceptibility of detail***, or even lead to ***misdiagnosis***. They can cause serious problems for the radiologist who has to provide a diagnosis from images obtained by the CT scanner. Therefore it is mandatory that the technologist understand the nature of artifacts in CT.

In general, ***an artifact is "a distortion or error in an image that is unrelated to the subject being studied"***. Specifically, a CT image artifact is defined as "***any discrepancy between the reconstructed CT numbers in the image and the true attenuation coefficients of the object"***.

Because CT numbers represent gray shades in the image, ***incorrect measurements will produce incorrect CT numbers*** that do not represent the attenuation coefficients of the object. These errors result in various artifacts that affect the appearance of the CT image.

Most types of CT artifacts fall into 3 categories:

a) **Streak artifacts**
b) **Shading artifacts**
c) **Ring artifacts**

Streak artifacts may appear as intense straight lines across an image, which may be caused by ***improper sampling of the data***, ***motion, metal, beam hardening, noise, spiral/ helical scanning, and mechanical failure or imperfections***.

These discrepancies are enhanced by the convolution process and manifested into lines during the back-projection, as shown in Figure (1,A).

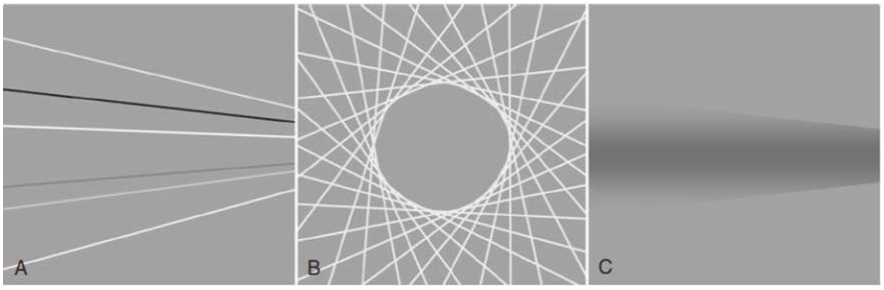

Fig. (1): Different appearances of artifacts. A, Streak. B, Ring. C, shading.

Streak artifacts may occur in all scanners. Although arising for many reasons, most are ***due to inconsistent or bad detector measurements***. Factors causing inconsistencies include motion (anatomy in different locations during different parts of the scan),

insufficient X-ray intensity (leading to high random errors), and malfunctions (tube arcing or system misalignment).

An inconsistency ***due to partial-volume effects*** is illustrated in Figure (2). During a 360 axial scans, the ***same ray (or nearly the same ray) is sampled twice***, but with ***X-rays traveling in opposite directions***. Because of beam divergence, however, the ***cone-shaped X-ray beam samples slightly different volumes in each direction***. A small structure, such as the ***edge of a bone, may partially extend into the volume so as to attenuate the beam traveling in one direction*** (say, downward when the tube is above) but ***may be missed when the beam is coming from the opposite direction*** (upward, when the tube is underneath). The two measurements of the same ray path are thus inconsistent and will lead to an image streak.

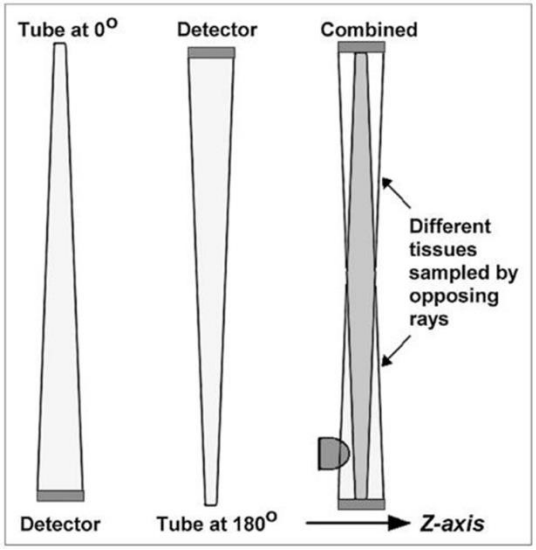

Figure (2): Partial-volume streaks are caused by opposing X-ray beams, which nominally pass through the same voxels but actually sample slightly different cone-shaped tissue volumes as a result of beam divergence. Small structure, such as piece of bone, is detected by beam from one direction but is missed by opposing beam. Resulting inconsistency leads to streak artifact.

Shading artifacts often appear near objects of high densities and can be caused by beam hardening, partial volume averaging, spiral/helical scanning, scatter radiation, off-focal radiation, and incomplete projections, as shown in Figure 2, C.

The ***most common type of shading*** artifact is ***beam- hardening effects***. Beam- hardening artifacts are actually present on all CT images to some extent and are due to ***imperfect beam-hardening correction***. They appear as ***non-uniformities in the CT numbers of a uniform material***, such as CT numbers that are lower at the center of a uniform phantom than at the periphery. Such non-uniformities are generally quite small ***(< 5 HU)*** and not apparent unless one is viewing a scan of a ***uniform phantom with a very narrow window***. Occasionally, however, a larger amount of hardening occurs when the scan is passing through ***thick regions of bone*** or through ***contrast medium***. In that case, regions of hypointensity (i.e., ***CT numbers that are lower than expected***) may appear ***downstream along the paths of rays*** that have been overly hardened. Scatter can also cause shading artifacts, although these are uncommon in most modern scanners.

Ring or partial ring (arc) artifacts are produced when the ***projection readings of a single channel or a group of channels consistently deviate from the truth***. They can be the result of ***defective detector cells or DAS channels***, ***deficiencies in system calibration***, or a ***suboptimal image-generation process***. This is predominately a ***third generation CT*** scanner phenomenon. Because a detector channel reading is always ***mapped to a straight line*** that is at a fixed distance to the ***iso-center of the system***, any such inaccuracies in measurements from a particular detector occurring during a scan (or part of a scan) are backprojected along the ray paths measured by that detector. These inaccuracies contribute ***only slightly to pixels over most of the image*** (because several hundred backprojected values contribute to each pixel) but tend to reinforce along a ring of radius d, where several such rays intersect. ***A defective reading forms a ring pattern during the back-projection process***, as illustrated in Figure 2, B.

Ring artifacts are usually readily recognizable by software ring- correction algorithms and thus can be removed from the image. Small-radius rings (i.e., near the center of rotation) or arcs of small angular extent may not be recognized as artifacts and thus wind

up in the image. In practice, third generation scanners are sensitive to detector inaccuracies, which, without corrective algorithms, would be visible on most or all CT images.

Causes of artifacts

CT artifacts are common and can occur for various reasons. Knowledge of these artifacts is important because they can mimic pathology (e.g. partial volume artifact) or can degrade image quality to non-diagnostic levels.

CT artifacts can be classified according to the underlying cause of the artifact.

1) Patient-based artifacts

- motion artifact
- transient interruption of contrast
- clothing artifact

2) Physics-based artifacts

- beam hardening
    - cupping artifact
    - streak and dark bands
    - metal artifact / high-density foreign material artifact
- partial volume averaging
- photon starvation
- aliasing
- truncation artifact

3) Hardware-based artifacts

- ring artifact
- tube arcing

- ❖ out of field artifact
- ❖ air bubble artifact
- ❖ helical and multichannel artifact
  - ✓ windmill artifact
  - ✓ cone beam effect