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Image artifacts on CT images deteriorating image quality and mimicking pathological processes

An artifact in computed tomography (CT), is any systematic discrepancy between the CT numbers in the reconstructed image and the true attenuation coefficients of the object. CT images are reconstructed from lots of independent detector measurements so any error of measurement will usually reflect itself as an error in the reconstructed image (1). The types of artifact that can occur are: streaking, which is generally due to an inconsistency in a single measurement; shading, which is due to a group of channels or views deviating gradually from the true measurement; rings, which are due to errors in an individual detector calibration; distortion, which is due to helical reconstruction.

These artifacts may be divided into four categories: physics-based artifacts, which result from the physical processes involved in the acquisition of CT data; patient-based artifacts, which are caused by such factors as patient movement or the presence of metallic materials in or on the patient; scanner-based artifacts, which result from imperfections in scanner function; helical and multisection artifacts, which are produced by the image reconstruction process (1).

The aim of the study is to present the types of CT artifacts, their reasons and methods of avoiding or reducing their effects on CT images.

PHYSICS-BASED ARTIFACTS

Beam hardening. As an x-ray beam composed of individual photons with a range of energies passes through an object, it becomes "harder," that is to say its mean energy increases, because the lowerenergy photons are absorbed more rapidly than the higher-energy photons (1).

In very heterogeneous cross sections, dark bands or streaks can appear between two dense objects in an image. They occur because the portion of the beam that passes through one of the objects at certain tube positions is hardened less than when it passes through both objects at other tube positions. This type of artifact can occur both in bony regions of the body and in scans where a contrast medium has been used. Beam-hardening streak artifacts from dense contrast material within the superior vena cava are commonly seen and can overlie the right pulmonary and upper lobe arteries. This artifact can mimic pulmonary embolism or aortic dissection (Fig. 1), and can by identified by recognizing its nonanatomic, poorly defined, radiating nature and can be reduced by flushing the superior vena cava with saline solution using dual chamber injectors (1, 2, 9). Hardening may be minimized by using filtration, calibration correction, and beam hardening correction software (1).

It is sometimes possible to avoid scanning bony regions, either by means of patient positioning or by tilting the gantry. It is important to select the appropriate scan field of view to ensure that the scanner uses the correct calibration and beam hardening correction data and, on some systems, the appropriate bowtie filter (1).

Fig. 1. Beam-hardening streak artifact (arrow) from dense contrast material within the superior *vena cava* simulating aortic dissection

Partial volume. The partial volume effect can lead to image artifacts in a number of ways. Partial volume artifact is the result of axial imaging of an axially oriented vessel. These artifacts are a separate problem from partial volume averaging, which yields a CT number representative of the average attenuation of the materials within a voxel (1, 9). One type of partial volume artifact occurs when a dense object lying off-center protrudes partway into the width of the x-ray beam (1). Partial volume artifacts can best be avoided by using a thin acquisition section width. This is necessary when imaging any part of the body where the anatomy is changing rapidly in the z direction. To limit image noise, thicker sections can be generated by adding together several thin sections (1).

Photon starvation. A potential source of serious streaking artifacts is photon starvation, which can occur in highly attenuating areas such as the shoulders. When the x-ray beam is traveling horizontally, the attenuation is greatest and insufficient photons reach the detectors. The result is that very noisy projections are produced at these tube angulations. The reconstruction process has the effect of greatly magnifying the noise, resulting in horizontal streaks in the image. If the tube current is increased for the duration of the scan, the problem of photon starvation will be overcome, but the patient will receive an unnecessary dose when the beam is passing through less attenuating parts. Therefore, manufacturers have developed techniques for minimizing photon starvation (1). On some scanner models, the tube current is automatically varied during the course of each rotation, which allows sufficient photons to pass through the widest parts of the patient without unnecessary dose to the narrower parts (1). Some manufacturers use a type of adaptive filtration to reduce the streaking in photon-starved images. This software correction smooths the attenuation profile in areas of high attenuation before the image is reconstructed (1).

Undersampling. The number of projections used to reconstruct a CT image is one of the determining factors in image quality. Too large an interval between projections (undersampling) can result in misregistration by the computer of information relating to sharp edges and small objects. This leads to an effect known as *view aliasing*, where fine stripes appear to be radiating from the edge of, but at a distance from, a dense structure. Stripes appearing close to the structure are more likely to be caused by undersampling within a projection, which is known as *ray aliasing*. In situations where resolution of fine detail is important, undersampling artifacts need to be minimized. View aliasing can be minimized by acquiring the largest possible number of projections per rotation (1, 7).

PATIENT-BASED ARTIFACTS

Metallic materials. Metallic prostheses generate starburst or streak artifacts that can substantially degrade CT image quality and make it hard for the radiologist to evaluate adjacent structures, which is especially crucial when assessment is required for potential surgical revision. These prostheses block incident x-ray beams, which lead to missing projection data and artifacts on the reconstructed CT images (Fig. 2). The severity of streak artifacts depends on the composition of the metallic prosthesis used (1, 5). Additional artifacts due to beam hardening, partial volume, and aliasing are likely to compound the problem when scanning very dense objects (1).

For nonremovable items, such as dental fillings (Fig. 3), prosthetic devices, and surgical clips, it is sometimes possible to use gantry angulation to exclude the metal inserts from scans of nearby anatomy. When it is impossible to scan the required anatomy without including metal objects, increasing technique, especially kilovoltage, may help penetrate some objects, and using thin sections will reduce the contribution due to partial volume artifact (1, 3).

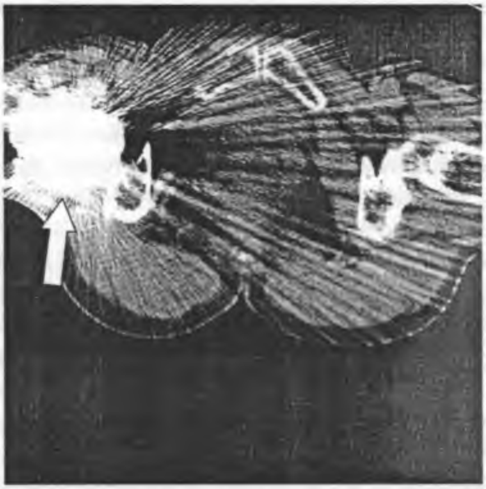

Fig. 2. Streak artifacts generated by hip prosthetic material (arrow) that substantially degrade CT image quality and make it hard for the radiologist to evaluate adjacent structures

Patient motion. Patient motion can cause misregistration artifacts, which usually appear as shading or streaking in the reconstructed image. Steps can be taken to prevent voluntary motion, but some involuntary motion may be unavoidable during body scanning. However, there are special features on some scanners designed to minimize the resulting artifacts (1). In some cases (e.g., pediatric patients), it may be necessary to immobilize the patient by means of sedation. Respiratory motion artifacts are the most common cause of indeterminate CT pulmonary angiography and can cause misdiagnosis of pulmonary emboliom (1, 9). The rapid motion of the heart can be minimized by combining electrocardiographic gating techniques with specialized methods of image reconstruction (1).

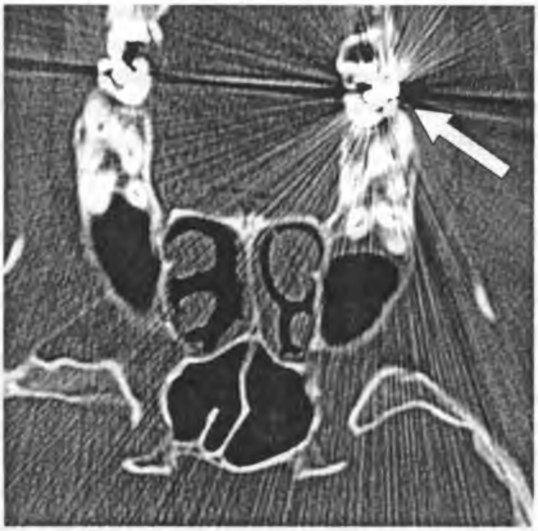

Fig. 3. Streak artifacts generated by dental amalgam (arrow) deteriorating the CT image of paranasal sinuses

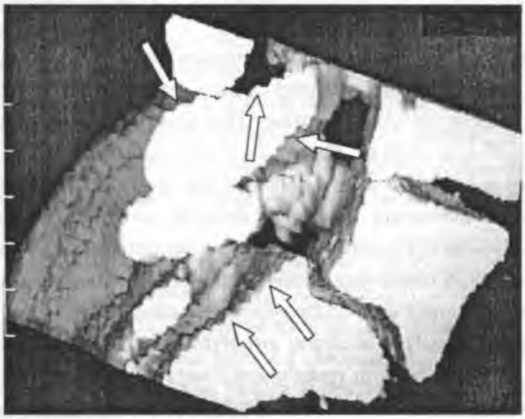

Fig. 4. Stair step artifacts (arrows) on 3D CT spine reformation

Incomplete projections. If any portion of the patient lies outside the scan field of view, the computer will have incomplete information relating to this portion and streaking or shading artifacts are likely to be generated. Similar effects can be caused by dense objects such as an intravenous tube containing contrast medium lying outside the scan field. Blocking of the reference channels at the sides of the detector array may also interfere with data normalization and cause streaking artifacts (1).

SCANNER-BASED ARTIFACTS

Ring artifacts. Rings visible in a uniform phantom or in air might not be visible on a clinical image if a wide window is used. Even if they are visible, they would rarely be confused with disease. However, they can impair the diagnostic quality of an image, and this is particularly likely when central detectors are affected, creating a dark smudge at the center of the image (1). The presence of circular artifacts in an image is an indication that the detector gain needs recalibration or may need repair services. Selecting the correct scan field of view may reduce the artifact by using calibration data that fit more closely to the patient anatomy. All modern scanners use solid-state detectors, but their potential for ring artifacts is reduced by software that characterizes and corrects detector variations (1).

PLANE: SINGLE-SECTION SCANNING AND MULTISECTION SCANNING

There are additional artifacts that can occur in helical scanning due to the helical interpolation and reconstruction process. The artifacts occur when anatomic structures change rapidly in the z direction (e.g., at the top of the skull) and are worse for higher pitches (1, 8). If a helical scan is performed of a cone-shaped phantom lying along the z axis of the scanner, the resultant axial images should appear circular. In fact, their shape is distorted because of the weighting function used in the helical interpolation algorithm (1, 2, 8).

The helical interpolation process leads to a more complicated form of axial image distortion on multisection scanners than is seen on single-section scanners. The typical windmill-like appearance of such artifacts is due to the fact that several rows of detectors intersect the plane of reconstruction during the course of each rotation. As helical pitch increases, the number of detector rows intersecting the image plane per rotation increases and the number of "vanes" in the windmill artifact increases (1, 4).

Cone beam effect. As the tube and detectors rotate around the patient (in a plane perpendicular to the diagram), the data collected by each detector correspond to a volume contained between two cones, instead of the ideal flat plane. This leads to artifacts similar to those caused by partial volume around off-axis objects. The artifacts are more pronounced for the outer detector rows than for the inner ones, where the data collected correspond more closely to a plane (1). Cone beam effects get worse for increasing numbers of detector rows. Thus, 16-section scanners should potentially be more badly affected by artifacts than four-section scanners. However, manufacturers have addressed the problem by employing various forms of cone beam reconstruction instead of the standard reconstruction techniques used on four-section scanners (1, 4).

Multiplanar and three-dimensional reformation. Major improvements in multiplanar and three-dimensional reformation have come about since the introduction of helical scanning and, to an even greater extent, with multisection scanning. The faster speed with which the required volume can be scanned means that the effects of patient motion are much reduced, and the use of narrower acquisition sections and overlapping reconstructed sections leads to sharper edge definition on reformatted images (1).

Stair Step Artifacts. Stair step artifact consists of low-attenuation lines seen traversing a vessel on coronal and sagittal reformatted images and is accentuated by cardiac and respiratory motion. This artifact can be eliminated or reduced by reconstructing the raw data with a 50% overlap prior to three-dimensional image reconstruction (Fig. 4) (1, 6). They are less severe with helical scanning, which permits reconstruction of overlapping sections without the extra dose to the patient that would occur if overlapping axial scans were obtained. Stair step artifacts are virtually eliminated in multiplanar and three-dimensional reformatted images from thin-section data obtained with today's multisection scanners. Stair-step artifacts characteristically deteriorate the appearance of two-dimensional reformation and 3D-rendered objects and may affect the accuracy of volume or diameter measurements of structures within the scanned volume (1, 7).

Zebra Artifacts. Faint stripes may be apparent in multiplanar and three-dimensional reformatted images from helical data because the helical interpolation process gives rise to a degree of noise inhomogeneity along the z axis. This "zebra" effect becomes more pronounced away from the axis of rotation because the noise inhomogeneity is worse off-axis (1, 7).

CONCLUSIONS

Artifacts can degrade the quality of a CT image to varying degrees. Many technologies incorporated into modern scanners minimize some types of artifact, and some can be partially corrected by the scanner software. However, there are many situations in which artifacts can be avoided by careful patient positioning and the proper selection of scan parameters. Therefore, detailed knowledge of the types of CT artifact and their reasons may be especially helpful in avoiding most of them, and perform correct diagnosis.

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SUMMARY

An artifact in computed tomography (CT), is any systematic discrepancy between the CT numbers in the reconstructed image and the true attenuation coefficients of the object. CT images are reconstructed from lots of independent detector measurements, so any error of measurement will usually reflect itself as an error in the reconstructed image. The aim of the study is to present the types of CT artifacts, .their reasons and methods of avoiding or reducing their effects on CT images. The types of artifact that can occur are: streaking, which is generally due to an inconsistency in a single measurement; shading, which is due to a group of channels or views deviating gradually from the true measurement; rings, which are due to errors in an individual detector calibration; distortion, which is due to helical reconstruction. These artifacts may be divided into four categories: physics-based artifacts, which result from the physical processes involved in the acquisition of CT data; patient-

-based artifacts, which are caused by such factors as patient movement or the presence of metallic materials in or on the patient; scanner-based artifacts, which result from imperfections in scanner function; helical and multisection artifacts, which are produced by the image reconstruction process. Artifacts can degrade the quality of a CT image to varying degrees. Many technologies incorporated into modern scanners minimize some types of artifact, and some can be partially corrected by the scanner software. However, there are many situations in which artifacts can be avoided by careful patient positioning and the proper selection of scan parameters. Therefore, detailed knowledge of the types of CT artifact and their reasons may be especially helpful in avoiding most of them, and in performing correct diagnosis.

Artefakty w obrazach TK pogarszające jakość obrazów oraz sugerujące obecność zmian patologicznych

Artefaktem w TK jest nazywana różnica między rzeczywistą wartością pochłaniania promieniowania przez badaną strukturę a jego wartością na zrekonstruowanym obrazie TK. Ponieważ obrazy TK powstają w wyniku rekonstrukcji bardzo wielu pomiarów niezależnych detektorów, błędy pomiarów najczęściej znajdują swoje odzwierciedlenie w błędach na powstałych obrazach TK. Celem pracy jest przedstawienie rodzajów artefaktów w TK, źródeł ich powstania i metod ich minimalizowania lub wyeliminowania. Artefakty występujące w TK to artefakty pasma, cienie, pierścienie lub zniekształcenia w wyniku spiralnej akwizycji. Mogą być podzielone na cztery główne kategorie: zależne od zjawisk fizycznych związanych z akwizycją obrazów w TK; zależne od pacjenta (protezy, wypełnienia zębów, ruchy pacjenta, ruchy oddechowe, ruchy serca); zależne od skanera TK; związane z akwizycją spiralną i akwizycją wielorzędową i rekonstrukcjami obrazów. Artefakty mogą znacznie pogarszać jakość uzyskanych obrazów TK. Producenci aparatów TK stosują wiele metod redukcji niektórych rodzajów artefaktów i część z nich może być skorygowana przez oprogramowanie skanerów. Jednak jest wiele sytuacji, w których można uniknąć artefaktów poprzez właściwe ułożenie pacjenta, poinstruowanie go o przebiegu badania, o sposobie zatrzymania oddechu oraz zastosowanie odpowiednich projekcji i parametrów badania. Dlatego znajomość rodzaju artefaktów występujących w TK oraz sposobów ich unikania bądź minimalizowania, jeśli jest to możliwe, jest niezwykle istotna.