

Detection of Artifacts and Its Effects in the Clinical Evaluation of Diagnostic and Therapy CT Images

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Abstract

Importance of imaging in all clinical or medical research, and especially, of Computerized Axial Tomography (CAT scan), has demonstrated a unique place in diagnostic or radiation therapy. Two-dimensional images of internal structures of the body are examined and reported. This process of imaging, any anatomical location, viz. head and neck, thorax, pelvis, etc. takes about 30 seconds to perform with a minimal dose of less than 1.6- 2.0 mGy. The images are constructed by the hardware with software algorithm, using the attenuation and absorption of X rays of tissues, of varying electron densities of the anatomical structures. Sometimes a contrast dye is injected to a patient intravenously, rectally or orally, to make hollow or fluid-filled structures such as blood vessels more visible. Radiologists and radiation oncologists are confronted with a task to delineate the information of the CT images to a meaningful diagnosis. The images are, therefore, valuable for diagnostic reports, some of these may relate to cancerous tumors and tissues. Cancer treatment, radiation therapy or else, from such observations may start. But an artifact and distortion on such images will contribute to erroneous and/or unusable interpretations in offering a clinical report to provide wrong clinical decisions. The implications of the presence of distortion in CT images is, for a patient, described here so as to instruct the experts, in medical and clinical fields, to rectify the situation in acquiring a sharp and flawless image or in reaching the correct clinical goal.

Keywords: Artifact; CAT scan.

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Introduction

Computed tomography (CT) is the science that creates two-dimensional cross-sectional images from three-dimensional body structures. Computed tomography utilizes a mathematical technique called reconstruction to accomplish this task. It is important for an individual, studying the CT science, to recognize that CT is a mathematical process. In a basic sense, a CT image is the result of "breaking apart" a

three-dimensional structure and mathematically putting it back together again and displaying it as a two-dimensional image on a monitor. The primary goal of any CT system is to accurately reproduce the internal structures of the body as two-dimensional cross-sectional images. This goal is accomplished by computed tomography's superior ability to overcome superimposition of structures and demonstrate

slight differences in tissue contrast. It is important to realize that collecting many projections of an object and heavy filtration of the X-ray beam play important roles in CT image formation. Distortion of image formation may happen to complicate the image evaluation.¹ Computed cross-sectional images are reconstructed from a large number of measurements of X-ray transmission through the patient which is known as projection data.

The first practical CT instrument was developed in 1971 by DR. G. N. Hounsfield in England and was used to image the brain.² The projection data were acquired in approximately 5 minutes, and the tomographic image was reconstructed in approximately 20 minutes.

CT technology has developed dramatically, and CT has become a standard imaging procedure for virtually all parts of the body in thousands of facilities throughout the world. Projection data are typically acquired in approximately 1 second, and the image is reconstructed in 3 to 5 seconds. One special purpose scanner described below acquires the projection data for one tomography image in 50 ms.² Basic system of a CT scanner generally consists of a gantry, a patient table, a control console, and a computer. The gantry contains the X-ray source, X-ray detectors, and the data acquisition system (DAS).²

Materials and method

CT Scanners and Its Developments

The word Tomography can be traced back to 1920. Dr. Godfrey Hounsfield, inventor of clinical computed tomography, scanned in 1972 and demonstrated a suspected brain lesion. Dr. Allan Cormack developed mathematical solutions for CT and first patient was scanned in 1972. Dr. Robert Ledley developed the first whole-body CT scanner.³

CT scanner must have 4 basic components like Gantry, X-ray tube, and detector control console. Technological developments led to 6th generation (helical) as shown Figures 1(a) & (b). The Helical CT scanners acquire data, while the table is moving. This allows the use of less contrast agent. Entire scan may be done within a single breath hold of the patient.

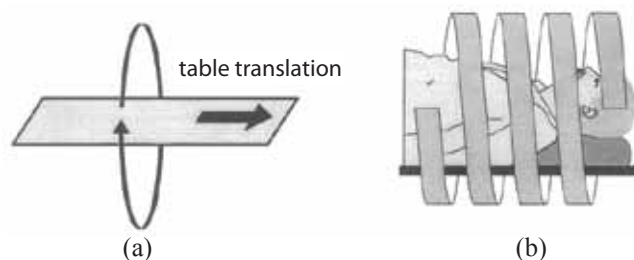


Fig 1: (a) X-ray tube rotation; (b) Helical X-ray tube path around patient

Developments led to the 7th generation CT scanners, where multiple detector arrays have been introduced. Here, as shown in Figures 2a and b, the collimator spacing is wider and more of the X-rays produced by the tube are utilized for image data. Opening up the collimator in a single array scanner increases the slice thickness which reduces the spatial resolution. With multiple detector array scanners, slice thickness is determined by detector size and not by the collimator.⁴

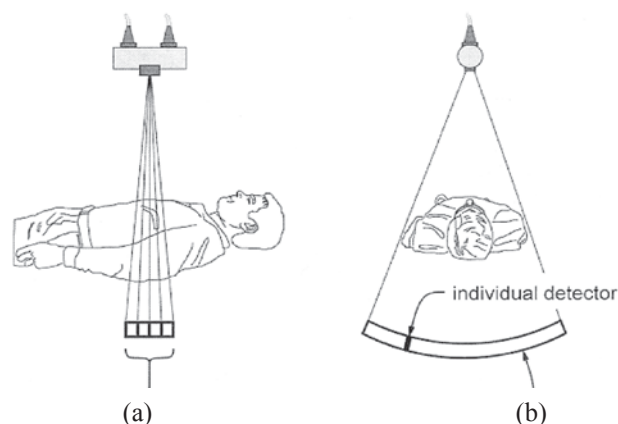


Fig 2: (a) Four detector arrays and (b) Detector array

Principle of Conventional CT images

Contemporary CT scanners offer isotropic or near isotropic display of images which does not need to be restricted to the conventional axial images. Instead, it is possible, for a software program, to build a volume by 'stacking' the individual slices one on top of the other. The program may then display the volume in an alternative manner.⁵

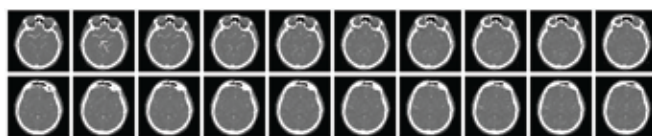


Fig 3: Conventional axial images showing individual slices

Uses of Diagnostic CT Images

Cranial: Diagnosis of cerebrovascular accidents and intracranial hemorrhage may be carried out by CT images. For detection of tumors, CT scanning with IV contrast is occasionally used but is less sensitive than Magnetic Resonance Imaging (MRI).

Chest: CT is excellent for detecting both acute and chronic changes in the lung parenchyma. For evaluation of chronic interstitial processes (emphysema, fibrosis, and so forth), thin sections with high spatial frequency reconstructions are used - often scans are performed both in inspiration and expiration. This special technique is called high resolution CT (HRCT). For detection of airspace disease (such as pneumonia) or cancer, relatively thick sections and general purpose image reconstruction techniques may be adequate.

Cardiac: With the advent of sub-second rotation combined with multislice CT (up to 64 slice), high resolution and high speed can be obtained at the same time, allowing excellent imaging of the coronary arteries (cardiac CT angiography). Images with an even higher temporal resolution can be formed, using retrospective ECG gating. In this technique, each portion of the heart is imaged more than once, while an ECG trace is recorded. The ECG is then used to correlate the CT data with their corresponding phases of cardiac contraction. Once this correlation is complete, all data that were recorded while the heart was in motion (systole) can be ignored and images can be made from the remaining data that happened to be acquired while the heart was at rest (diastole). In this way, individual frames, in a cardiac CT investigation, have a better temporal resolution.

Abdominal and pelvic: CT is a sensitive method for diagnosis of abdominal diseases. It is used frequently to determine stage of cancer and to follow its progress. To investigate acute abdominal pain, renal/urinary stones, appendicitis, pancreatitis, diverticulitis, abdominal aortic aneurysm and bowel obstruction are diagnosed and assessed with CT images. CT is also the first line for detecting solid organ injury after trauma.

Reconstruction of CT images

CT slice is subdivided into a matrix of up to 1024×1024 volume elements (voxels). Each voxel has been

traversed, during the scan, by numerous X-ray photons. Intensity of the transmitted radiation is measured by detectors. From these intensity readings, the density or attenuation value of the attached tissue point, in the slice, can be calculated. Specific attenuation values are assigned to each individual voxel. The viewed image is then reconstructed from the respective matrix of picture elements (Pixels).⁶

Slice / cut - matrix, voxel and pixel: The cross sectional portion of the body, as shown in Fig. 4 which is scanned for the production of CT image is called a slice. The slice has width and, therefore, volume. The width is determined by the width of the x-ray beam.

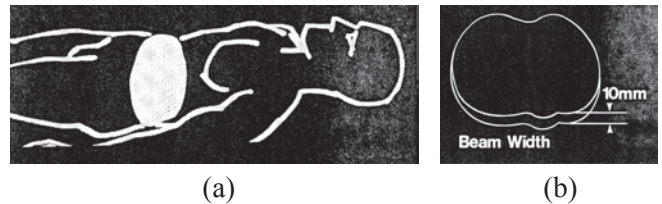


Fig 4: (a) Represents slice of a CT image and (b) Represents beam width

The image is represented as a MATRIX, as shown in Fig 5, of CT numbers. The Matrix is, a two dimensional array of numbers, arranged in rows and columns. Each number represents the value of the image at that location.

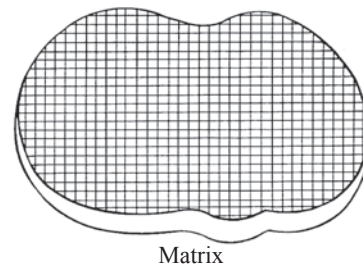


Fig 5: Represents a matrix

The Voxel is represented in Fig 6 and is defined, as individual element or number, in the image matrix representing a three dimensional volume element in the object.⁶

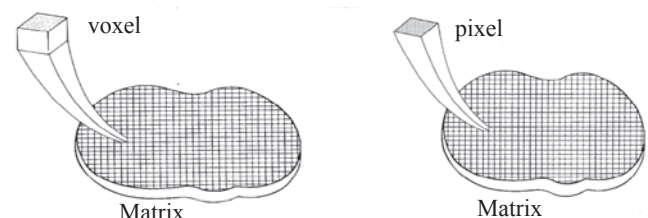


Fig 6: Represents Voxel and Pixel

The VOXEL is represented in the image as a two dimensional element called PIXEL (picture element) as given in Fig 6.

Modification of CT images: CT values contain the linear absorption coefficients of the underlying tissue in every volume element with respect to the μ -value of water. Using this definition the CT values of different organs are relatively stable and independent of the X-ray spectrum.

$$\text{CT value} = (\mu - \mu_{\text{water}}) / \mu_{\text{water}} \times 1000 \text{ HU}$$

Thus the CT number of any particular tissue is the fractional difference of its linear attenuation coefficient relative to water. Small differences in CT number can be amplified visually by increasing the contrast of the display.

Manipulations of CT images: The windowing facility (W), window level (WL) and window width can enhance the viewing of the image for higher resolution, contrast and brightness or darkness.

Fig 7 shows the spread of CT numbers for a guideline in viewing the images of various anatomical sites. A window level adjustment for a CT number of (+) 40 (Fig 8a) and that of (-) 600 (Fig 8b) depict the importance on image quality for soft tissue and lung respectively.⁷⁻⁸

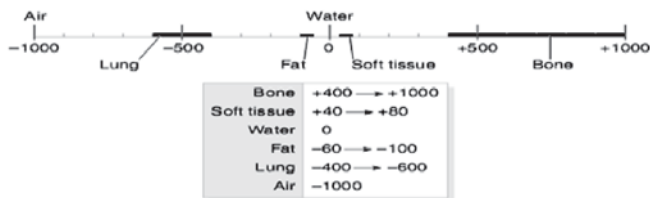


Fig 7: The Hounsfield scale of CT number related to the structures

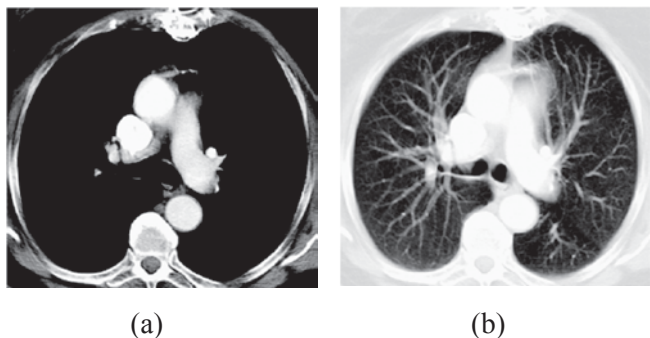


Fig 8: (a) Soft tissue around mediastinum and (b) Lung field

Effect of Pitch: Pitch is the distance in millimeters that the table moves during one complete rotation of the X-ray tube, divided by the slice thickness (millimeters). The image is sharper. (a) for lower pitch, the table moves less for each table revolution. (b) for higher pitch, the table moves further for each revolution so the resulting image is more blurred. The helix is stretched.



**Fig 9: (a) Pitch is low; (b) Pitch is high
Images in 3 planes after reconstruction:**

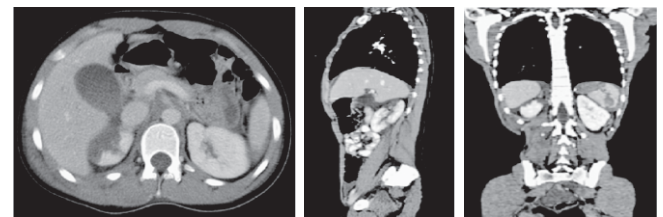


Fig 10: The three images demonstrate a haemoperitoneum, shattered right kidney and a lacerated spleen in (a) axial, (b) sagittal and (c) coronal planes

An artifact is a feature or appearance that is seen on an image, which does not actually exist. They occur in all imaging modalities and are often unavoidable. Recognizing the presence of artifacts is important in order to avoid confusion with pathology and wrong diagnosis and reports.⁹

Types of artifact

Motion due to patient movement during a scan, commonly in breathing streak (beam hardening) where dark ‘streaks’ behind highdensity objects e.g. dental amalgam and metallic joint (see Fig 11) replacements. Partial voluming due to different tissue densities, within a single voxel, lead to ‘averaging’ of data e.g. small black object is a larger white one.

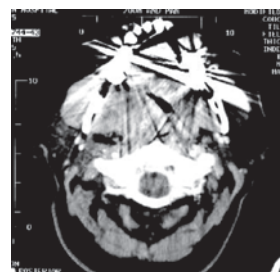


Fig 11: Represents artifact for metallic joint in dental amalgam

Ring artifacts: The rotate/rotate geometry of 3rd generation scanners leads to a situation in which each detector is responsible for the data corresponding to a ring in the image. Drift in the signal levels of the detectors over time affects the mt values that are back projected to produce the CT image, causing ring artifacts. Figures 12(a) and (b) show the obvious demonstration of artifact that may be due to the misaligned or a bad detector for producing the image. This experiment in a scan at Delta Hospital (Fig 12c) provided a clue for the CT engineer to rectify the cause of artifacts and improve the image quality of the patients.¹⁰

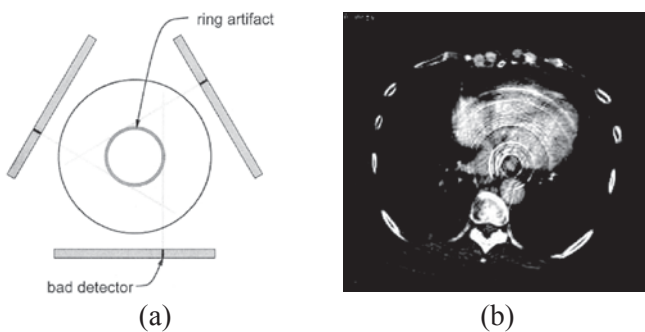


Fig 12: Both (a) & (b) represent ring artifact

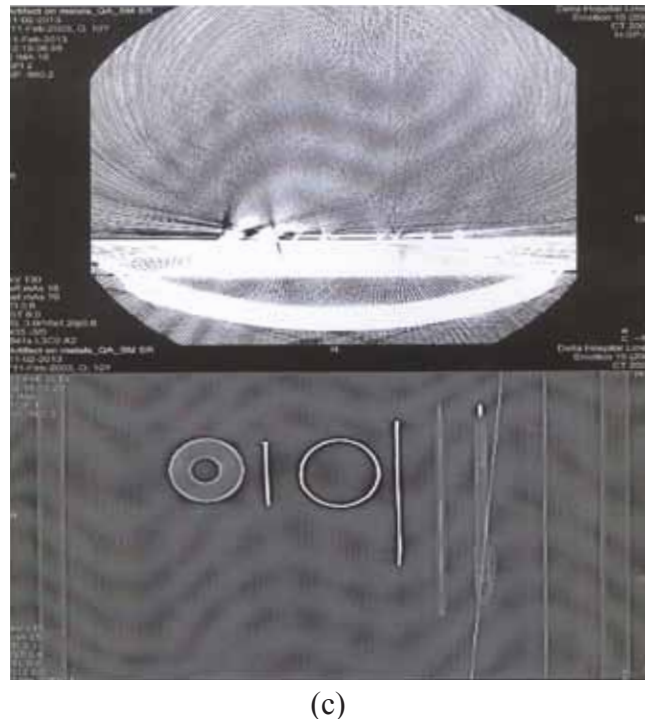


Fig 12: (c) Represents artifacts, which has been generated in a CT scanner (Somatom Emotion 16 Slice, Model No: 80529), to identify the cause of artifacts in the CT images. Several objects of different electron densities have been scanned¹¹⁻¹²

Results

Both CT and conventional X-rays take pictures of internal body structures. In conventional X-rays, the structures overlap. For example, the ribs overlay the lung and heart. In an X-ray, structures of medical concern are often obscured by other organs or bones, making diagnosis difficult. In a CT image, overlapping structures are eliminated, making the internal anatomy more apparent. CT images allow radiologists and other physicians to identify internal structures and see their shape, size, density and texture. This detailed information can be used to determine a medical problem as well as the extent and exact location of the problem, and other important details. The images can also show if no abnormality is present. A CT scan that shows no abnormality still provides useful data. The information aids a diagnostician by focusing attention away from unnecessary medical concerns.

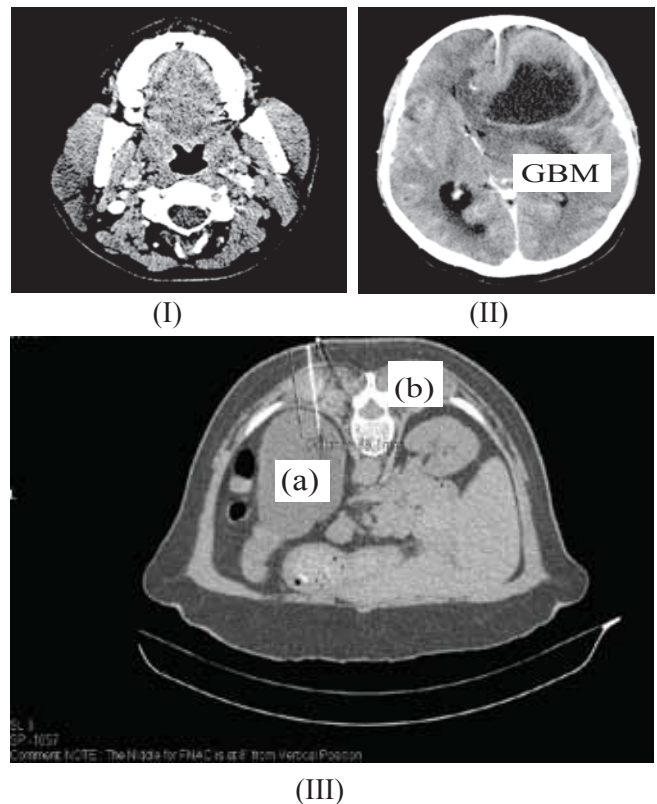


Fig 13: The results of image formation, after the replacement and calibration of the misaligned detectors, at the gantry of the CT scanner. (I) refers to an image of heterogeneous structure of anatomy, (II) shows a sharp glioblastoma multiforme (GBM) with no artifact and (III) refers to the insignificant artifact visualization of a fine needle at an FNAC, fine needle aspiration cytology, image at the proximity of a lead (Pb) marker at the anterior position

Artifacts generated due to the faults of misaligned detectors as shown in Fig 12(c) has been corrected by the Siemens' technician resulting in the Figures of 13 (I, II and III) providing acceptable images, even with a better quality, as observed in the image of GBM (Glioblastoma multiforme).¹³

Modern CT scanners acquire this information in seconds, sometimes in fractions of a second, depending on the examination. An experiment, in finding the cause of artifact in the CT scanner of Delta Hospital Ltd., has been depicted in Fig 12(c). Detection of the cause of artifact is described below.¹⁴

Discussion

Present study and Figures 12 a, b and c show very clearly the hazards of artifacts in producing an inaccurate and bad report in the diagnosis of abnormalities for patients. The confusion or error in a bad image can trigger a potential danger for a wrong treatment. It is imperative that a problem in an image should be identified and rectified immediately before diagnostic or planning reports are examined and finalized. It may be mentioned here that the artifacts, viewed in our image set of Fig 12(c), is due to two bad and imbalanced detectors in the CT scanner. This paper recommends that the cause of any artifacts is recognizable for its origin, in anatomical scanning, and correctable by physicist and CT engineer.

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