Al-Mustaqbal University College
Department of Medical Instrumentation Techniques Engineering
Class:Third
Subject: Medical Instrumentation (II)
Lecturer: Forqan Ali Wahhab
Lecture: Computed Tomography

1. Computed Tomography

- Computed tomography is commonly referred to as a CT scan. A CT scan is a diagnostic imaging procedure that uses a combination of X-rays and computer technology to produce images of the inside of the body.
- CT scans are more detailed than standard X-rays. In standard X-rays, a beam of energy is aimed at the body part being studied. A plate behind the body part captures the variations of the energy beam after it passes through skin, bone, muscle and other tissue. While much information can be obtained from a regular X-ray, a lot of detail about internal organs and other structures is not available.
- In CT, the X-ray beam moves in a circle around the body. This allows many different views of the same organ or structure and provides much greater detail.
- The X-ray information is sent to a computer that interprets the X-ray data and displays it in two-dimensional form on a monitor. Newer technology and computer software makes three-dimensional images possible.
- CT scans may be performed to help diagnose tumors, investigate internal bleeding, or check for other internal injuries or damage. CT can also be used for a tissue or fluid biopsy.
- CT scans are frequently done with and without contrast agent to improve the radiologist’s ability to find any abnormalities.

Email: forqan.ali.wahhab@uomus.edu.iq

Al-Mustaqbal University College
Department of Medical Instrumentation Techniques Engineering
Class:Third
Subject: Medical Instrumentation (II)
Lecturer: Forqan Ali Wahhab
Lecture: Computed Tomography

Fig1: Computed Tomography (CT) scan

Email: forqan.ali.wahhab@uomus.edu.iq

2. What Can CT Scans Detect?

A CT scan is a painless, non-invasive procedure that can be used to visualize nearly every part of the body. Since the introduction of CT technology in 1972 the imaging procedure first used in diagnosis has advanced with applications in disease prevention, screening, and management.

A CT scan is typically used when an X-ray cannot provide enough detail of an injury or disorder, especially in emergency situations where time is of the essence.

Among the many uses of a CT scan are:

1. **CT scanning of the abdomen** may be used to identify masses in the liver, kidney, or pancreas, or to search for causes of bleeding in the urinary tract (hematuria).
2. **CT scanning of the cardiovascular system** can be used to map the flow of blood (CT angiography) and to help to diagnose kidney disorders, aortic aneurysm, atherosclerosis, or pulmonary edema.
3. **CT scanning of the heart** can help diagnose and monitor coronary artery disease (CAD) or aid in valve replacement surgery.
4. **CT scanning of the head** and brain may be used to look for tumors, hemorrhage, bone trauma, blood flow obstruction, and brain calcification (commonly seen in people with Parkinson's disease and dementia).
5. **CT scanning of the lungs** can help detect changes in the lung architecture as a result of fibrosis (scarring), emphysema, tumors, atelectasis (collapsed lung), and pleural effusion.

Email: forqan.ali.wahhab@uomus.edu.iq

6. **CT scanning of the skeletal system** can aid in the diagnosis of a spinal cord injury, pathologic fractures, bone tumors, or lesions, and to help evaluate a complex fracture, osteoporosis, or joint damage caused by arthritis.

3. *What are the risks of a CT scan?*

(For Females) If you are pregnant or think you may be pregnant, you should notify your health care provider. The amount of radiation dose used in a CT scan is small. You may want to ask your doctor about the amount of radiation used during the CT procedure and the risks related to your particular situation. If you are claustrophobic or tend to become anxious easily, tell your doctor ahead of time. You may be prescribed a mild sedative to take before the procedure to make you more comfortable.

4. *Part of CT Scan machine:*

1. *Gantry*

The CT gantry contains all devices that are required to record transmission profiles of a patient, since transmission profiles have to be recorded under different angles these devices are mounted on a support that can be rotated.

On the rotating part of the gantry are mounted for example:

• the X-ray tube, the detector, the high voltage generator for the X-ray tube, the (water or air) cooling of the X-ray tube, the data acquisition system, the collimator, and the beam shaping filters.

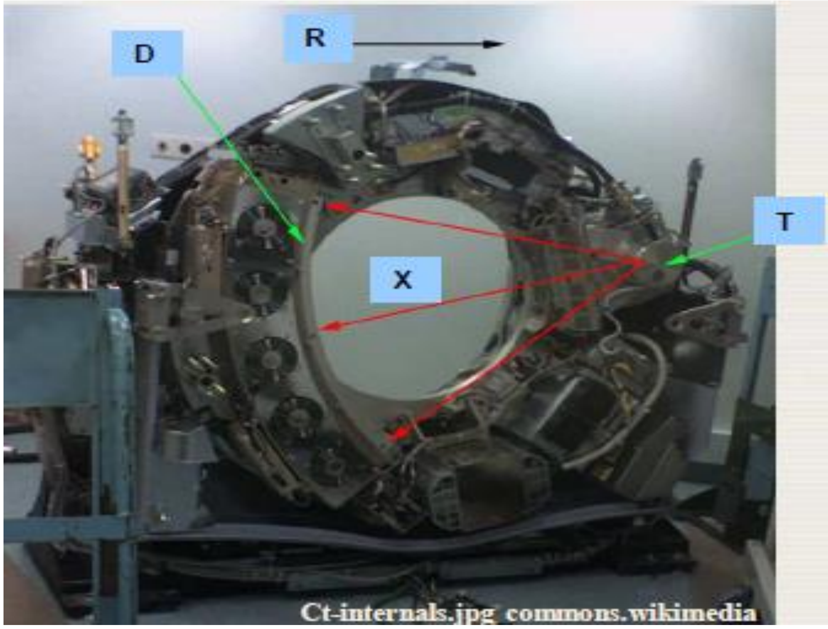
Al-Mustaqbal University College
Department of Medical Instrumentation Techniques Engineering
Class:Third
Subject: Medical Instrumentation (II)
Lecturer: Forqan Ali Wahhab
Lecture: Computed Tomography

T X-ray tube

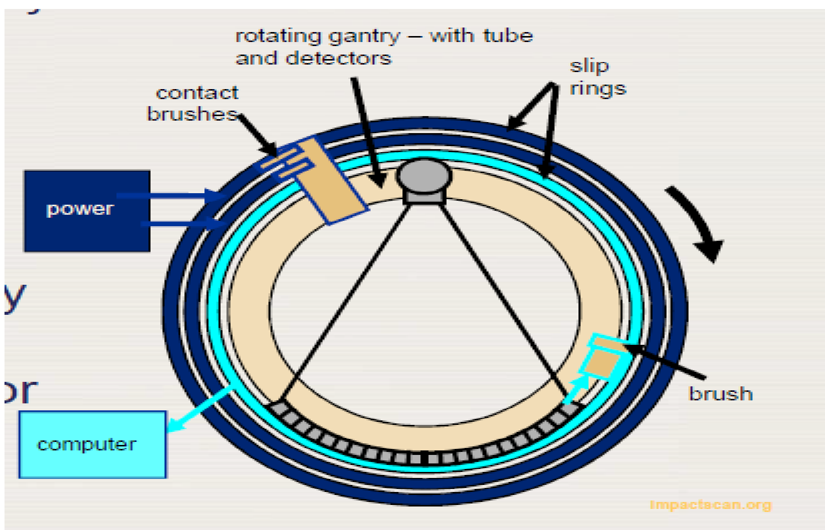
D X-ray detectors

X X-ray beam

R Gantry rotation



- Electrical power is generally supplied to the rotating gantry through contacts (brushes) from stationary slip rings.
- Projection profiles are transmitted from the gantry to a computer usually by wireless communication (or slip ring contacts).

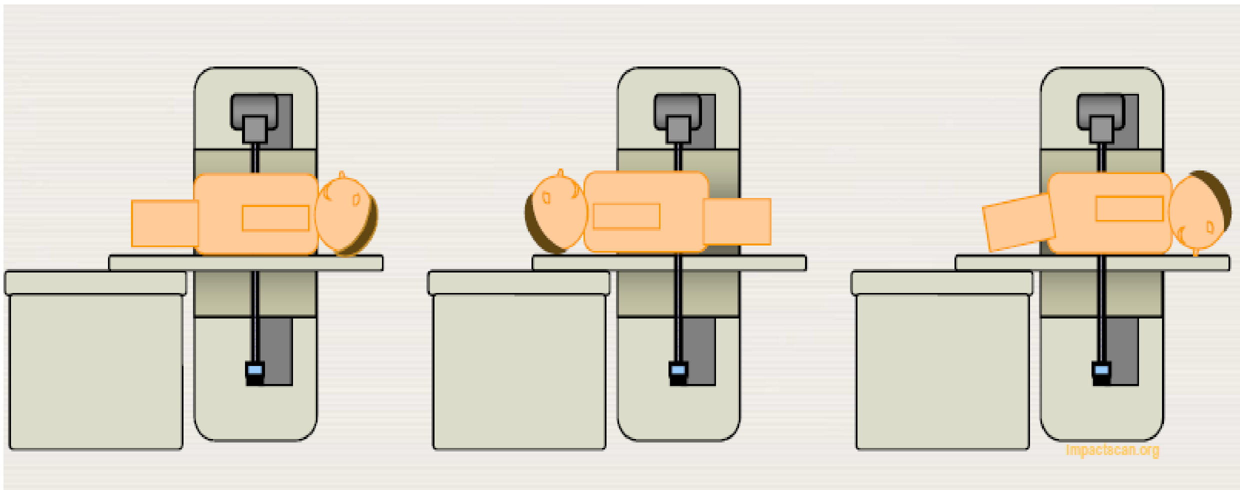


The position of the patient on the table can be

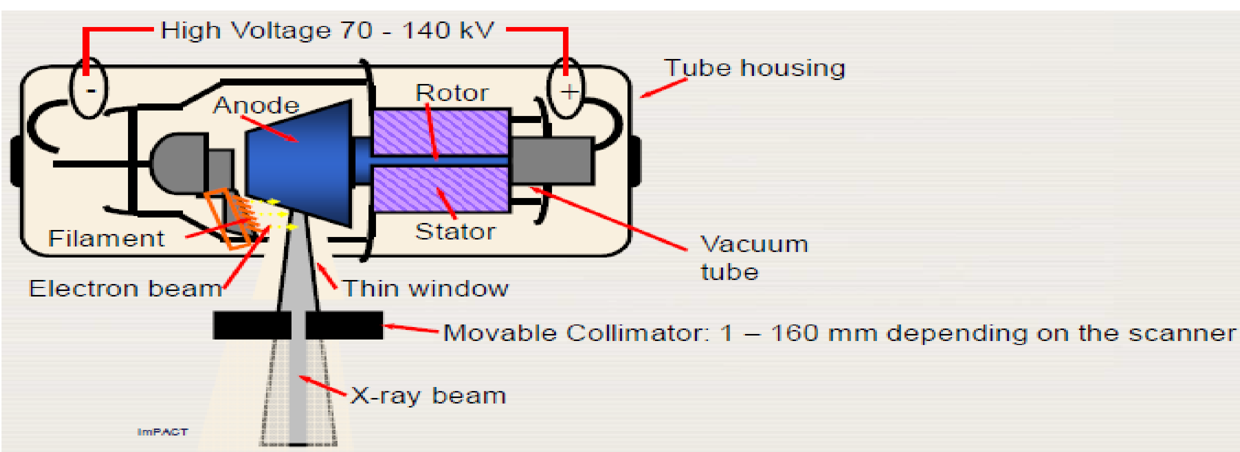
• head first or feet first

• supine or prone

The position is usually recorded with the scan data.



- An x ray tube (with a rotating tungsten anode) and high voltage generator are used for generating the x ray beam.
- The beam is collimated to create the ‘dose slice’ (or’cone’)



Beam shaping filters are being used to create a gradient in the intensity of the X-ray beam

• They are sometimes called “bow-tie” filters

• They are mounted close to the X-ray tube.

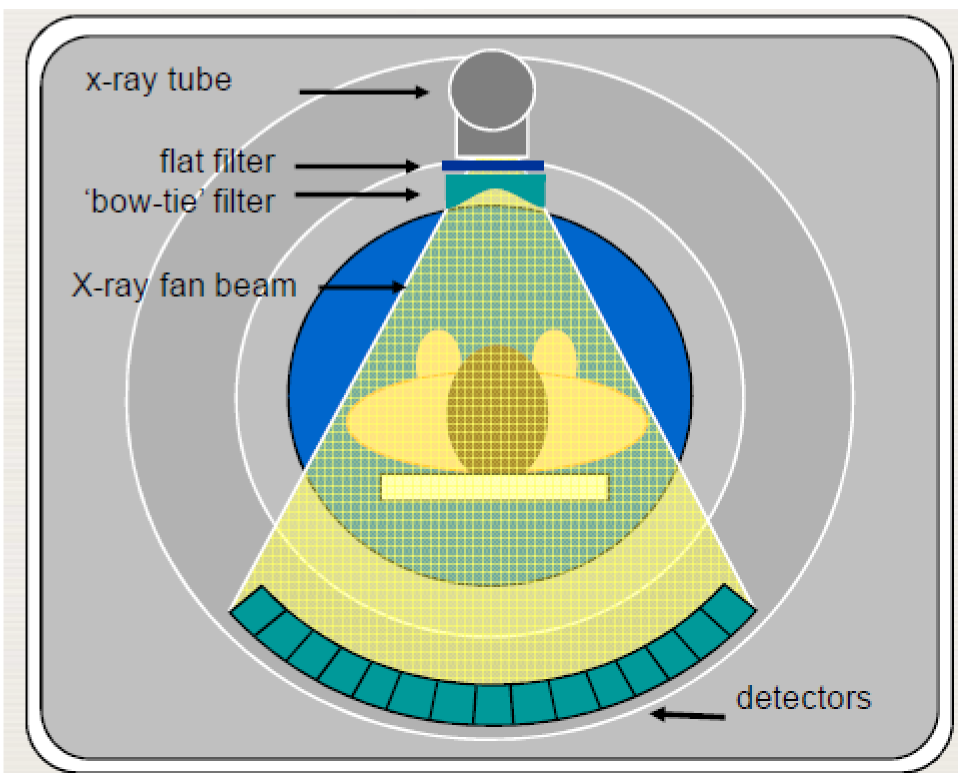
The purpose of the beam shaping filter is to:

• reduce the dynamic range of the signal recorded by the CT detector.

• Reduce the dose to the periphery of the patient

• Attempt to normalise the beam hardening of the beam – to aid with calibration.

Schematic figure showing the fan beam, flat and beam shaping (‘bow-tie’) filters.

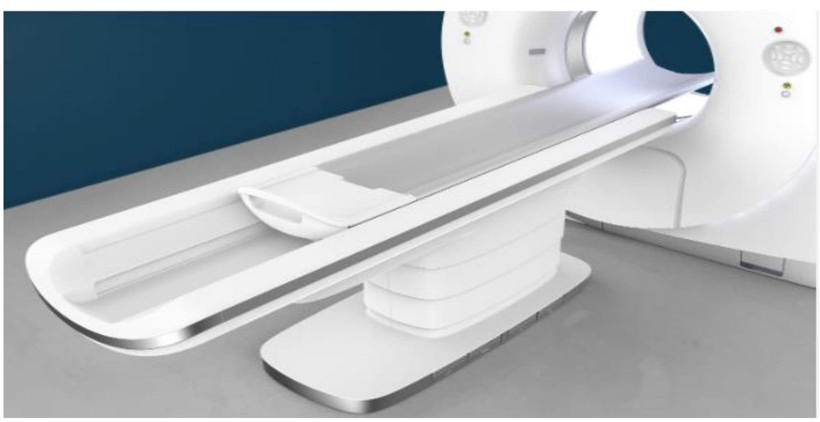


- Collimator is a device used to minimize the field of view , avoid unnecessary exposure using lead plates. Lead shutter are used to restrict the beam. The collimator is attached to the X-ray below the glass window where the useful beams is emitted.

- CT scanners include two types of collimators, the source collimator (also called a diaphragm) and the detector collimator (also called a grid). The diaphragm configures the X-rays produced by the X-ray tube into a beam shape.

2. *Patient Table*

The patient's table moves through the gantry during the scan. The distance the table moves during a complete rotation of the gantry is referred to as the table pitch or detector pitch. Table pitch equals the forward table movement in millimeters (mm) during a complete gantry rotation divided by beam collimation (the slice thickness in mm). Faster moving tables are described as having greater pitches. Increased table speed reduces scanning time and radiation but also can reduce image resolution if the circuitry of the machine cannot process the information as quickly as the table moves.



5. ***How does CT Scan work?***

The CT scanner machine rotates the X-ray tube around the patient's body through a circular structure known as the gantry. Each time the machine rotates, computerized information is acquired. The patient is slowly moved up or down in the table, and different cross-section images are produced. In each rotation, a 2D image slice is constructed. Each subsequent image slice's thickness is decided on the operator and the physician/radiologist's request but usually ranges from 1 to 10 millimeters. The gantry can be moved at the desired angle to accommodate the best cross-sectional image. When the desired number of slices are obtained, a scan is reproduced into the computer image and can easily be reproduced and stored. The image is created using pixels according to its radiosensitivity and is displayed using the Hounsfield scale units, which are compared to known tissue density. Water is 0, while air is negative 1000, and bone is positive 400 to 2000. Intravenous iodine can be injected into the bloodstream to demarcate blood vessels, tumors and identify infectious processes. Intravenous iodine-based or oral barium-based contrast is used to visualize the digestive system. The images can be computer-tacked together to produce a 3D image of the area of interest. The CT scans are obtained in the cranial direction, meaning from feet to head. It is important to note that current CT machines display the image opposite the patient's side as the image is produced as viewed from the patient's foot. Thus the right side of the image is the patient's left side.

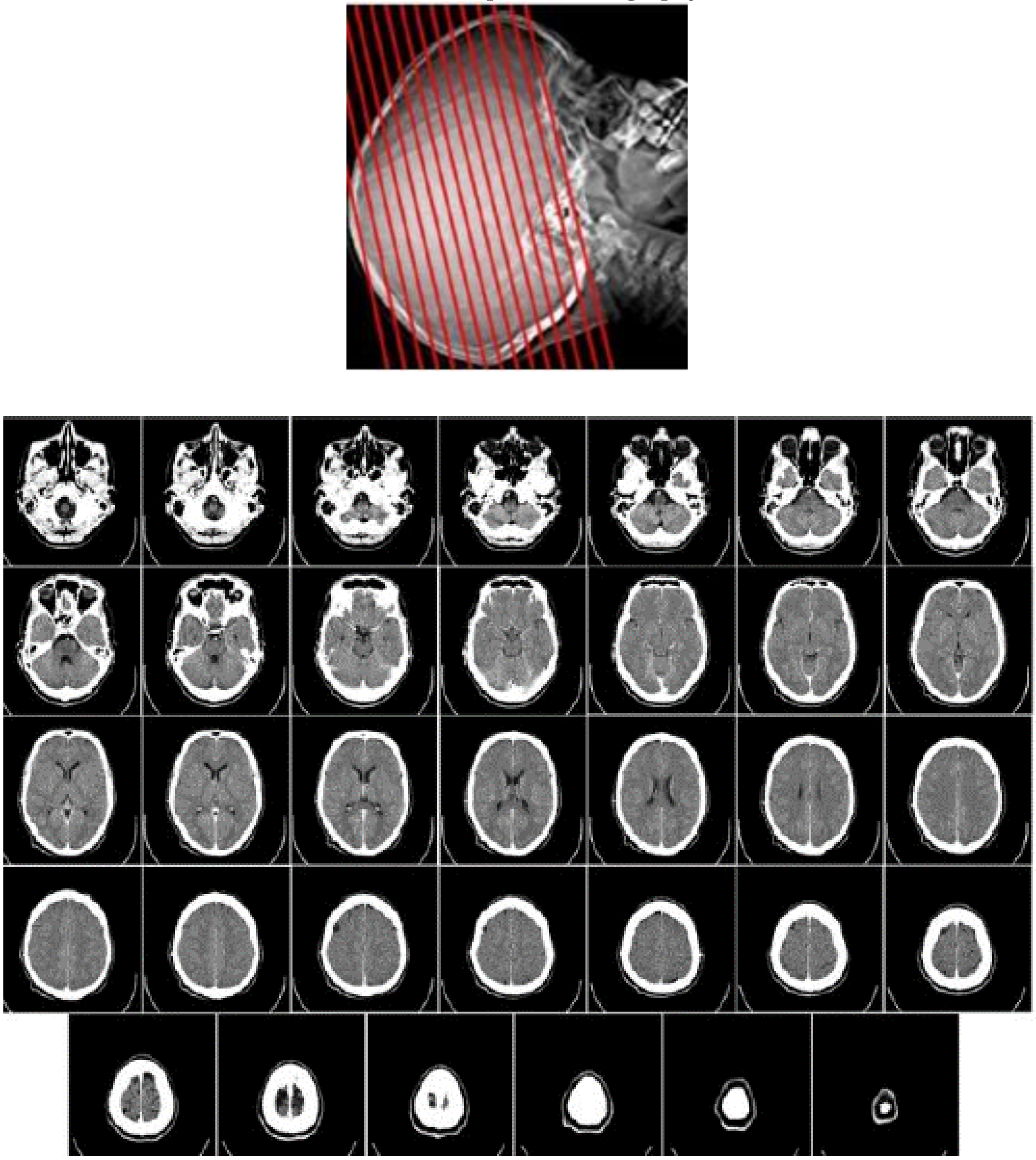
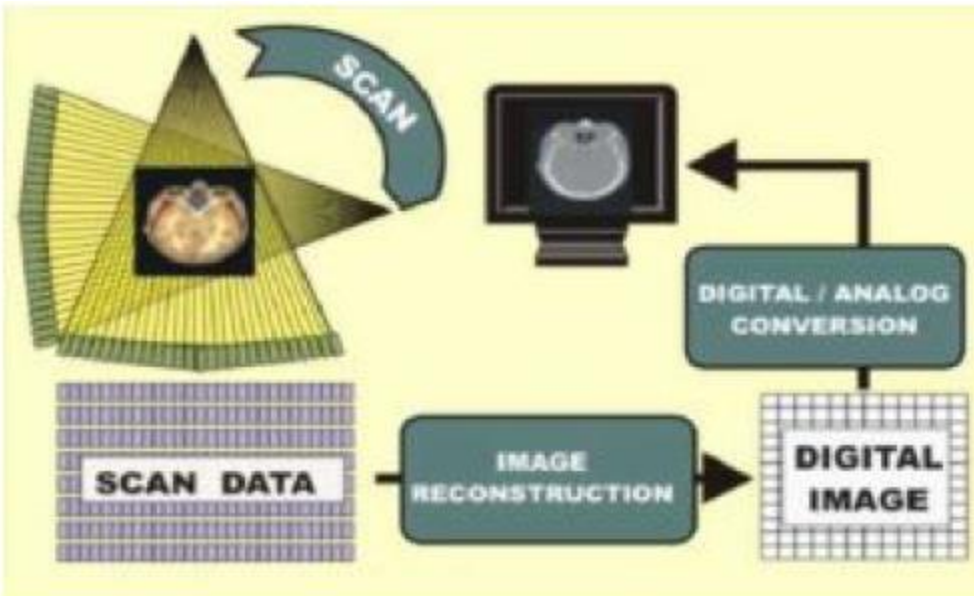


Fig: CT scan of the head

There are three steps of taking a CT scan, as follows:

1. Data Acquisition

2. Image Reconstructions
3. Image Display



6. CT Generations

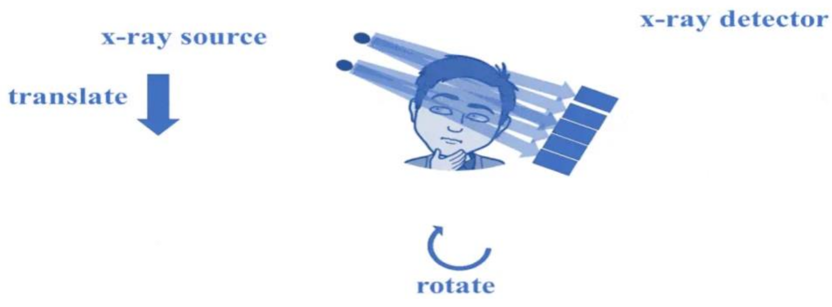
1st Generation:

In first generation CT scanners, there was one X-ray source and one X-ray detector. So, in order to acquire an axial image of the patient, one ray would go through body of patient and be measured using a single detector. The x-ray source and the detector moved together to collect the data. In order to reconstruction one slice the x-ray source would have to translate many times for each view. Then the source and tube were rotated with respect to the patient (or another object being imaged).

2nd Generation:

Second generation CT was a refinement on first generation CT but still using the same general concepts. The translate and rotate acquisition was still used but while 1st generation CT had only one x-ray source and detector, in 2nd generation CT there was a small fan beam appeared that enabled more coverage than just one detector (5-53 detectors at a time).

Second generation CT was significantly faster taking an average exam from a significant fraction of an hour to the order of minutes. An average scan during on this system was ~1.5 minutes. Each slice went from taking 5 minutes on 1st generation to as low as 20 seconds on 2nd generation.

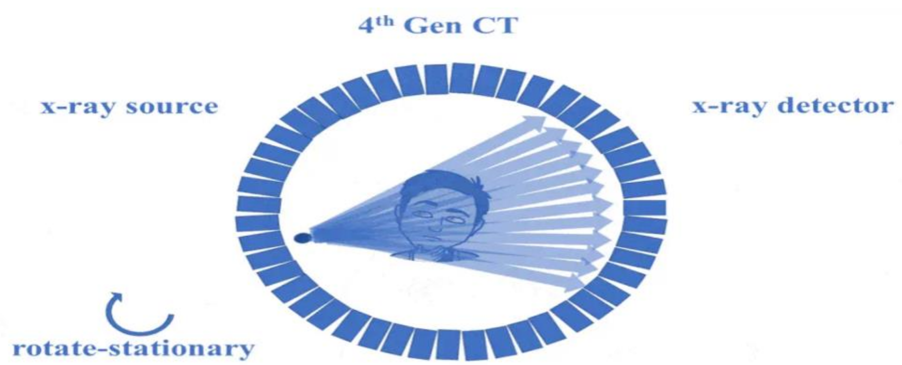


3rd Generation:

Then a significant improvement was again made going from 2nd generation CT to 3rd generation CT where the translation of source within each view was eliminated by having a fan-beam shaped x-ray beam acquiring all the data (for a slice) within each view.This acquisition mode can be termed rotate-rotate as both the x-ray source and x-ray detector are rotating together. Using a rigid ring the x-ray tube and detector can be mounted such that they rotate around the patient.

4th Generation:

The 4th generation CT geometry is considerably different from 3rd generation geometry in that the x-ray detectors surround the entire circle (much like a P.E.T. detector).

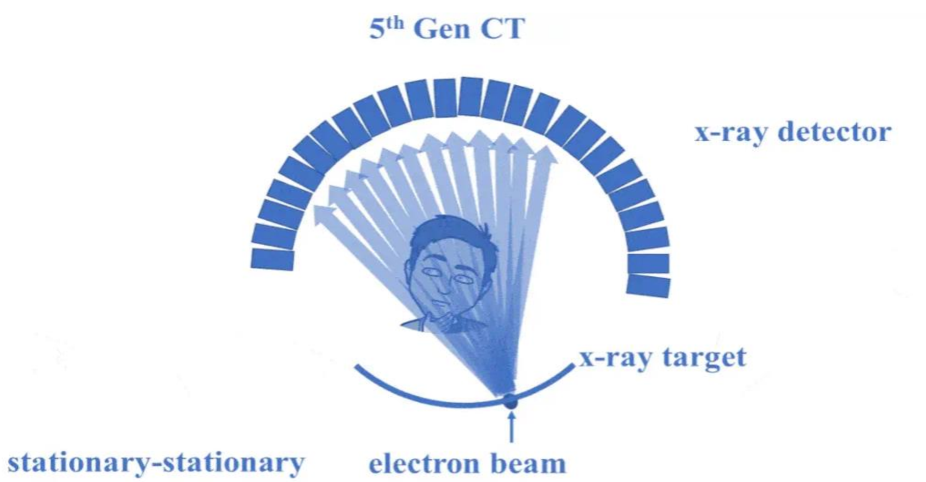


5th Generation:

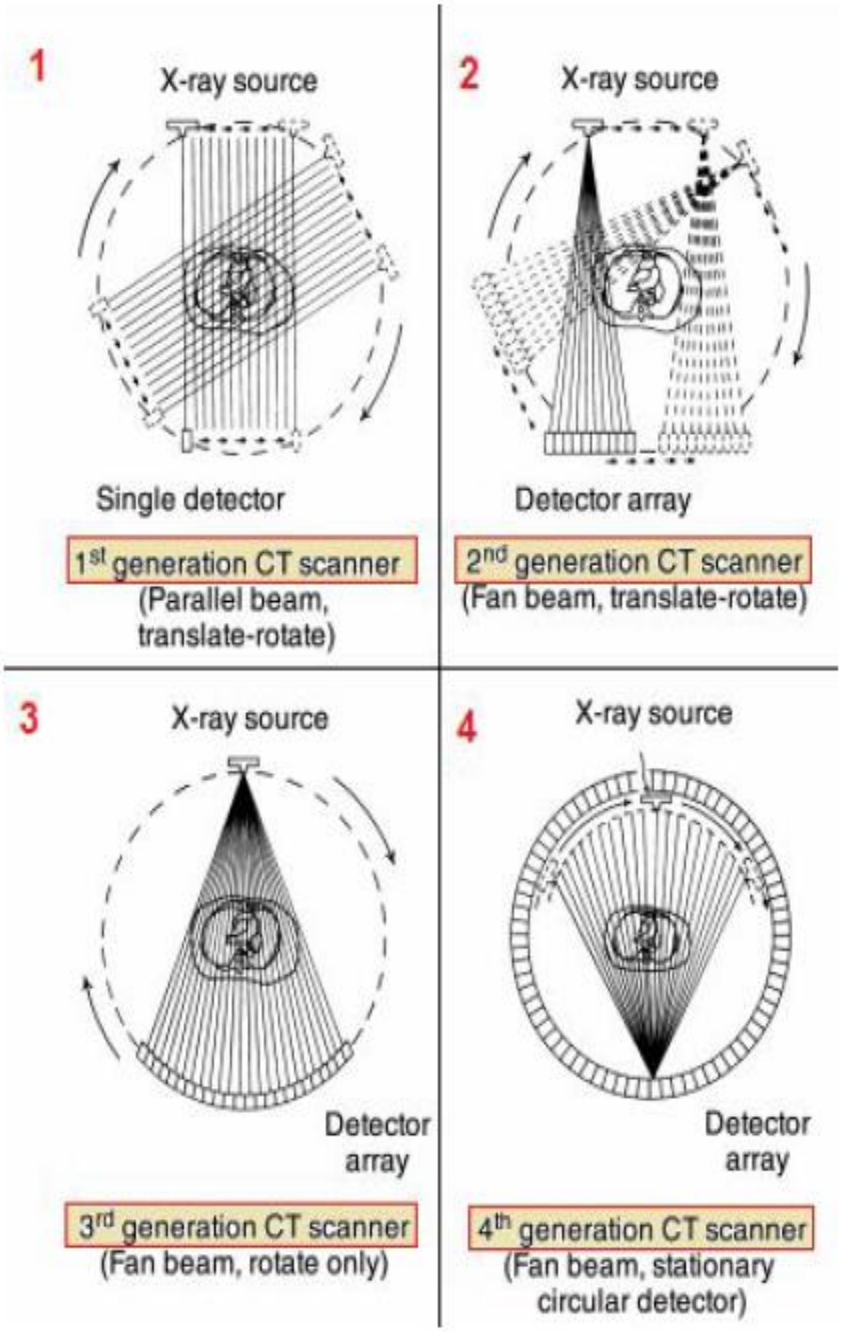
The final generation of CT which is truly a different acquisition method is that of 5th generation CT. In all of the other methods above there is significant mechanical motion of the parts on the gantry.

In 5th generation CT both the x-ray source material and the detector are stationary. In this sense this is a stationary-stationary design.

The x-tube in this design is a scanning x-ray tube, where the electrons are steered magnetically (like in old TVs) rather than physically moving the x-ray tube. This method allows for very fast acquisitions and is ideal for cardiac scanning (with a temporal resolution of a given slice as low as 17ms).



Summary of the four generations of CT scans



7. CT artifacts: causes and reduction techniques

Email: forqan.ali.wahhab@uomus.edu.iq

Artifacts are commonly encountered in clinical CT and may obscure or simulate pathology. There are many different types of CT artifacts, including noise, beam hardening, scatter, pseudoenhancement, motion, cone-beam, helical, ring and metal artifacts. We review the cause and appearance of each type of artifact, correct some popular misconceptions and describe modern techniques for artifact reduction. Noise can be reduced using iterative reconstruction or by combining data from multiple scans. This enables lower radiation dose and higher resolution scans. Metal artifacts can also be reduced using iterative reconstruction, resulting in a more accurate diagnosis. Dual- and multi-energy (photon counting) CT can reduce beam hardening and provide better tissue contrast. Methods for reducing noise and out-of-field artifacts may enable ultra-high resolution limited field of view imaging of tumors and other structures.

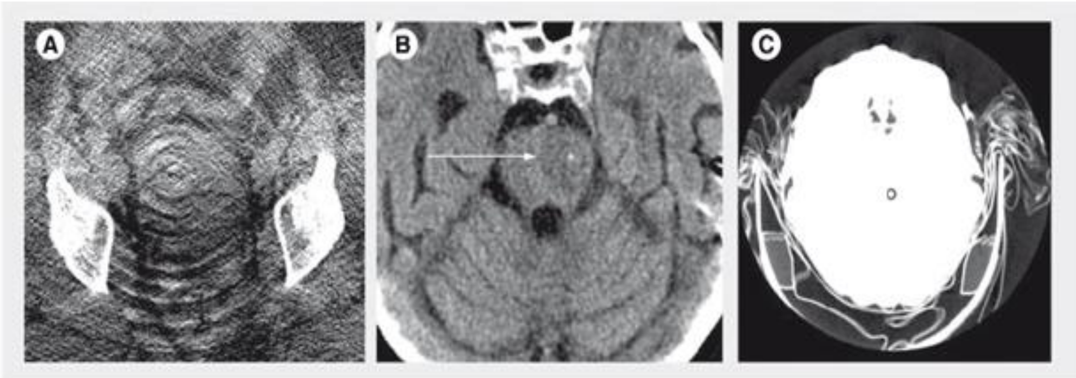


Figure 1. Ring artifact. (A) Pelvic CT showing severe ring artifact. **(B)** Head CT with subtle ring artifact simulating a pons lesion (arrow). **(C)** Changing the window/level settings shows the circular reconstruction region, which is centered at the center of rotation. The pons pseudolesion (marked with a small circle) is exactly at the center of the circular reconstruction region and thus consistent with a ring artifact. Follow-up MRI showed a normal pons.

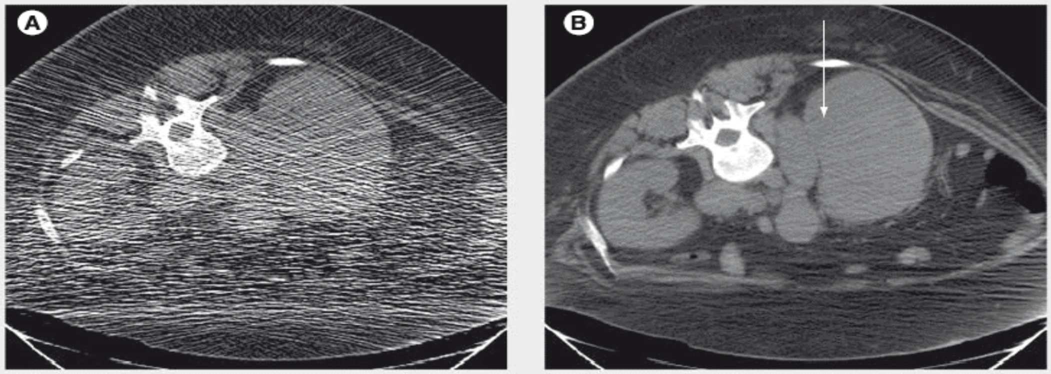


Figure 2. Effect of mA on Poisson noise. (A) Low-dose CT image obtained during a CT-guided biopsy shows extensive Poisson noise (60 mA, 120 kVp, slice thickness 5 mm). These streaks are the same whether or not the abdomen or arms are partially outside the field of view. **(B)** Postbiopsy image obtained at 7.3-times higher dose has $\sqrt{7.3} = 2.7$-times less noise (440 mA, 120 kVp, slice thickness 5 mm). The images show an enlarged retroperitoneal lymph node (arrow) and infiltration of the right kidney in a patient with Hodgkin's lymphoma.

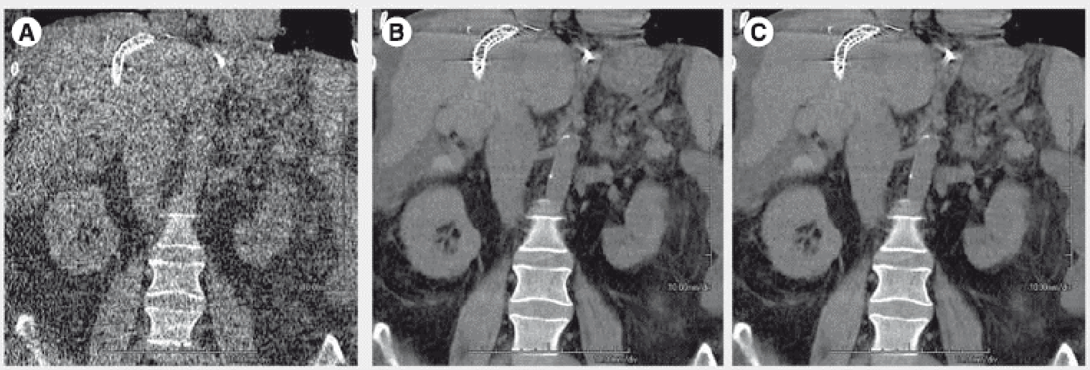


Figure 3. Iterative reconstruction reduces noise and improves image quality. (A) Filtered backprojection image obtained at low dose (50 mA) is extremely noisy. **(B)** Model-based iterative reconstruction of the same low-dose scan (50 mA) has dramatically reduced noise, revealing new soft-tissue details. In particular, note the nodular cirrhotic liver and the details in the right renal hilum. **(C)** A higher dose (754 mA) filtered backprojection image confirms the details in the model-based iterative reconstruction image.
Modified with permission from [4].

Al-Mustaqbal University College
Department of Medical Instrumentation Techniques Engineering
Class:Third
Subject: Medical Instrumentation (II)
Lecturer: Forqan Ali Wahhab
Lecture: Computed Tomography

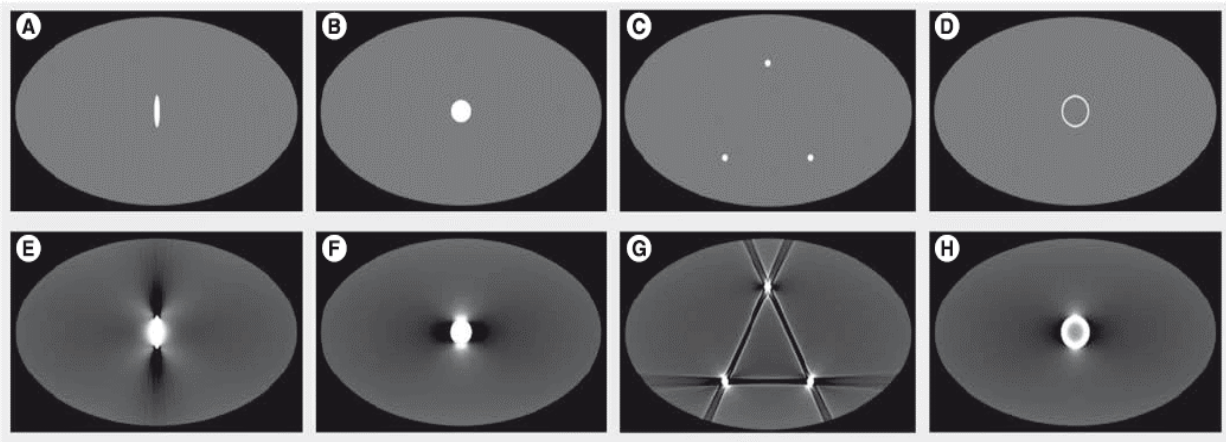


Figure 4. Beam hardening in simulated scans. (A–D) Simulated scans without and **(E–H)** with beam hardening, showing that dark streaks occur along the lines of greatest attenuation, and bright streaks occur in other directions. Scatter produces artifacts that look similar to this. Also note the subtle decrease in Hounsfield units just beneath the surface of the 'abdomen', which is caused by beam hardening. This is called cupping artifact and it is corrected by the simple beam hardening correction built in to modern scanners.

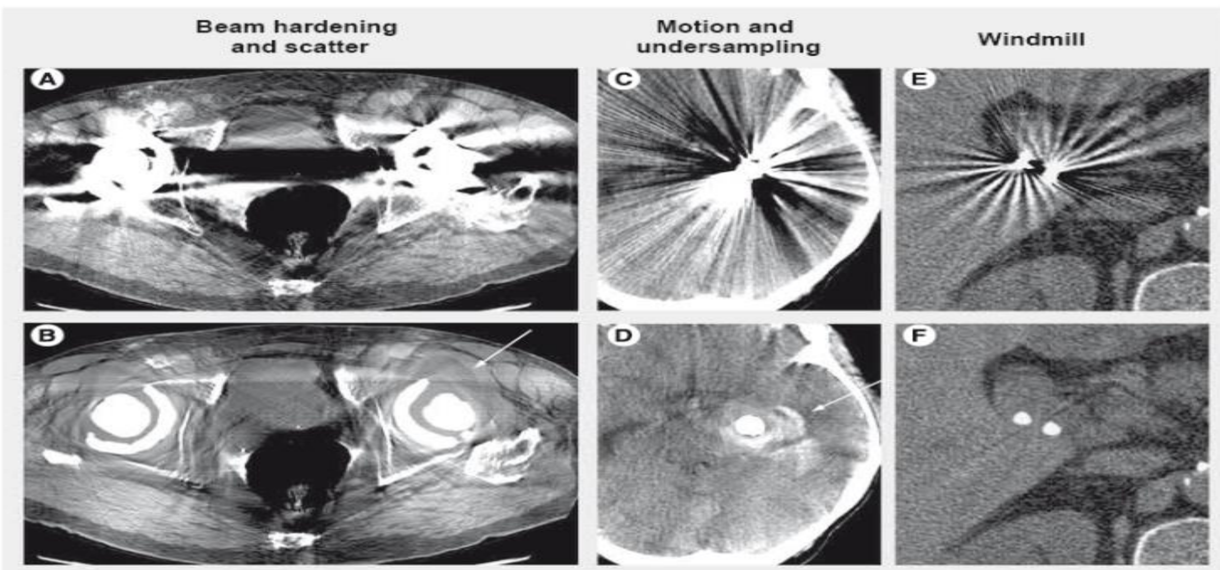


Figure 5. Metal Deletion Technique reduces many different types of metal artifacts, and can reveal new findings. (A) Dark streak between hip replacements is mostly due to beam hardening and scatter. **(B)** The Metal Deletion Technique image more clearly shows a fluid collection adjacent to the left hip replacement. **(C)** Sharp, thin alternating streaks surrounding an aneurysm coil are mostly due to motion and undersampling. **(D)** Metal Deletion Technique image reveals hemorrhage around the coil. **(E)** Smoothly undulating streaks around cholecystectomy clips are due to windmill artifact. **(F)** Metal Deletion Technique reduces this artifact.

Email: forqan.ali.wahhab@uomus.edu.iq

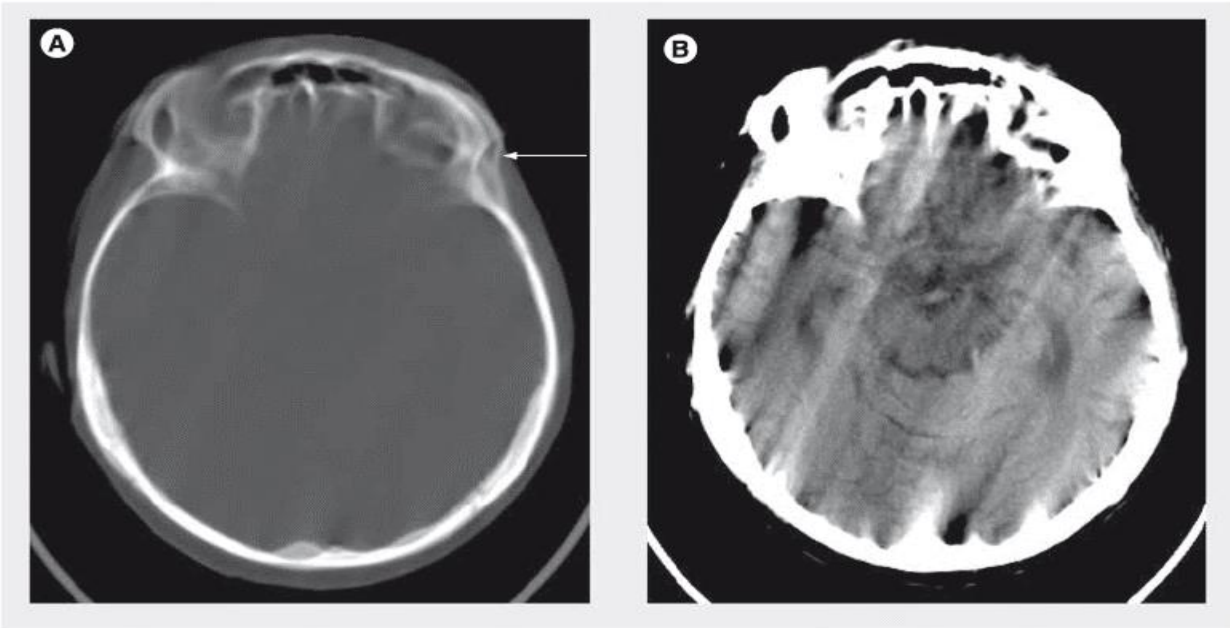


Figure 6. Motion artifact in a head CT. (A) Motion causes blurring and double images, **(B)** as well as long range streaks.