جامعة الانبار
كلية العلوم التطبيقية – هيت
قسم الفيزياء الحياتية

الاجهزة الطبية
Computed Tomography

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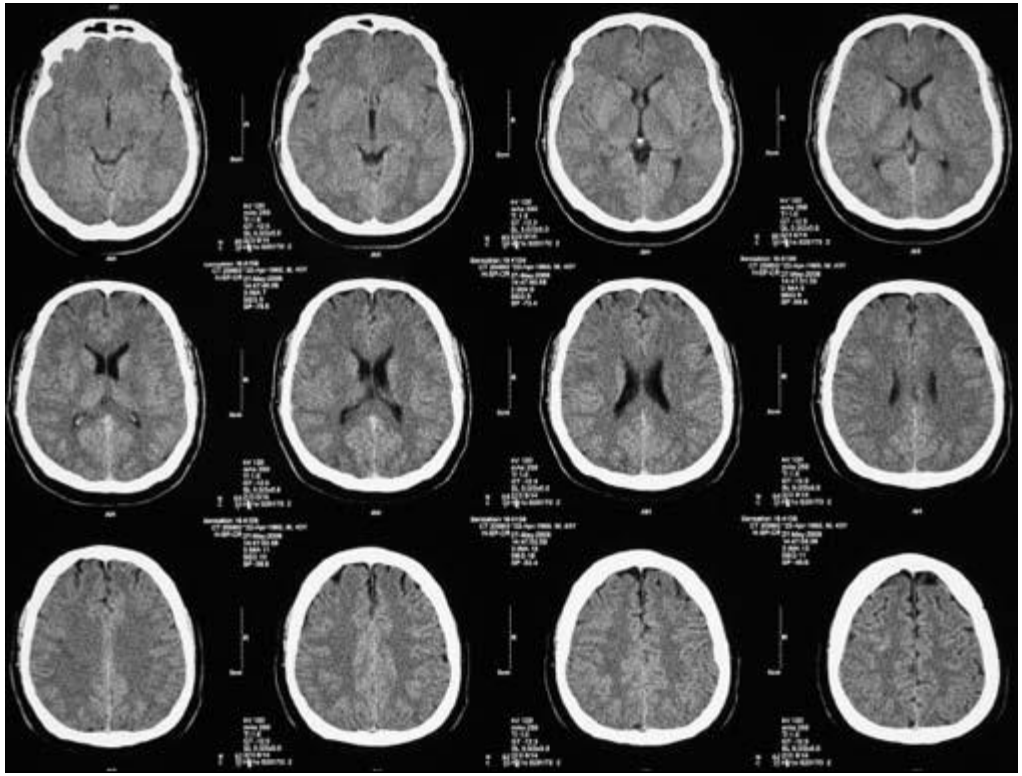
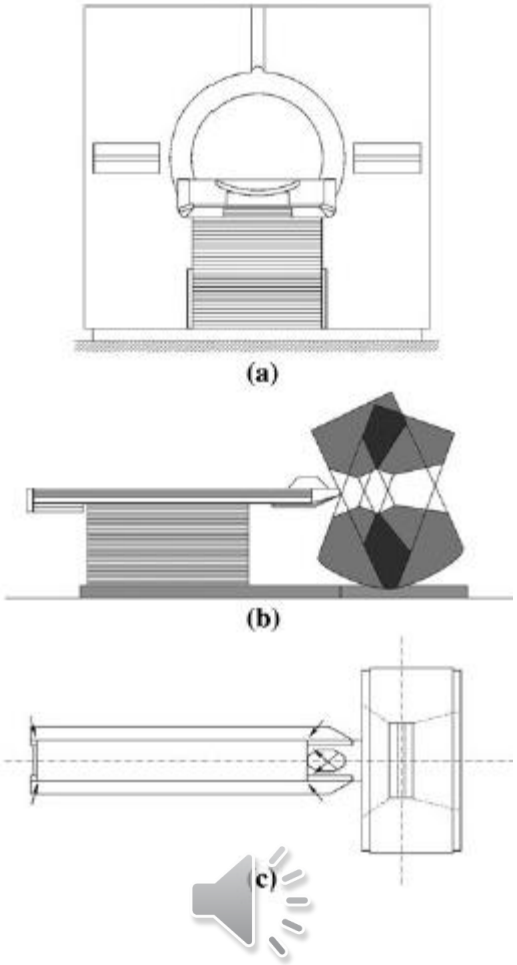
Computed Tomography

- X-ray based imaging method
- Main feature: sectional imaging rather than projection imaging



Computed Tomography Components

- **Gantry** with a central opening, into which the patient is moved during the examination.
- **X-ray tube**, the source of the X-rays that pass through the body situated in the gantry in the form of a series of projections;
- **Detector** array converts the projection values, in the form of radiation intensities, into electrical quantities. Usually, the whole detector array rotates synchronously with the X-ray tube around the test object
- **Table** allows the patient to be maneuvered easily into position



CT Scanner Design

One of three basic tube-detector projection systems

1. A projection system using a parallel beam of radiation

   Parallel-beam system

2. A system using a beam of radiation in the shape of a fan

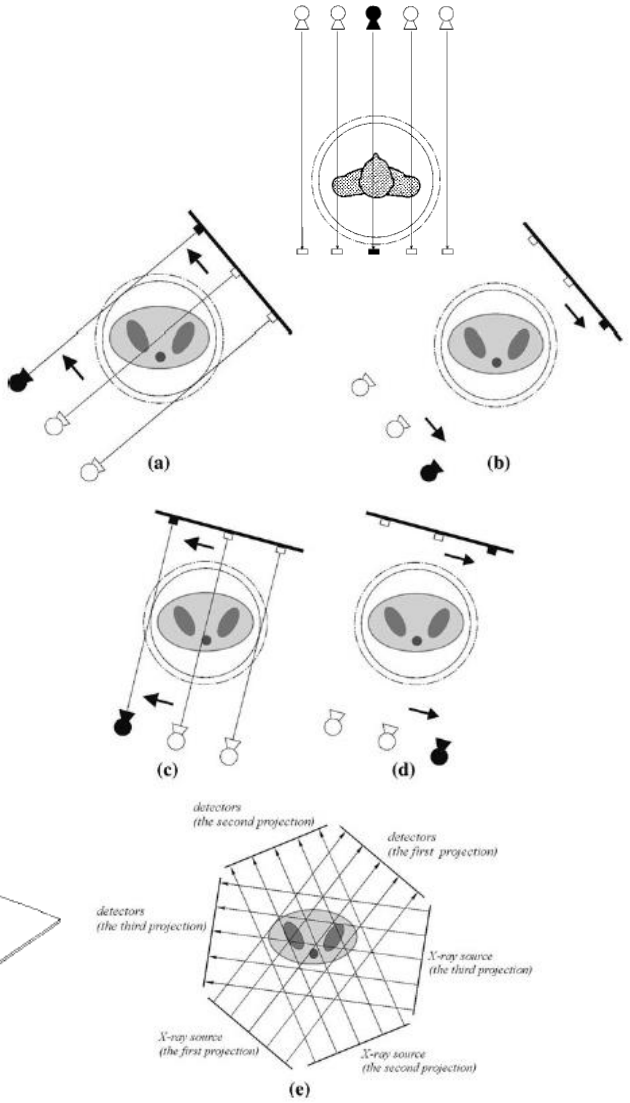
   Fan-beam system

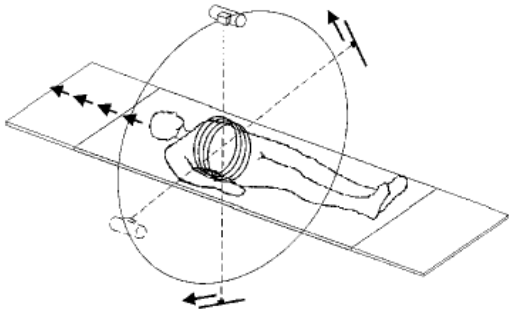
3. A system using a beam of radiation in the shape of a cone

   Cone-beam system

First-Generation CT Scanners

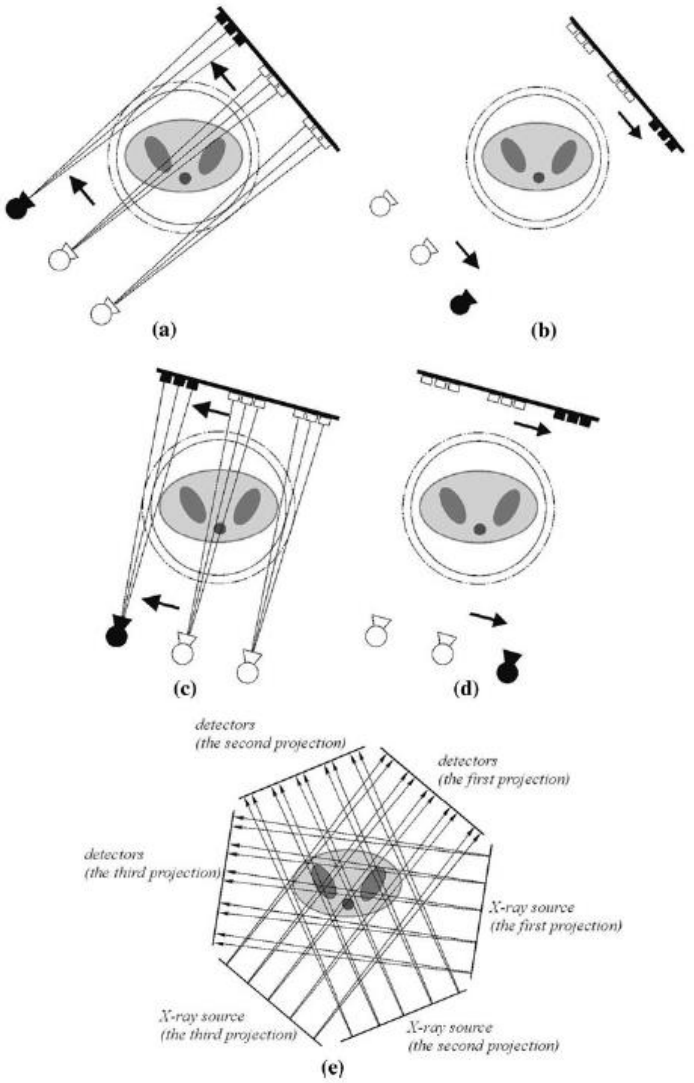
- Pencil beam or translation/rotation single detector CT scanners
  - belong to the parallel-beam projection system
- Two components to the movement of the rigidly coupled tube-detector system
  - lateral movement to make a single projection
  - circular movement about the central opening in the gantry to gather all projections necessary to form the image
- Very slow (5 min/slice)





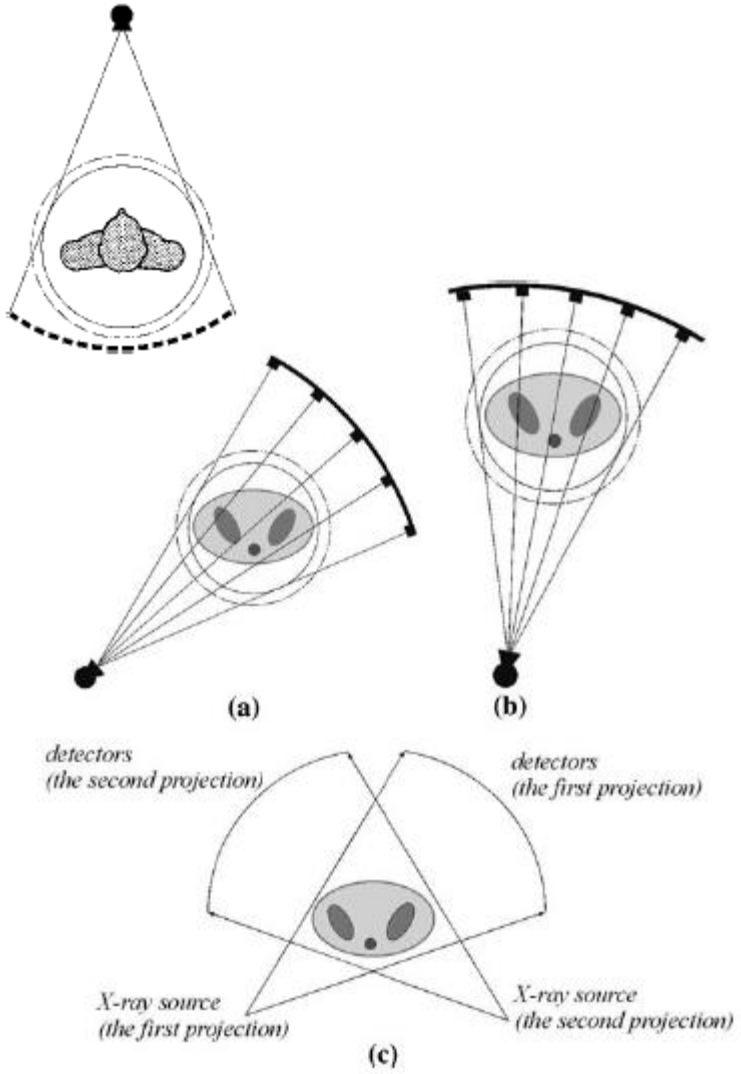
Second-Generation CT Scanners

- Partial fan beam or translation/rotation multiple detector scanners
- 3-52 detectors in the array
  - enable the projections to cover a larger area of the patient's body at any one time
  - results in reduction of number of projections needed to reconstruct an image
  - Faster!



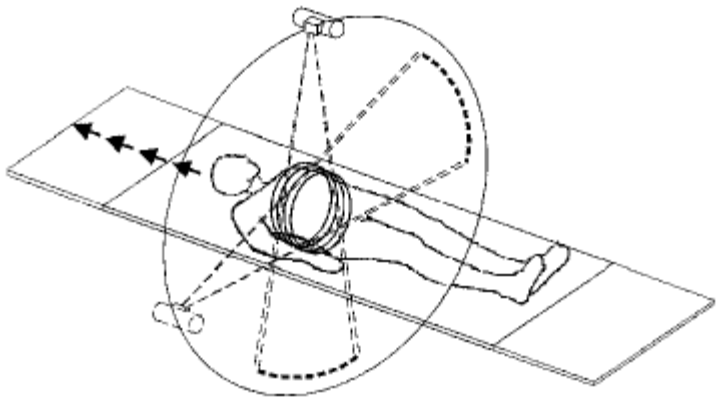
Third-Generation CT Scanners

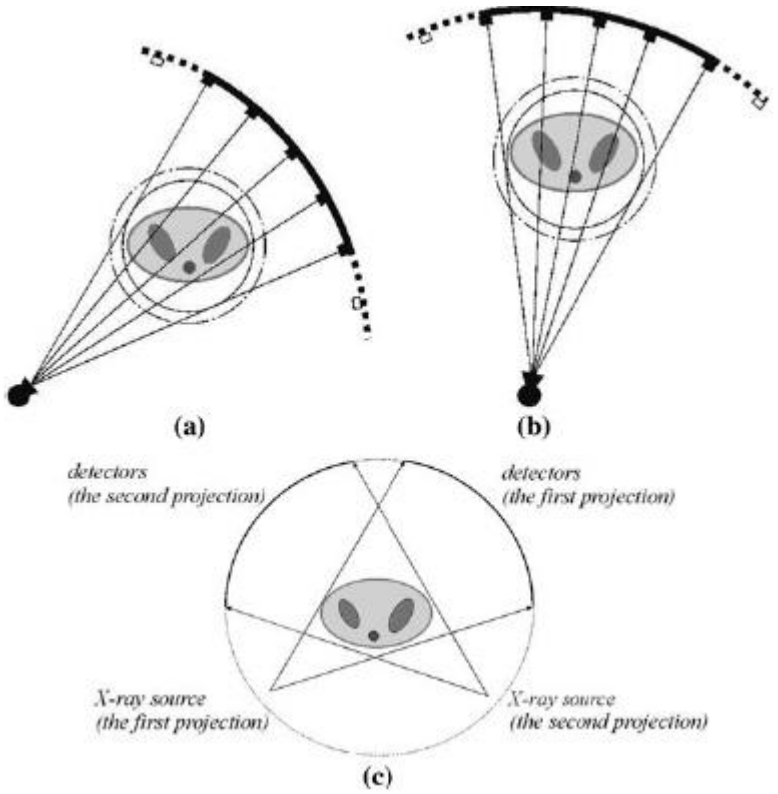
- Elimination of lateral movement of tube-detector system
- Fan-beam or continuous rotation scanner
  - Fan beam of radiation (40-55 degrees) to encompass whole object
- Increase number of detectors in the array moving synchronously with rotating X-ray tube (up to 1,000 detectors)
- Much faster: 5 s/slice



Fourth-Generation CT Scanners

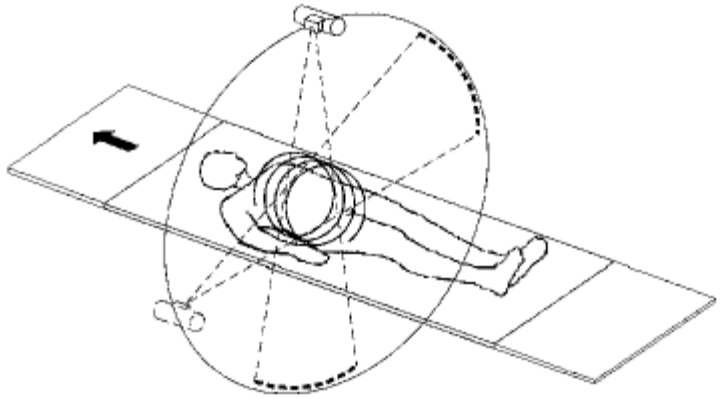
- Differ only slightly from the third generation
  - Rotation of the detector array is eliminated by arranging it on a stationary ring
  - “Rotate-fixed” scanner

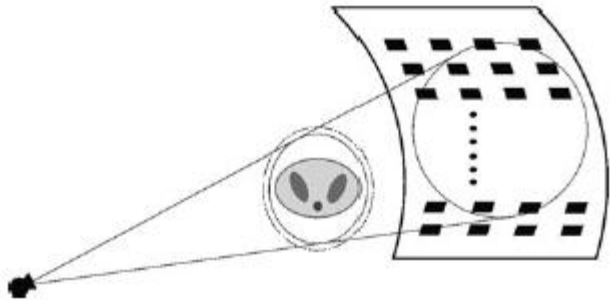




Spiral Scanners

- Fan beam scanning + table motion
- Single-slice spiral CT scanner (SSCT)
- Multi-slice spiral CT (MSCT)
  - 8-34 rows of detectors
- Cone beam spiral CT (CBCT)
  - possible to increase width of detector array to 16 or even 320 elements
  - Allowing simultaneous acquisition of up to 256 adjacent image slices
  - No collimation losses: less x-ray power
  - Faster, higher resolution scanning





Hounsfield Units

- It is common practice in medical applications to use units on the Hounsfield scale: Hounsfield units (HU) .
  - Value usually varies in the range -1,000 (air) to 3,000 (bone), making it necessary to apply a so-called window (center C and width W).

$$\text{CT number} = 1000\frac{(\mu - \mu_w)}{\mu_w}$$

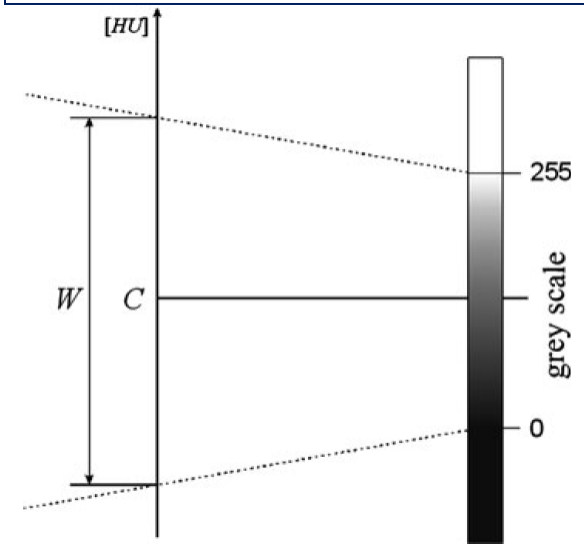
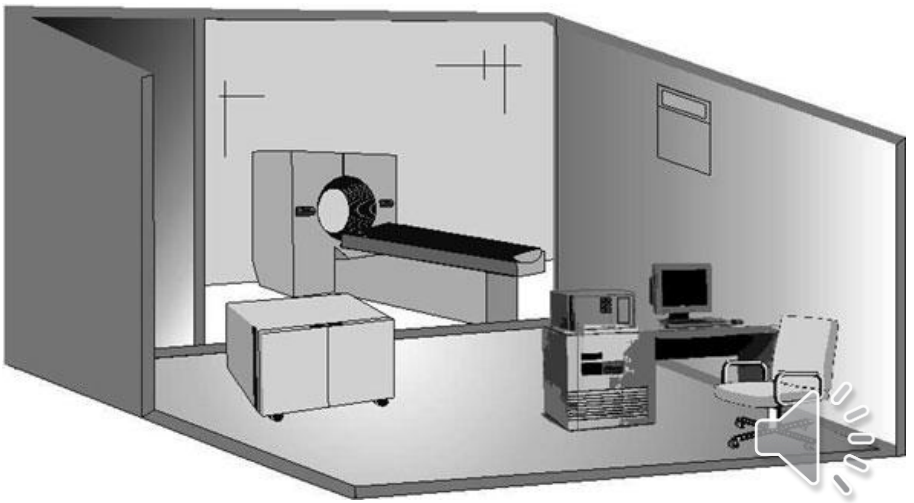


Fig. 3.41 The same slice viewed with different values of window parameters: the left image with the pulmonary window ($C = -600$, $W = 1,600$), the right image with the mediastinal window ($C = 50$, $W = 350$)

CT Installation

- CT room must meet several requirements
  - it must have floors with adequate load-carrying capacity
  - its walls must be constructed of X-ray absorbing material (this is usually a barium (Ba) plaster)
  - the floor should be lined with material that is both anti-slip and antistatic
- Separate rooms for CT scanner and radiographers;
  - Separated by special protective window-glass (containing lead, Pb)

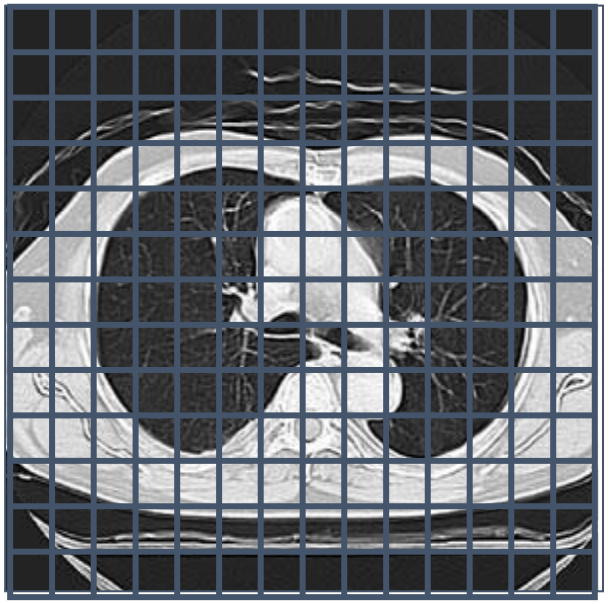


CT Scanner Physical Elements

- A CT scanner consists of the following main elements
  - a data acquisition system that carries out the X-ray projections
  - a computer to reconstruct the images from the projections and to assist in the analysis of the reconstructed images
  - a variable power supply
  - a monitor to display the routine operation of the computer system and to act as an interactive interface in the diagnosis of reconstructed images
  - a documentation camera to produce an image on film similar to traditional X-ray images
  - other data archiving systems, such as tape or disk, collectively referred to as storage devices

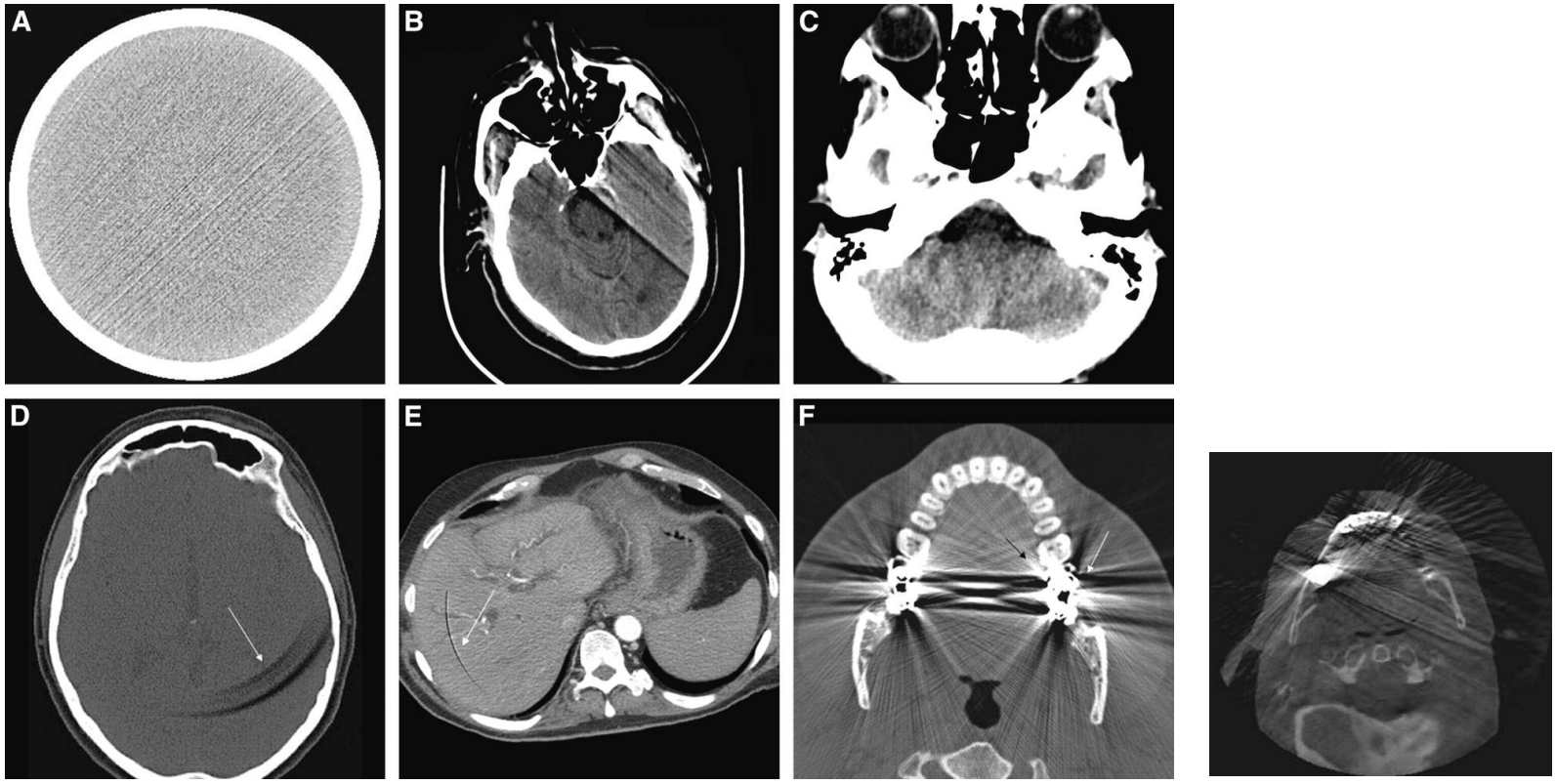
Image Reconstruction Problem

- For an $N \times N$ image, we have N^2 unknowns to estimate
  - Sufficient equations must be available
  - In most cases the problem can be formulated as a linear system
  - Simplest case when the acquired data correspond directly to the image points (i.e., diagonal linear system matrix), e.g., ultrasound imaging.



CT Image Artifacts

- Examples of CT artifacts: Streak artifact: scattering (A), motion artifact: motion (B), beam-hardening artifact high attenuation materials besides low attenuations surroundings (C), ring artifact: mis-calibrated detectors (D and E), and bloom artifact: stents and calcium to appear larger than they are(f)



Evaluation of CT Devices

- The final CT image is produced as a result of a whole chain of processes and is affected by a range of **factors**
  1. Technical parameters of the scanner
  2. Type of projection system
  3. Type of reconstruction algorithm applied

- Assessment of the physical and technical capabilities of CT scanners is made possible by the establishment of standardized, quantitative, comparative criteria.

Technical Parameters of CT Devices

- **Cycle Time:** The total time taken to scan and reconstruct the image
  - The smaller the cycle time, the greater the chance of avoiding the creation of artifacts caused by **patient movement**, including **physiological movements** such as the **beating heart** or **chest movements while breathing**

Technical Parameters of CT Devices

- **Spatial Resolution:** The minimum area in the image in which changes can be detected.
  - This quantity is defined using the MTF, modulation transfer function
  - MTF defines the frequency domain relationship between the original and the reconstructed image in the presence of noise, and determines the ability of the scanner to capture rapidly changing attenuation coefficients in the object.
  - Spatial resolution is most often defined in terms of the cut-off frequency of the one dimensional transfer function, i.e. the value at which the function MTF(f) drops to the 50, 10 or 2% level.

Technical Parameters of CT Devices

- **Low-Contrast Resolution (Contrast Detail):** The ability to detect small differences of attenuation coefficient in tissues.
  - It is defined as the ratio between the smallest detectable difference of attenuation coefficient (on the Hounsfield scale) and the average value within an object of a given size, for a specific radiation dose
    - This last factor is introduced because low-contrast resolution is proportional to the radiation dose
  - Current scanners have a resolution of between 0.3 and 0.4%. This can be increased by increasing the radiation dose or extending the scanning time

Start-Up and Test Procedures

- To ensure reliable operation of CT scanner throughout the whole of its working life, it is important that all manufacturer's recommended procedures for startup and testing are followed

1. After sliding the table out of the scanner's gantry (Feed Out), image quality is tested (Test Image), but without the emission of radiation to confirm the correct operation of the imaging system
2. Next step is to prepare x-ray tube for operation by heating it up (Warm Up).
3. Next step (Calibration) takes place in the absence of any radiation-absorbing material in the gantry of scanner.

   Measurements made at this time form the basis of the corrections that must be made to the projections obtained during the routine operation of the scanner

Start-Up and Test Procedures

4. After calibration, procedures testing operation of CT scanner are carried out (Quality) and can be divided into two types:

- Qualitative tests, performed each day or weekly
- Stability tests, performed each month
- Annual tests.

5. Set of **daily/weekly** tests (performed by technicians) to check the quality of the reconstructed image might include:

- Test to measure the homogeneity of the image
- Test of the point spread function
- Check of the X-ray tube voltage

Start-Up and Test Procedures

6. A battery of tests performed by service personnel or technicians on a **monthly** basis might consist of measuring the following items:

- Spatial resolution
- Positioning accuracy
- Linearity
- Slice thickness

7. Annual tests might be a combination of the following examinations (performed by physicists):

- Daily/weekly tests evaluations
- Index accuracy and table positioning test
- Contrast scale test
- Distance accuracy test
- Patient dose

Start-Up and Test Procedures

8. In an emergency, if the time needed to perform the entire start-up procedure could affect the life or health of the patient, a fast start-up procedure (Quick start) can be carried out, which excludes all the points selected in the start-up window

9. Appropriate tests should also be carried out on the scanner after the installation of the equipment and after any routine maintenance or servicing

- Application software installed on the scanner's computer enables the results of the tests to be saved, so creating a history of the device for purposes of comparison.