Generating Image in CT

- **Image Generation in CT**

- Computed Tomography (CT) transforms raw X-ray data into cross-sectional images.

- The process involves four major stages:
- Planning
- Acquisition
- reconstruction, and display.

- Each step requires careful parameter selection to balance image quality and patient safety.

CT exams follow a systematic sequence:

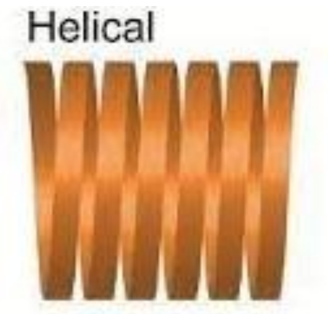
Protocol selection (deciding what and how to scan).

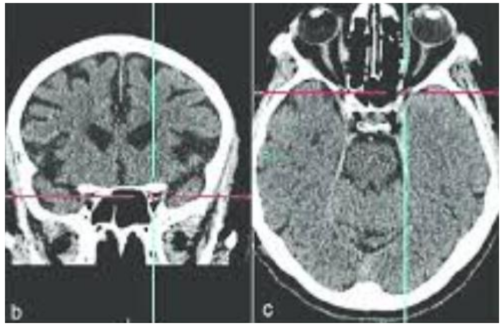
Patient positioning (accurate centering prevents artifacts).

Scanning (data acquisition, either axial or spiral).

Reconstruction (mathematical processing of attenuation data into Hounsfield Units).

Display (DFOV, window/level adjustments).





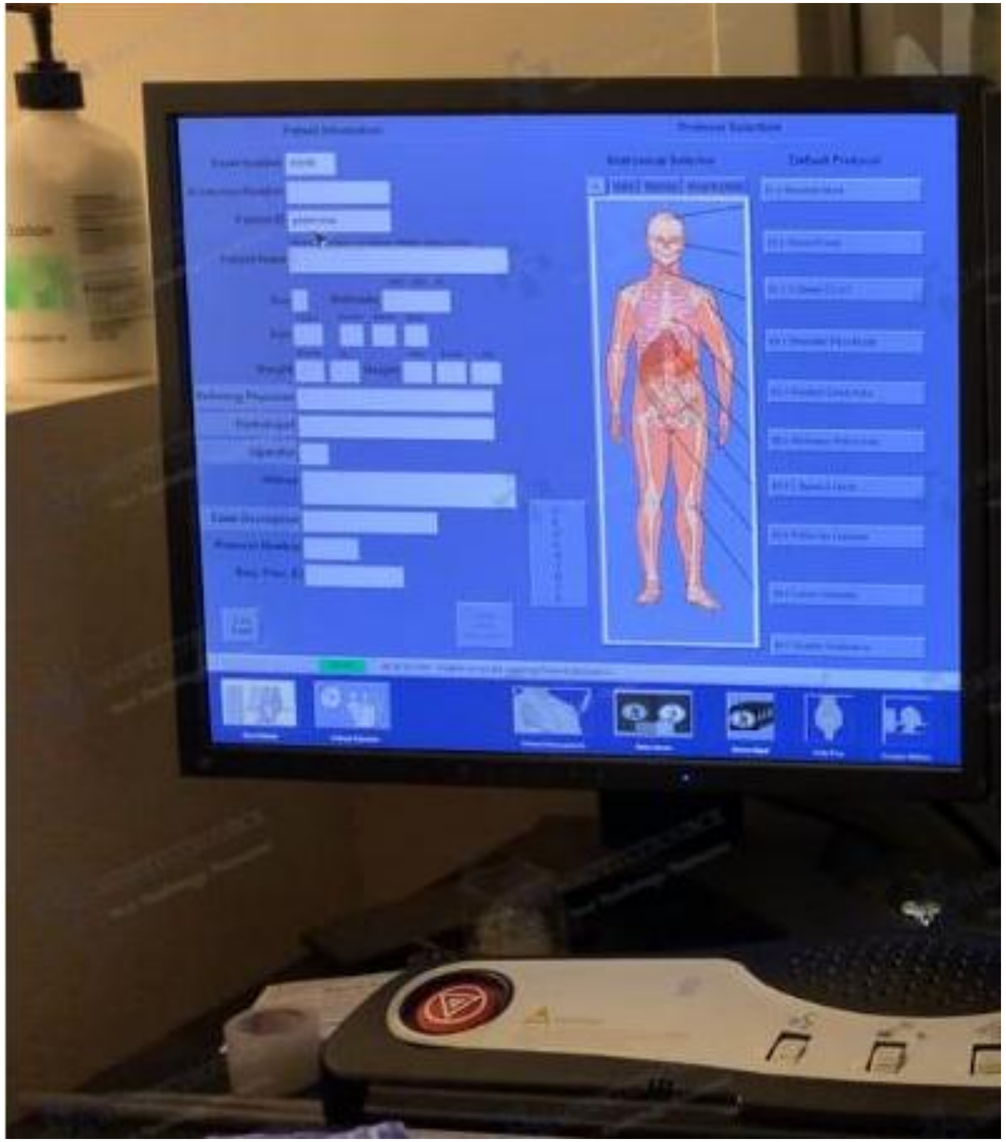
Protocol & Technique

Protocol Selection

•Protocols are tailored to anatomy (head, chest, abdomen, extremities) and patient group (adult vs pediatric).

• Pediatric scans must always prioritize lowest dose (ALARA).

•Special protocols exist for vascular studies (CTA) vs soft tissue imaging.



kVp: Controls photon energy, penetration,and quantity of radiation Higher kVp reduces contrast but decreases noise.

mA and Time (mAs): Control the total number of photons.

Time: Scan time (acquisition) or Tube rotation time

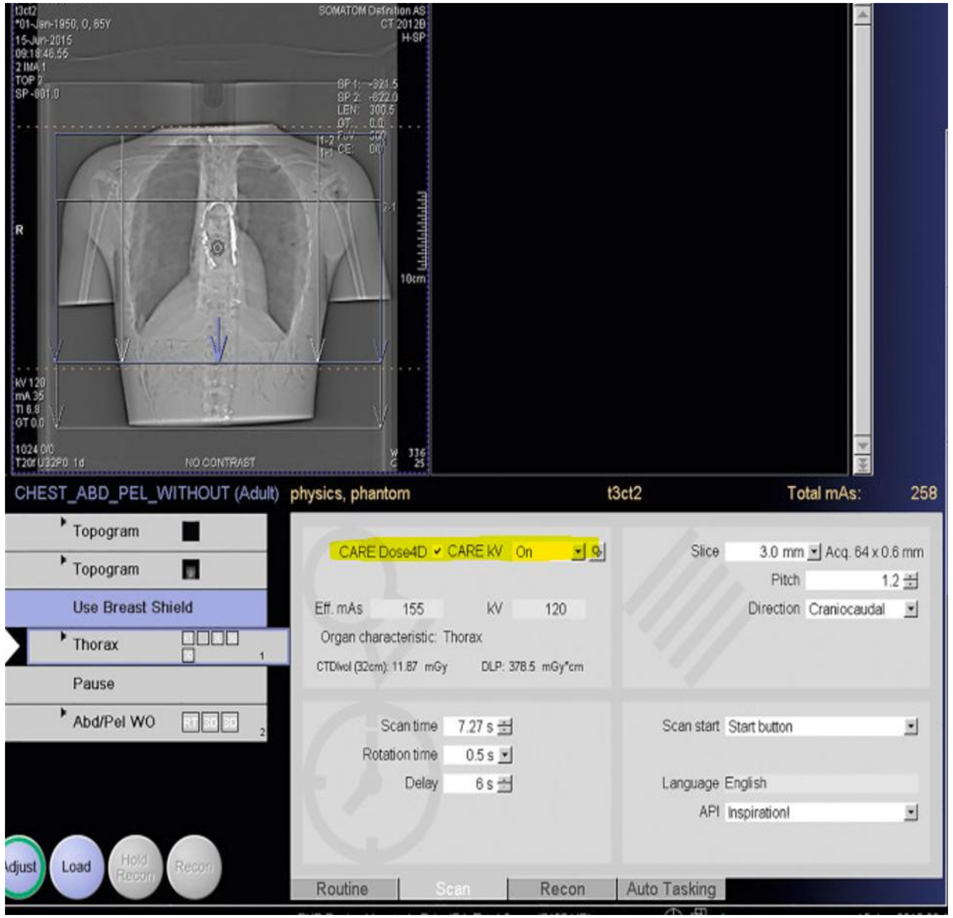
Directly proportional to dose and SNR.

Rotation Time: Shorter = less motion blur, but potentially more noise if mAs are low.

Scanning direction: cranio–caudal or caudo-cranial.

Care Dose 4D:

•**Purpose:** To optimize radiation dose while maintaining consistent image quality.
•**How:** The system automatically adjusts the tube current (mA) during the scan, based on patient size, shape, and attenuation.



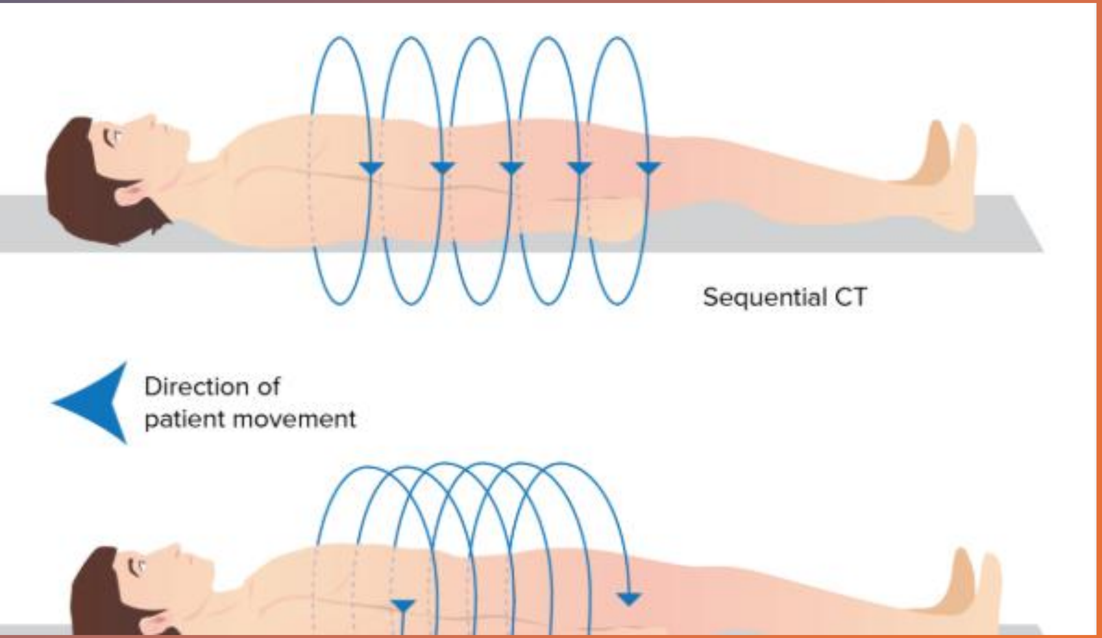
How It Works

1.Topogram (Scout Image):
   1. The system analyzes the patient's anatomy before the scan (from the scout view) to set baseline tube current.

2.Angular Modulation:
   1. As the tube rotates, the mA changes depending on how dense the body is at each angle (e.g., higher through shoulders, lower through lungs).

3.Longitudinal (z-axis) Modulation:
   1. Along the length of the patient, mA increases for denser areas (abdomen, pelvis) and decreases for less dense ones (chest).

4.Real-Time Adjustment (the "4D" part):
   1. It adapts throughout the entire scan in four dimensions:
      1. x-axis (left-right)
      2. y-axis (anterior-posterior)
      3. z-axis (head-to-toe)
      4. time (as the patient is scanned)



Scanning Modes

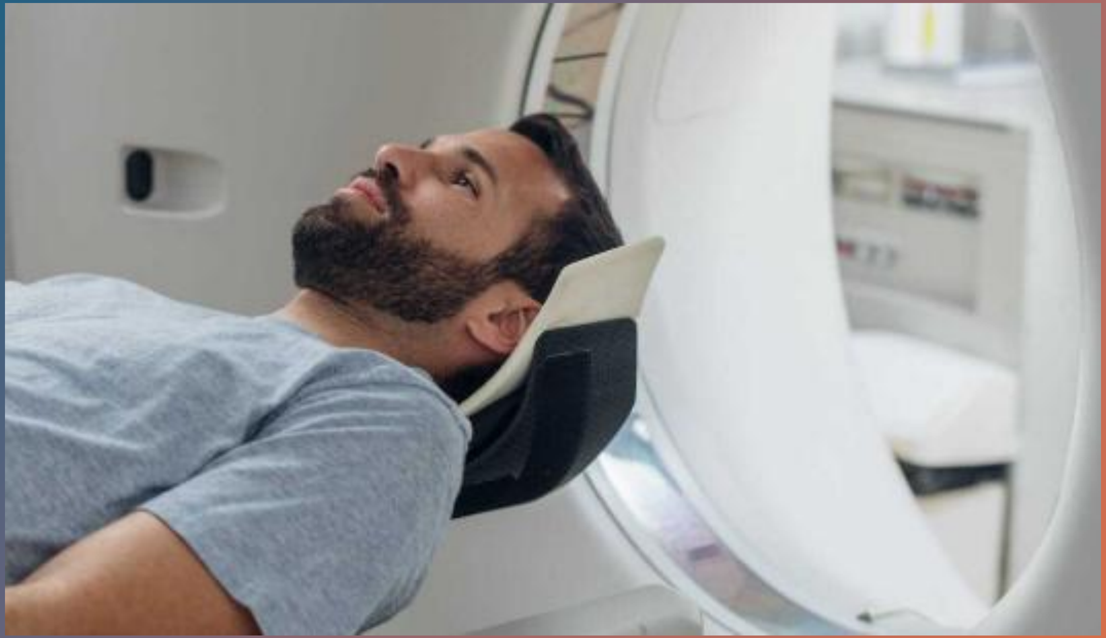
- **Axial (step-and-shoot):** High precision, used in neuro. Table pauses → fewer motion artifacts.

- **Spiral (helical):** Continuous rotation + table movement. Faster, isotropic voxels, better for 3D reformats.

Patient Positioning

- Correct centering ensures uniform dose modulation and minimizes artifacts. Off-centering can cause miscalculated mA (ATCM), increased noise, and inaccurate HU values.

Supine, Prone, Lateral decubitus



Patient Orientation

- Options: head-first vs feet-first.
- Must be properly documented in DICOM header for correct anatomical labeling.
- Incorrect orientation may confuse the radiologist or cause reconstructions to invert anatomy.

The body part being scanned **must be positioned at the isocenter** to ensure:

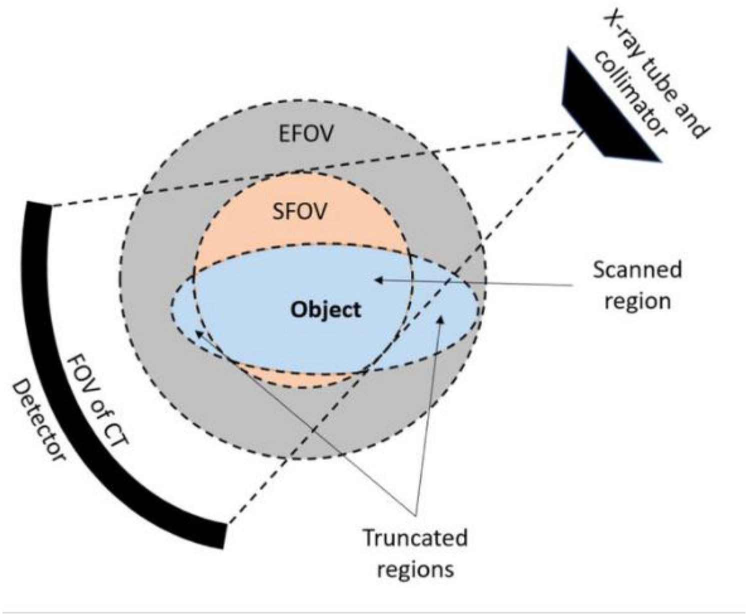
- **Accurate image geometry** (no magnification or distortion).
- **Consistent image quality** across the scan field.
- **Correct function of ATCM systems** (like Care Dose 4D).

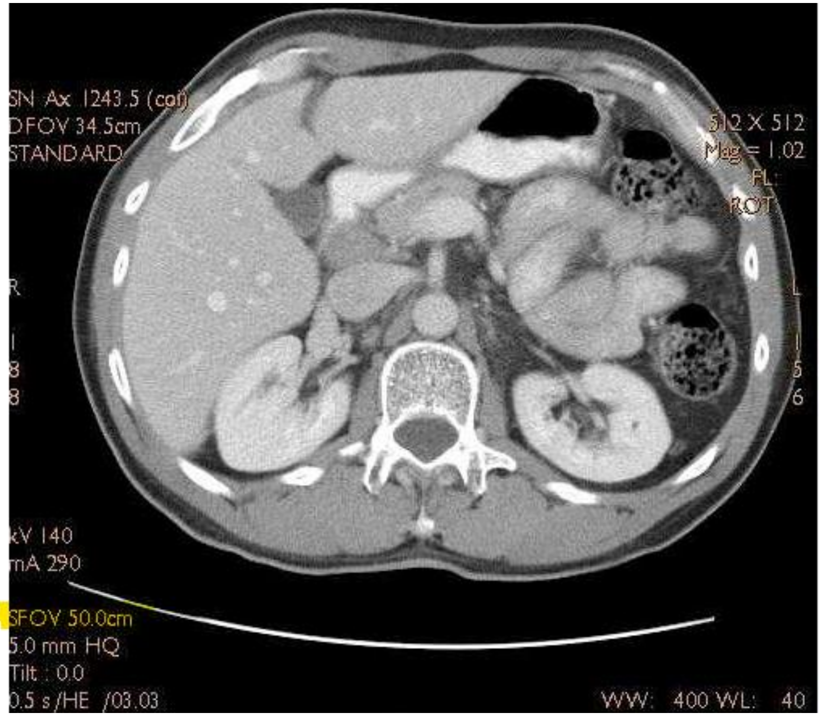
Scanning Field of View (SFOV)

•**Definition:** The SFOV is determined by the scanner hardware — detector selection and calibration.

•**Purpose:** It defines the maximum circular area from which the system acquires **raw projection data**.

Only anatomy inside the SFOV contributes to the reconstructed image. Anything outside is ignored, even if it appears in the display.





Importance of Correct SFOV Selection:

•**Image Quality:** Choosing the appropriate SFOV ensures that detectors capture the entire region of interest with proper resolution.

•**Anatomy Coverage:** A too-small SFOV can cut off or exclude important anatomy (e.g., shoulders, extremities).

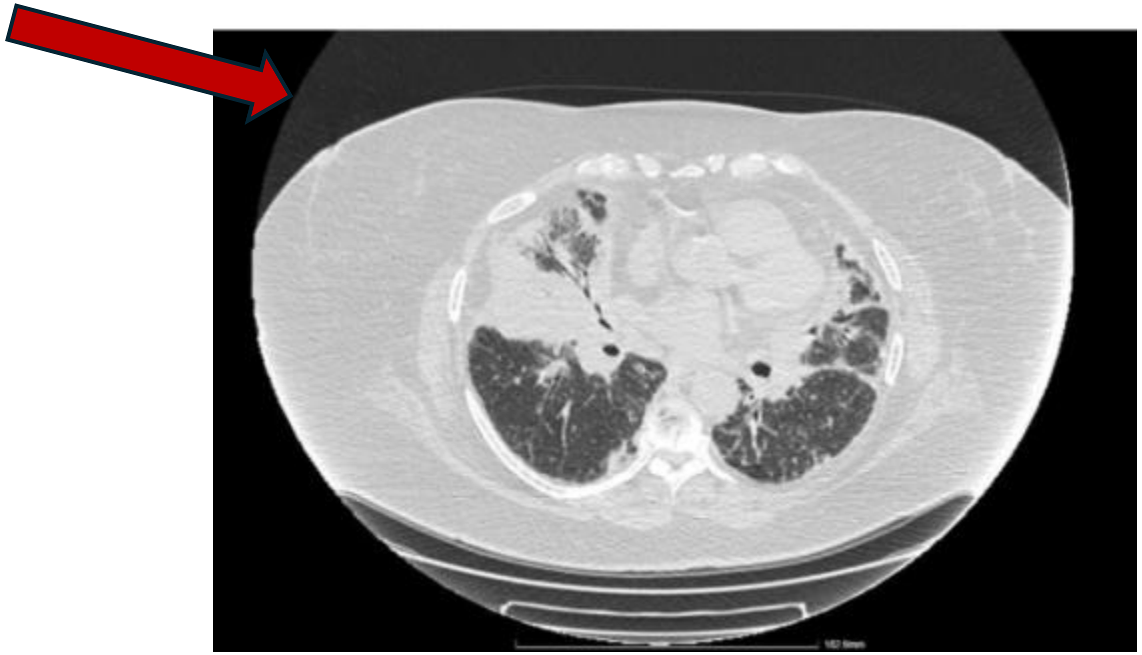
•**Spatial Resolution:** Using the smallest SFOV that fully covers the patient improves spatial resolution because smaller detector areas are sampled more finely.

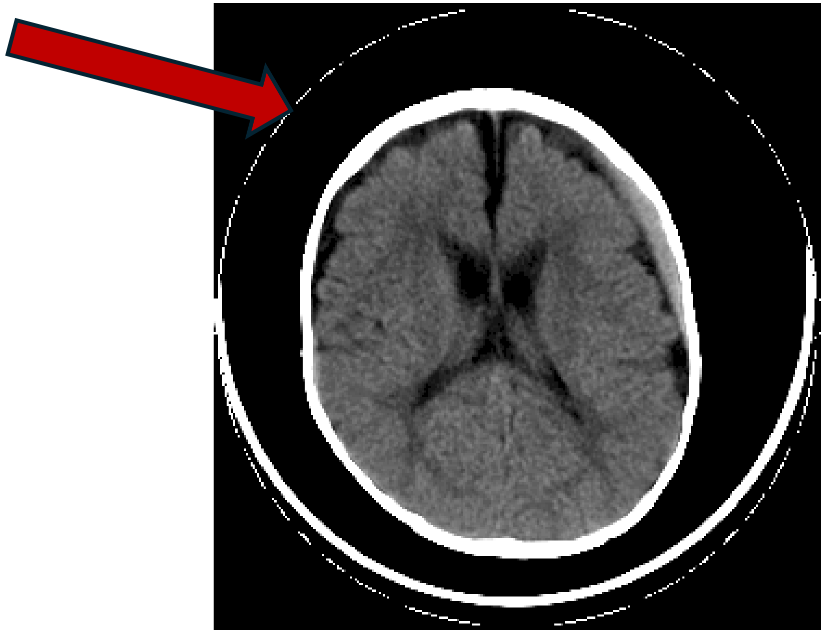
•**Noise and Artifacts:** Incorrect SFOV choice can increase image noise, introduce truncation artifacts, or degrade diagnostic value.

•**Reconstruction Limits:** Once data is not acquired (outside SFOV), it cannot be recovered during reconstruction.

Practical Considerations

- **Match to Patient Size:** Select SFOV large enough to include all relevant anatomy but not excessively large.
- **Consistency:** Use standardized SFOV protocols (e.g., Head, Body Small, Body Large).
- **Centering:** Proper patient isocenter positioning is critical; miscentering can result in anatomy falling outside the intended SFOV

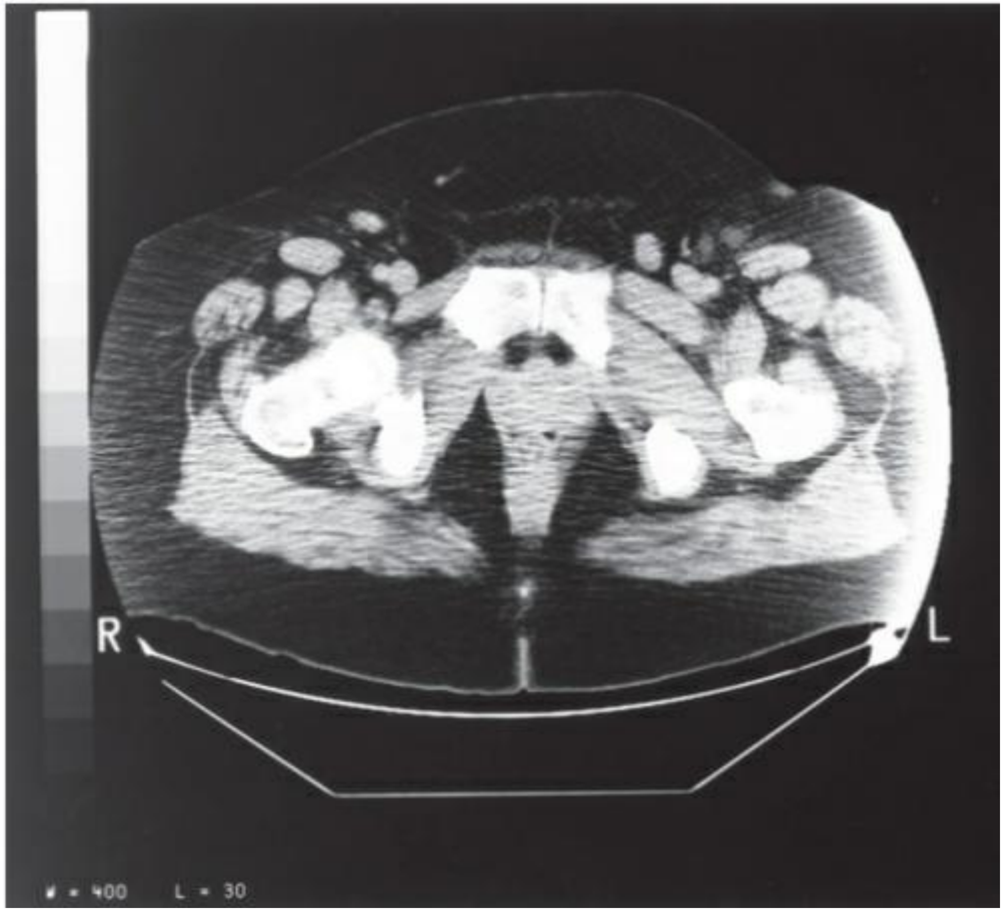


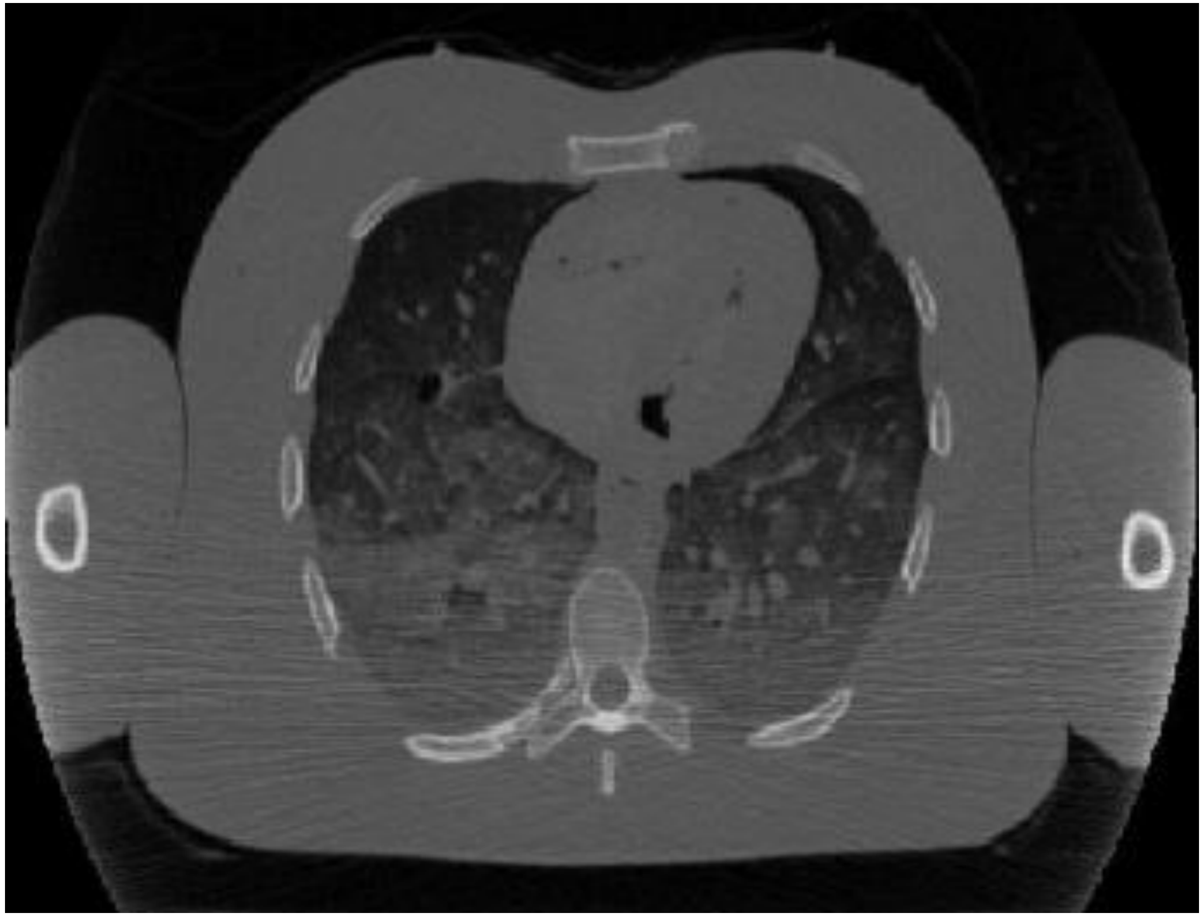


Out-of-Field Artifact

•If anatomy extends beyond SFOV, no raw data collected. Appears as streaks, truncation, or missing anatomy.

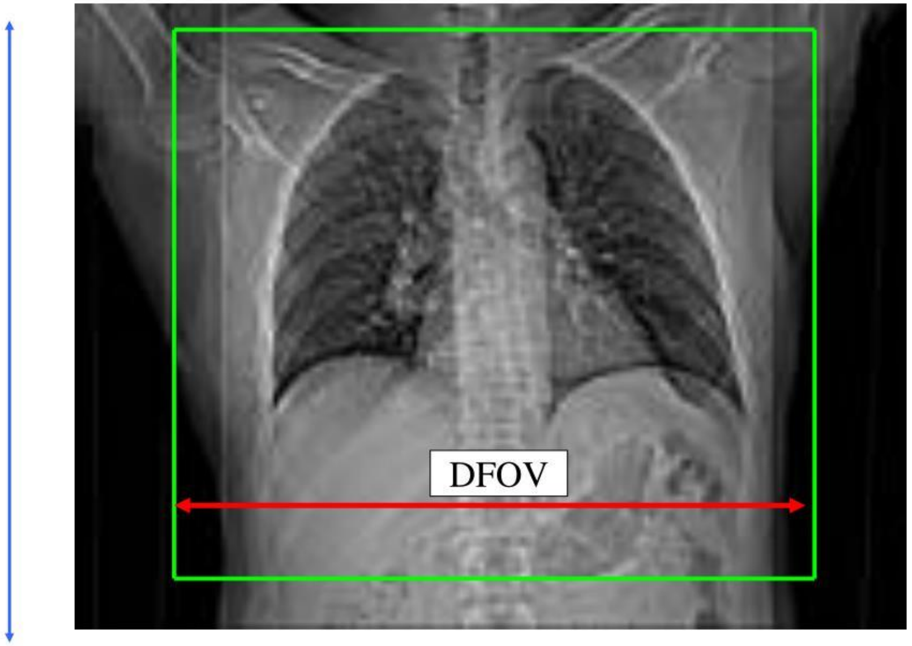
•**Image:** Shoulder scan with truncation artifact.

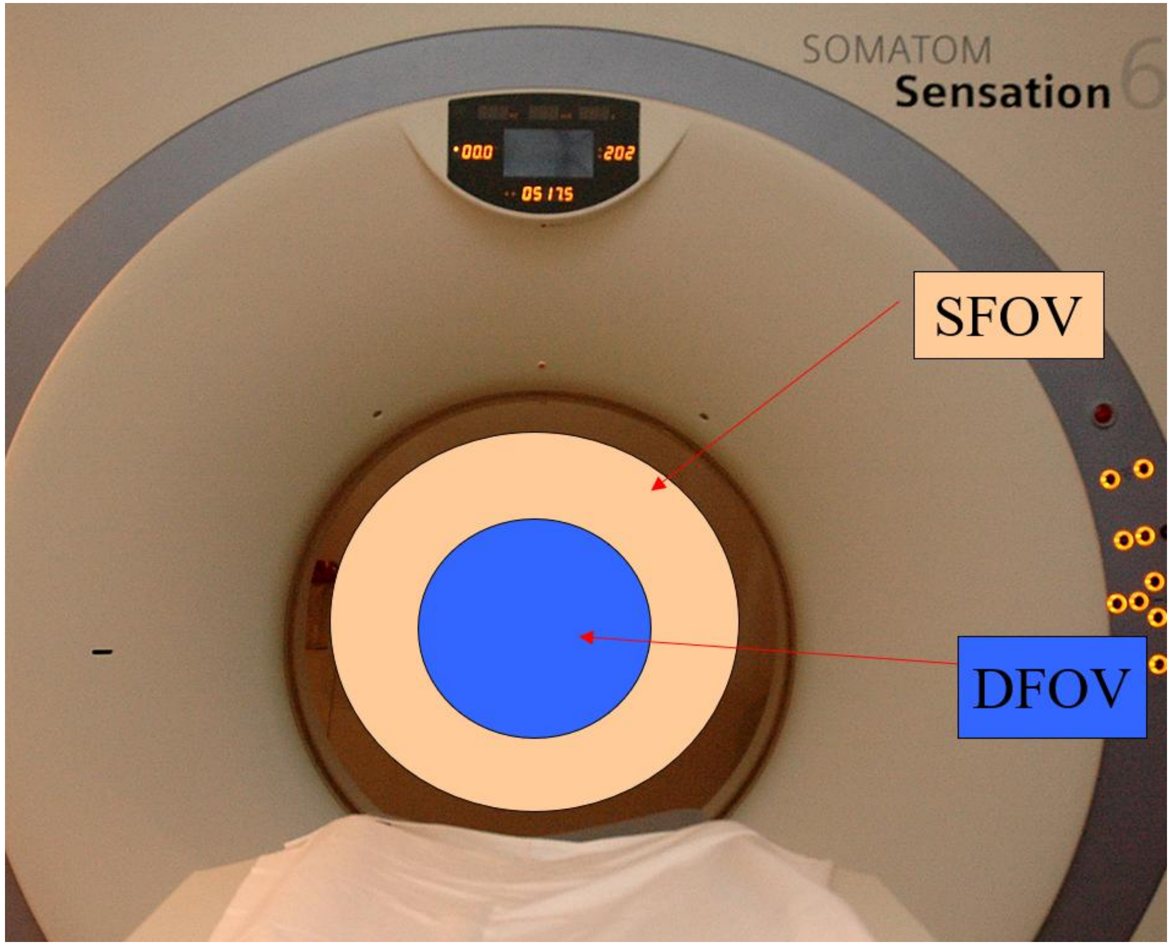




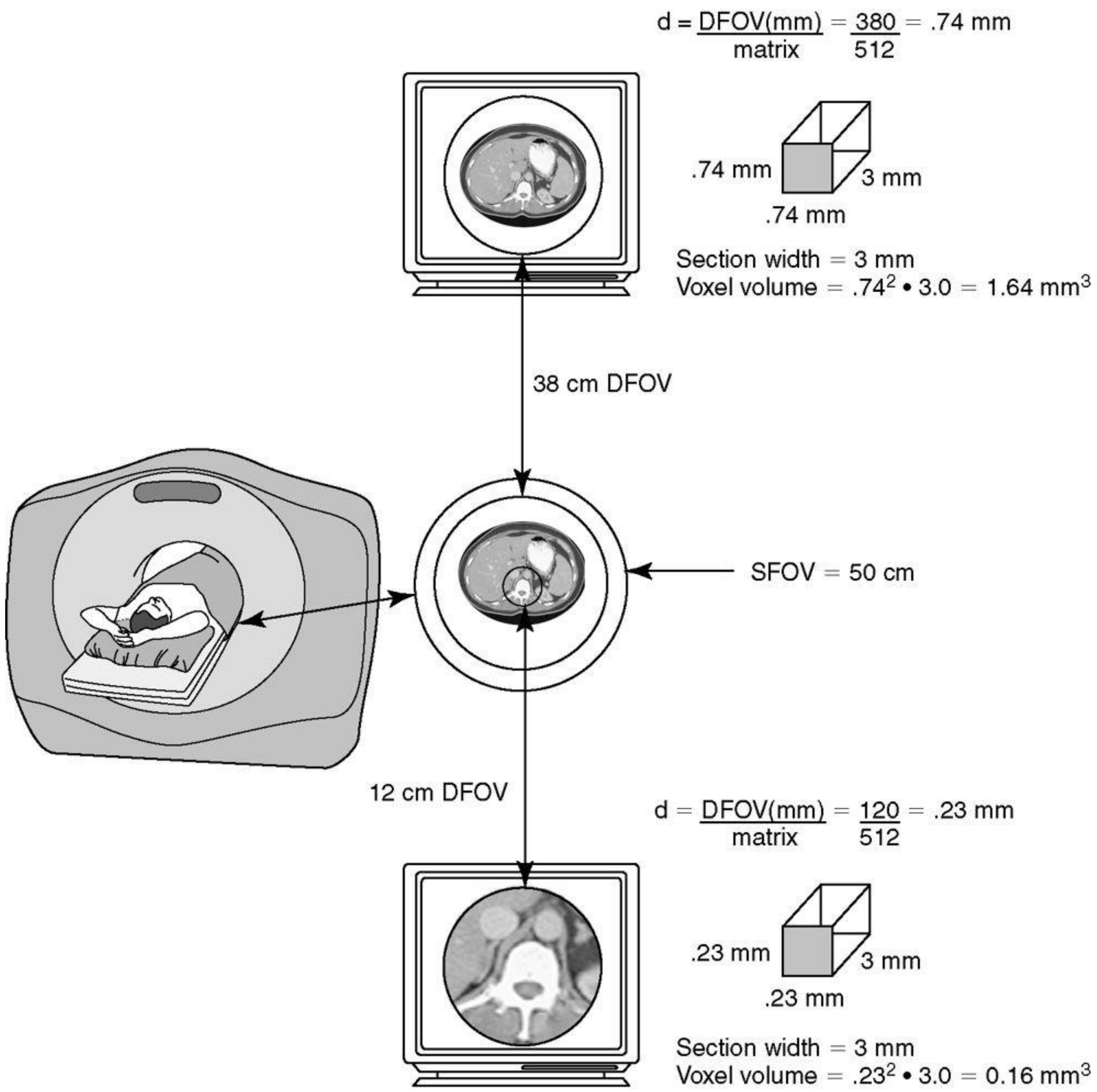
Display Field of View (DFOV)

- **Definition:** The DFOV determines how much of the acquired raw data (from the SFOV) is displayed in the final reconstructed image.
- **Relationship to SFOV:**
    - DFOV can be **equal to** or **smaller than** the SFOV.
    - DFOV can **never be larger**, since raw data outside the SFOV was never acquired.
- **Function:** Acts like a “zoom window” on the acquired data — it controls what anatomy is displayed and at what scale





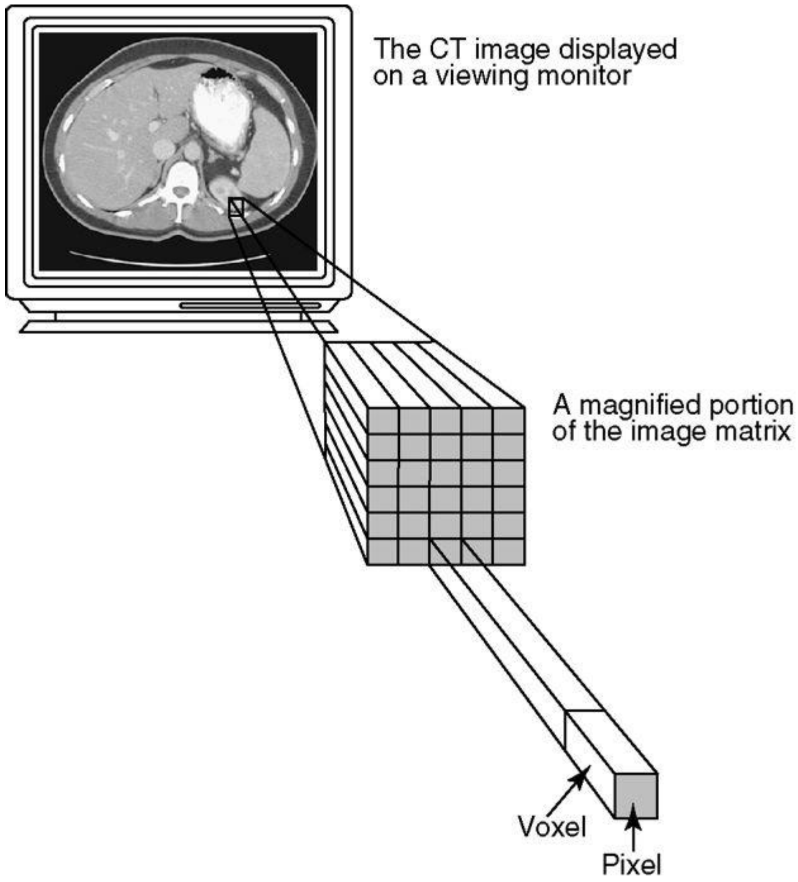
DFOV can be **equal to or smaller than SFOV**, never larger.



- **Effect on Image Quality**
- **Smaller DFOV:**
  - Increases image magnification of the region of interest.
  - Decreases pixel size (higher spatial resolution).
  - Formula (ARRT relevant): **Pixel size = DFOV ÷ Matrix**
    - Example: DFOV 25 cm ÷ 512 matrix ≈ 0.49 mm/pixel.
- **Larger DFOV:**
  - Shows more anatomy, but each pixel represents a larger area (lower resolution).
  - Useful for overview images but may reduce diagnostic detail.

CT and Voxels

•**Voxel** = 3D volume element (like a cube).
•In CT, the patient is divided into many small **voxels** during image reconstruction.
•Each voxel has a single value representing the **average attenuation coefficient** (how much X-rays were absorbed) for that tiny volume of tissue



Scanning

Slide 13 – Topogram (Scout)

•2D projection, tube stationary. Used to plan start/stop positions, angle gantry, and avoid radiosensitive areas.

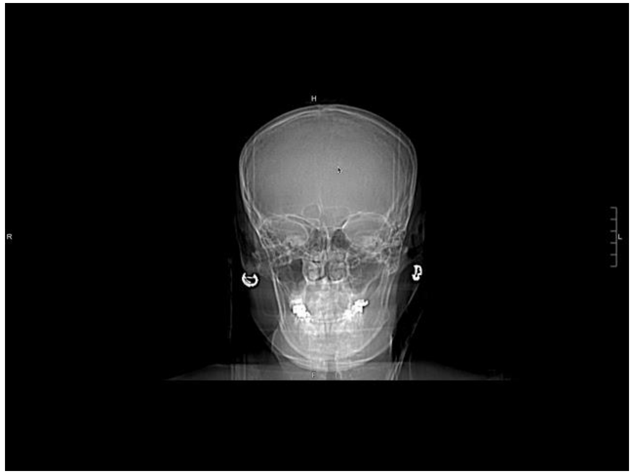
•Errors in scout → misaligned slices.

•During the scout acquisition, the tube is not rotating around the patient.

AP Scout

Lateral Scout

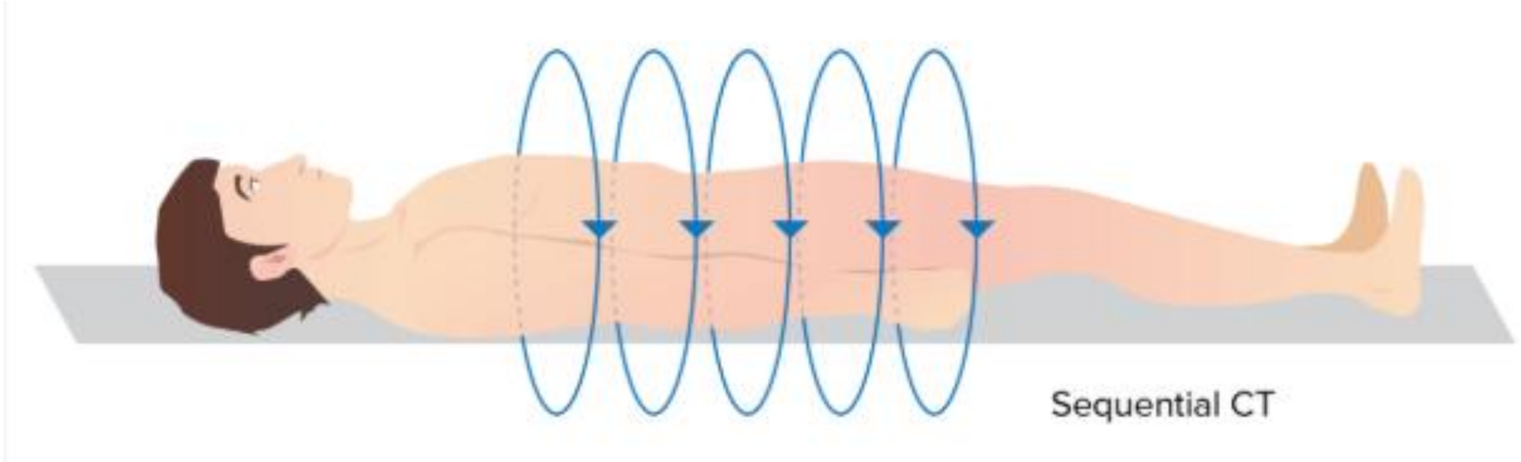
AP Scout



Lateral Scout

Axial (Sequential) CT Scans

- **Acquisition Method:**
    - Known as **“step-and-shoot.”**
    - The table moves to a set position → X-ray tube rotates → acquires one slice.
    - Table then moves again, repeats for the next slice.
- **Advantages:**
    - **High contrast stability**: Each slice is acquired at a fixed position, so tissue contrast is consistent.
    - **Lower risk of interpolation artifacts** compared to helical mode (no interpolation between slices).
    - Precise anatomical detail, especially useful when motion or fine bony detail is critical.
- **Disadvantages:**
    - Slower than helical scanning (table must stop for each slice).
    - Potential for slice misregistration if the patient moves between acquisitions.
    - Limited use for dynamic studies or large-volume scans



Spiral (Helical) CT Scans

•**Acquisition Method:**

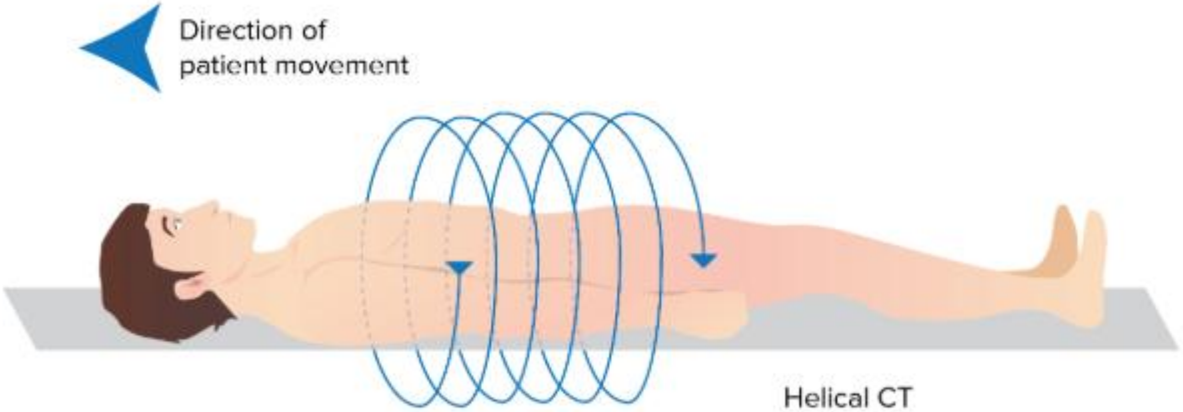
- X-ray tube rotates **continuously** around the patient while the table **moves smoothly** through the gantry.
- This creates a **helical (spiral) path** of data acquisition.

Advantages

•**Speed:** Much faster than step-and-shoot; ideal for trauma, pediatrics, chest/abdomen/pelvis.
•**Continuous Coverage:** No slice gaps, allowing imaging of long body regions in one breath-hold.
•**Less Motion Artifact:** Faster scans reduce patient motion issues and respiratory misregistration.

Disadvantages

•Requires interpolation between spiral paths → risk of **helical interpolation artifacts** (esp. at high pitch).
•Slight trade-off in contrast stability compared to axial mode.



Acquisition Terminology

Ray

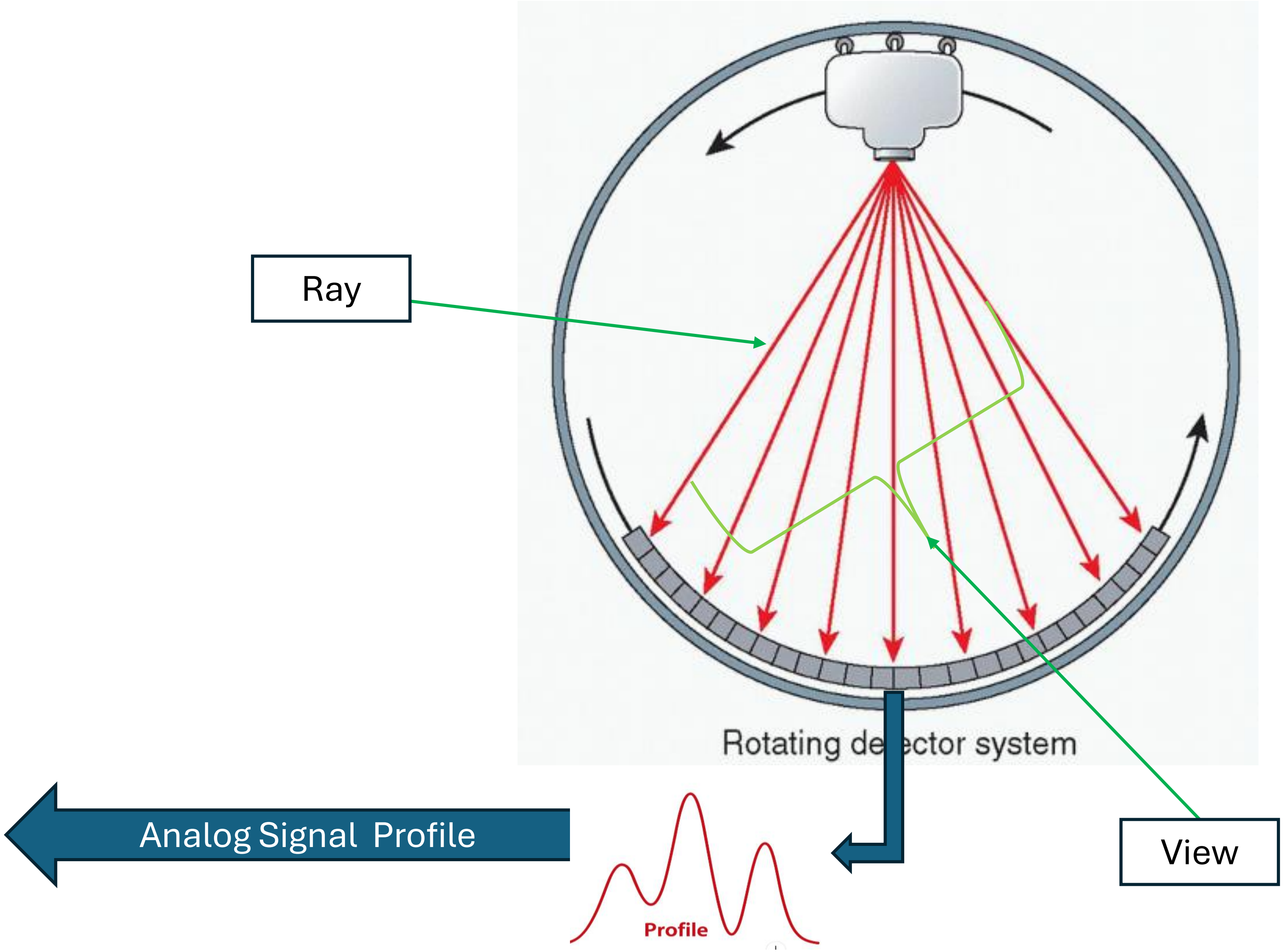
- A single path of X-ray photons traveling through the patient to strike **one detector element**.
- Each ray measures attenuation along its path.

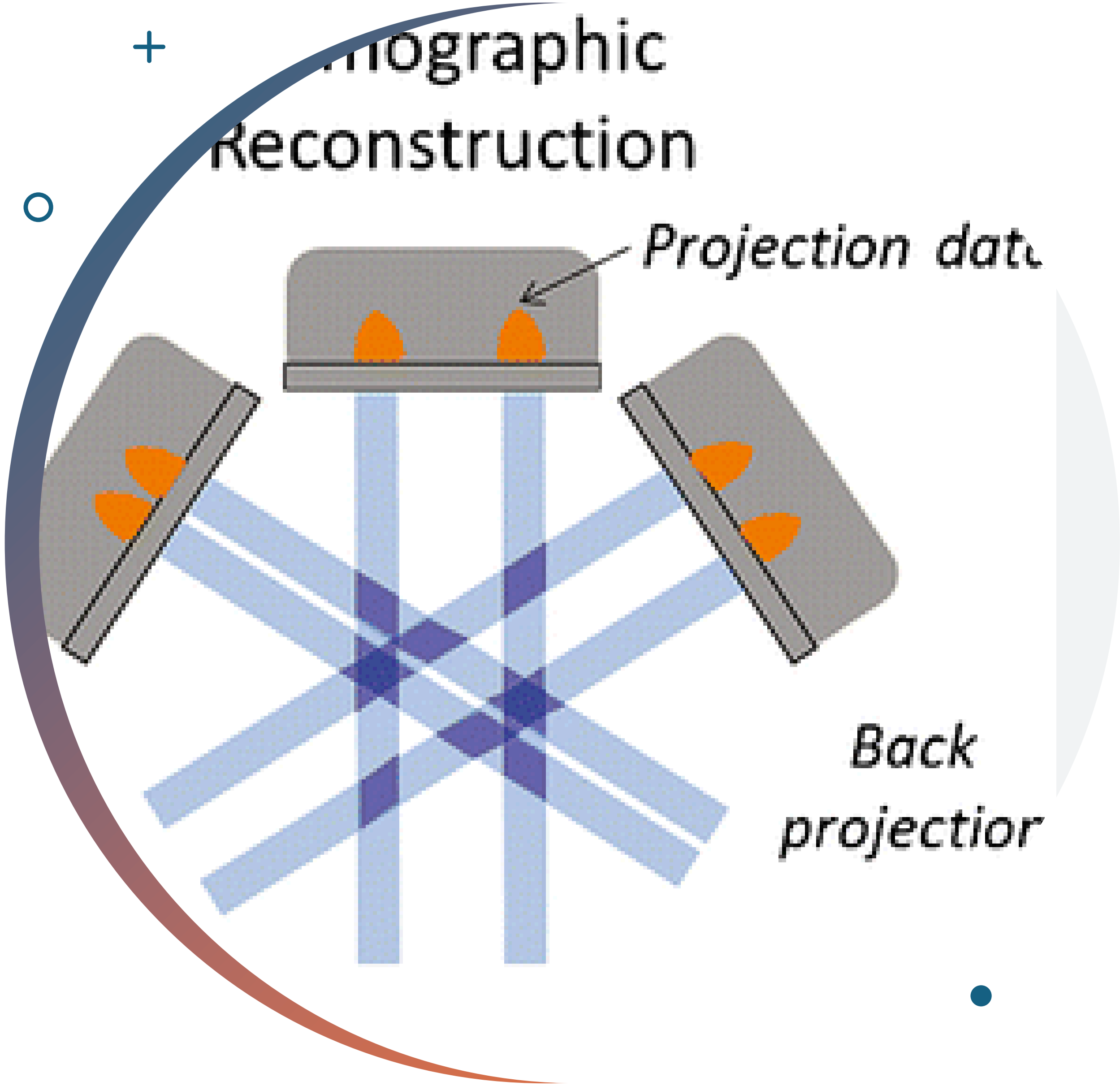
View

- A **collection of rays** acquired at one tube position during a single projection.
- As the tube rotates, many views are collected at different angles around the patient.
- Example: 1,000+ views per rotation.

Profile

- The **analog signal** from a single view.
- Represents the summed attenuation values from all rays in that projection before being digitized.
- Once digitized, profiles become the **raw data** used for reconstruction.


Ray
View
Rotating de ector system
Analog Signal Profile
Profile



Reconstruction Basics

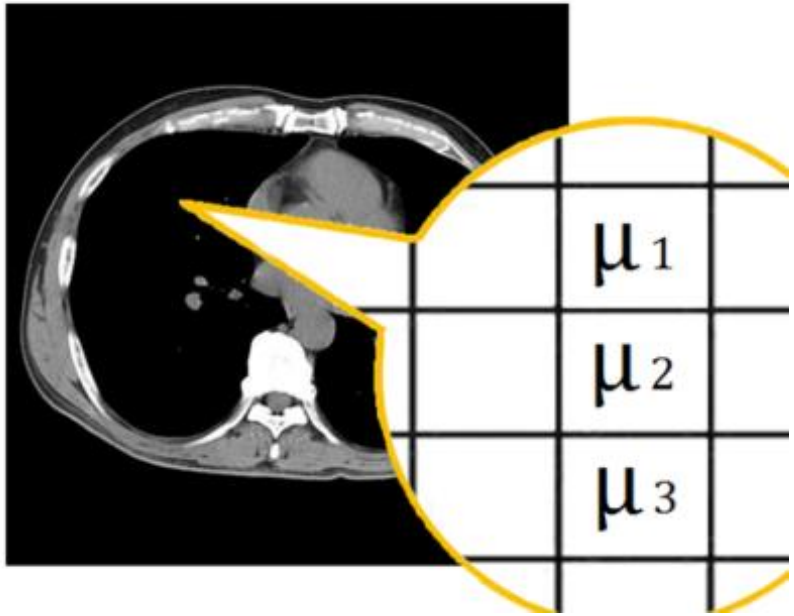
- Raw data → mathematical backprojection → image matrix.
- Modern scanners use filtered backprojection or iterative reconstruction.

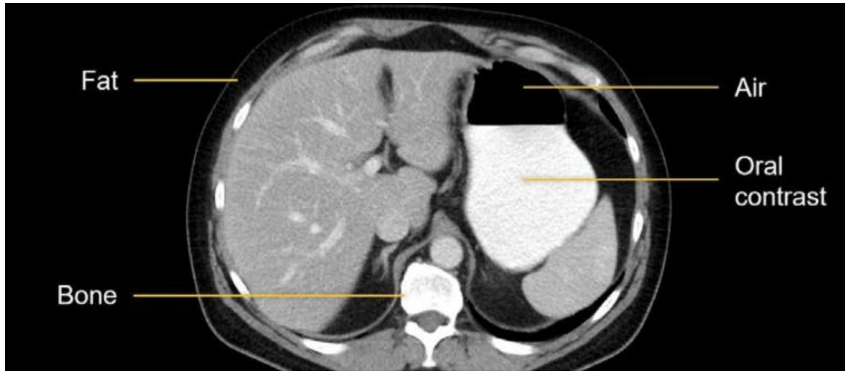
Linear Attenuation Coefficient (μ) - Reconstruction

- **Definition:**
  - A physical property that describes how strongly a material (tissue) absorbs or weakens an X-ray beam as it passes through.
  - Units: cm^{-1} (per centimeter).

- **Mathematical Meaning:**
  - Expressed in the equation **$I = I_0\, e\text{^}(-\mu x)$ (Lamber –Beer Law)**
    - I_0 = incident X-ray intensity
    - I = transmitted X-ray intensity
    - μ = linear attenuation coefficient
    - x = thickness of material

  - Higher μ → faster exponential decay → less X-ray passes through





- **Tissue Examples (at diagnostic energies)**
- **Bone:** High μ (dense, high atomic number, absorbs more). Appears white on the CT image

- **Soft Tissue:** Moderate μ. Appears grey on the CT image

- **Air:** Very low μ (almost transparent to X-rays). Appears black on the CT image

CT scanners measure tissue attenuation using the **linear attenuation coefficient (μ)**, but because raw μ values vary with scanner settings and beam energy, they are standardized into **Hounsfield Units (HU)**. Water is used as the reference point (set at 0 HU), and all other tissues are expressed relative to it: air, with almost no attenuation, is –1000 HU; fat is about –100 HU; soft tissue is +30 to +60 HU; and dense bone reaches +700 or more. This conversion provides a universal scale that ensures images are consistent and comparable across patients and scanners

$$HU = \frac{(\mu_{tissue} - \mu_{water})}{\mu_{water}} \times 1000$$

Suppose:

- $\mu water = 0.20\ cm^{-1}$
- $\mu muscle = 0.212\ cm^{-1}$

Step 1: Apply formula

$$HU = \frac{(\mu_{tissue} - \mu_{water})}{\mu_{water}} \times 1000$$

$$HU = \frac{(0.212 - 0.200)}{0.200} \times 1000$$

Step 2: Simplify

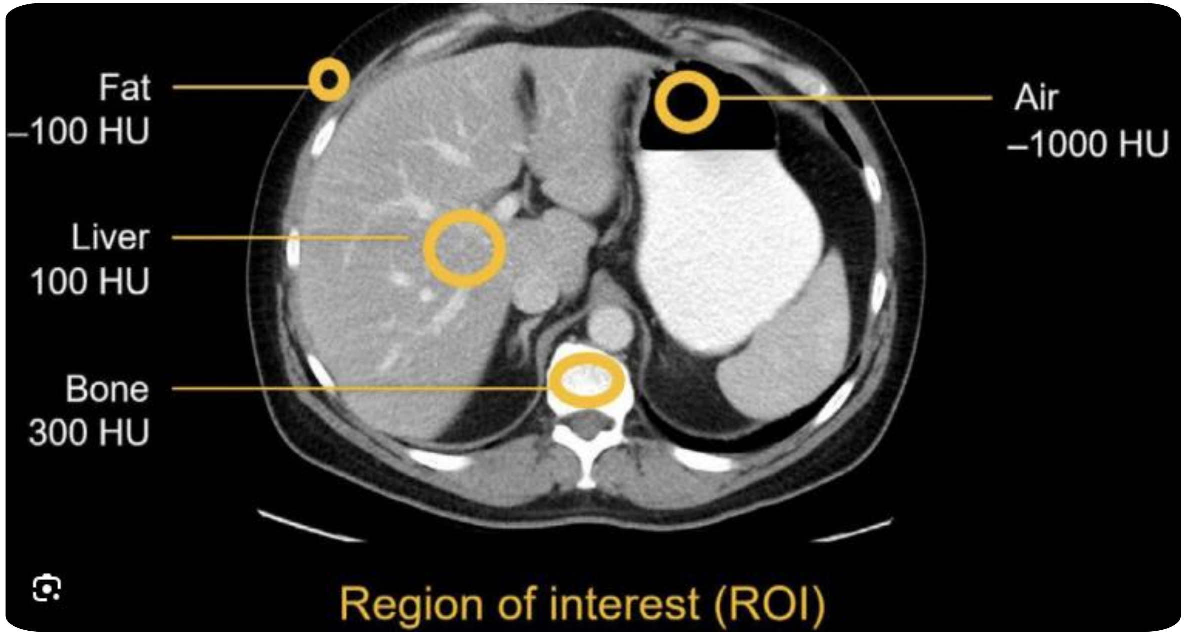
$$HU = \frac{0.012}{0.200} \times 1000$$

$$HU = 0.06 \times 1000 = +60$$

CT# of +60 is associated with muscle

Typical Hounsfield Units (CT Numbers)

Tissue / Material	HU Value
Air	−1000
Lungs (aerated)	−900 to −300
Fat	−100 to −50
CSF	+15
Grey Matter	+40
White Matter	+45
Soft Tissue	+50
Muscle	+60
Blood (Acute Hemorrhage)	+50 to +70
Spongy Bone	+300 to +800
Compact Bone	+1000+

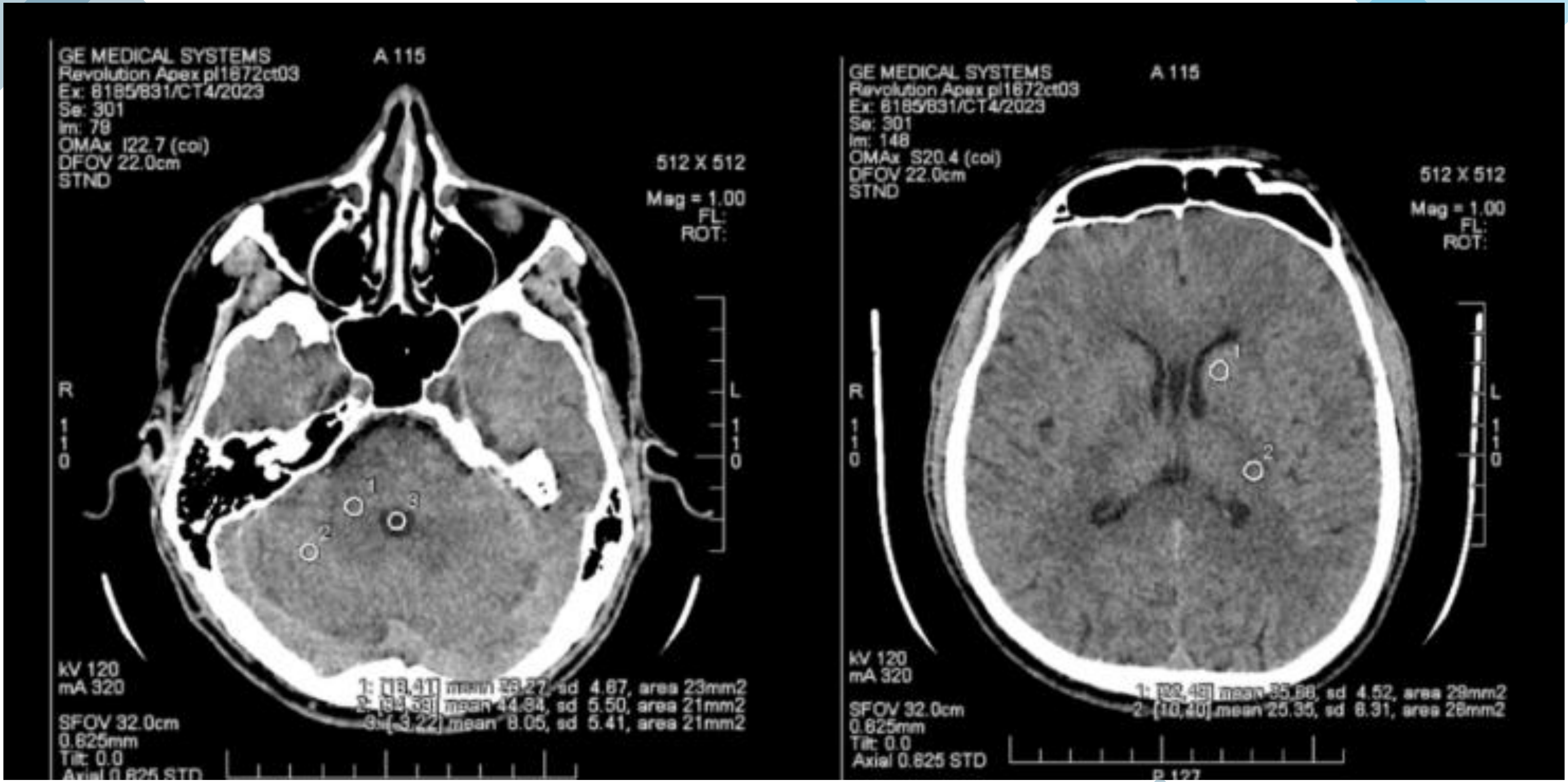


In CT imaging, **ROI** stands for **Region of Interest**.

•

An ROI is a **selected area on the CT image** (outlined by the technologist or radiologist) used for **quantitative measurements**.

- The CT computer then calculates statistics (average HU, standard deviation, area, etc.) within that region.

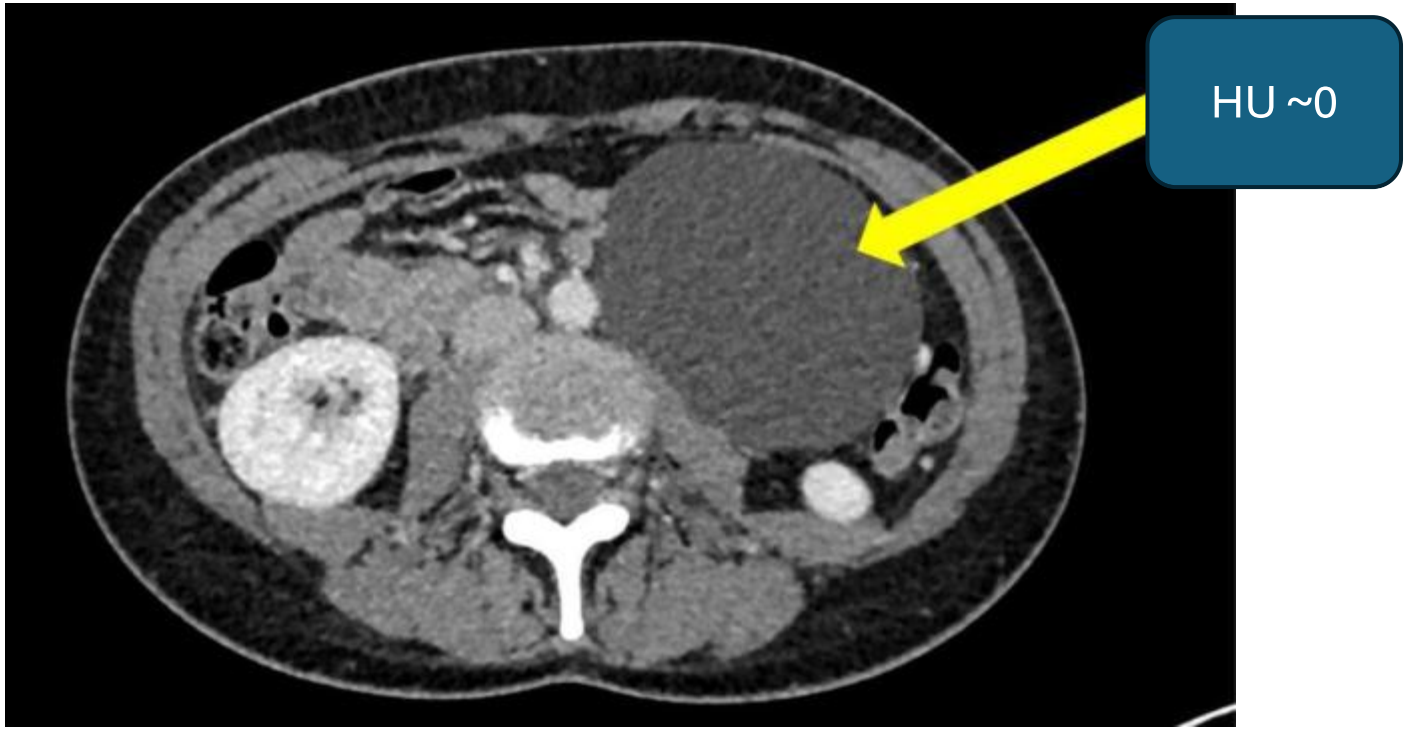

GE MEDICAL SYSTEMS
A 115
Revolution Apex pl1872ct03
Ex: 8185/831/CT4/2023
Se: 301
Im: 79
OMAx I22.7 (coi)
DFOV 22.0cm
STND
512 X 512
Mag = 1.00
FL:
ROT:
kV 120
mA 320
2: [84,59] mean 44.84, sd 5.50, area 21mm2
3: [-3,22] mean 8.05, sd 5.41, area 21mm2
SFOV 32.0cm
0.625mm
Tilt: 0.0
Axial 0.625 STD
GE MEDICAL SYSTEMS
A 115
Revolution Apex pl1872ct03
Ex: 8185/831/CT4/2023
Se: 301
Im: 148
OMAx S20.4 (coi)
DFOV 22.0cm
STND
512 X 512
Mag = 1.00
FL:
ROT:
kV 120
mA 320
1: [32,48] mean 35.66, sd 4.52, area 29mm2
2: [10,40] mean 25.35, sd 6.31, area 26mm2
SFOV 32.0cm
0.625mm
Tilt: 0.0
Axial 0.625 STD

Clinical HU Applications

Cystic Lesions (Water Density)

•CT cyst = ~0 HU. Appears homogeneous, water-like.

•Helps distinguish cysts from solid tumors.



Angiomyolipoma is diagnosed on CT when the lesion contains regions with negative HU values (–10 to –100), representing macroscopic fat.

CT Appearance of Lipoma

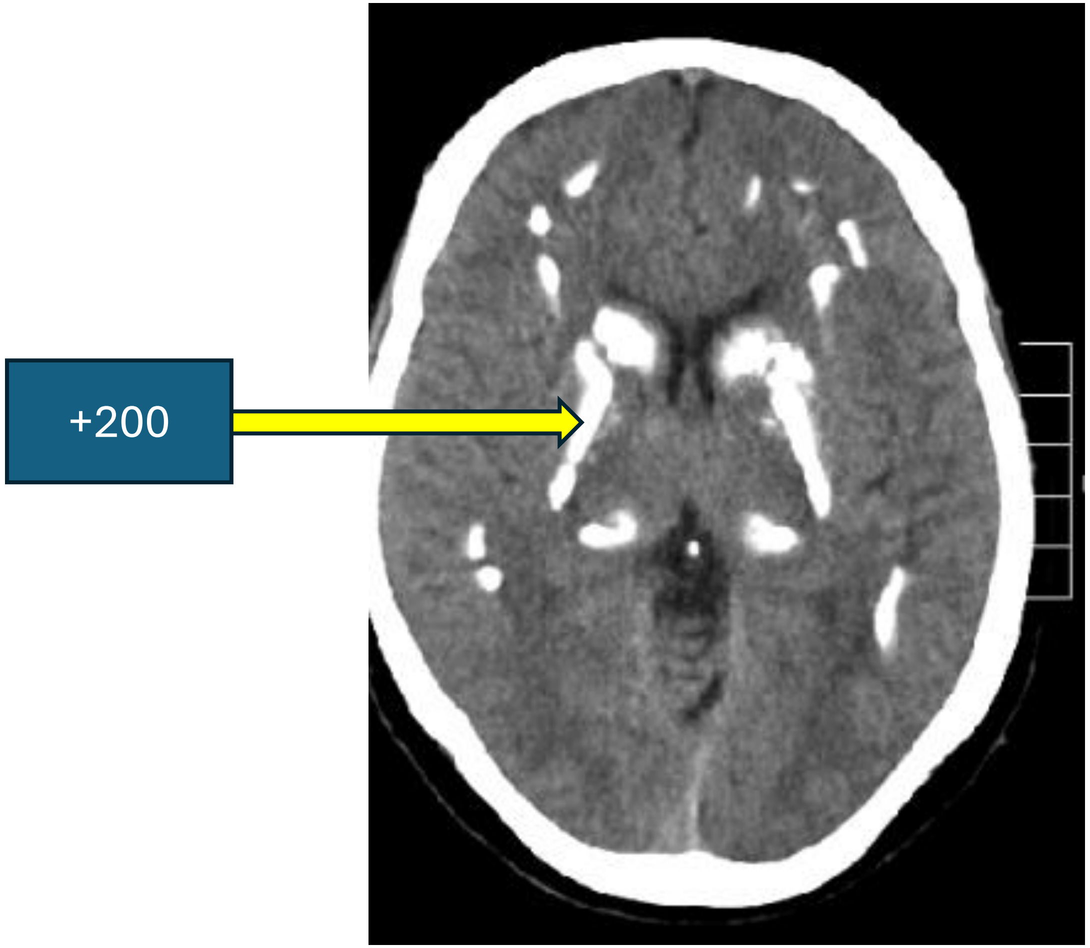
•**Attenuation (CT Numbers):**

- Lipoma = **fat density**, typically **–50 to –100 HU**.
- Homogeneous, well-defined low-density lesion.

Brain Calcification and CT Numbers

•**Attenuation:**

- Calcifications measure **+100 to +400 HU** (depending on density and thickness).
- Denser calcifications can approach **+1000 HU**, overlapping with bone.



CT Numbers of Hemorrhage

•Acute Hemorrhage (fresh blood):

- Typically **+30 to +45 HU**
- Appears hyperdense (bright) compared to brain parenchyma.
- Early recognition is key in trauma and stroke imaging.