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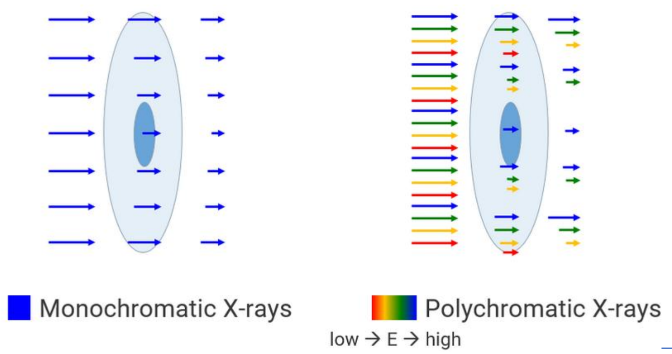
Lecture No.: 2

Lecture Title: Polychromatic X-Ray Beam .

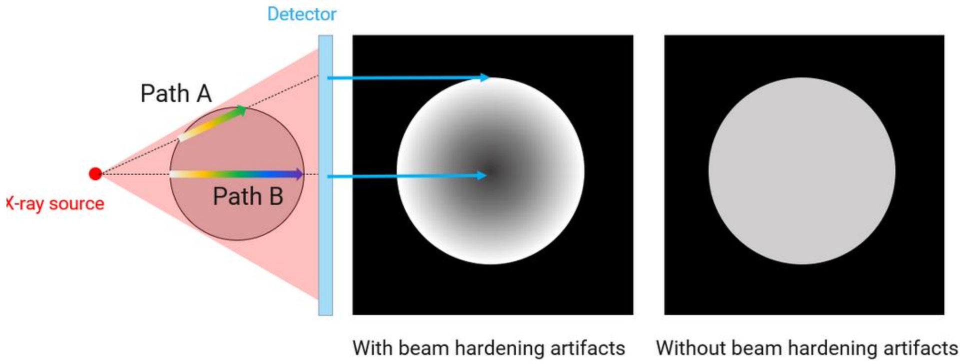
Polychromatic X-Ray Beam

- Polychromatic X-Ray energy: the x-ray beam comprises photons with varying energies ranging from weak x-ray photons to others that are relatively strong.
- Low-energy X-ray photons are more readily attenuated by the patient, producing artifacts on the image, which degrade the image quality.
- Artifacts that result from preferential absorption of the low energy photons, which leaves higher-intensity photons to strike the detector array, are called beam-hardening (cupping) artifacts.



Polychromatic X-Ray Beam

- Filtering the X-ray beam with Teflon or aluminum helps to reduce the range of X-ray energies that reach the patient by eliminating the photons with weaker energies, and makes the beam more homogeneous.
- Creating a more uniform beam intensity improves the CT image by reducing artifacts.
- Additionally, filtering out soft (low-energy) photons reduces the patient's radiation dose.



Polychromatic X-Ray Beam

The Beer-Lambert Law

- Because the X-ray beam comprises photons with varying energies, the theoretical attenuation can be calculated using the Beer-Lambert Law: $I=I_0e^{-\mu x}$
- Where I_0=initial intensity, I = transmitted intensity, x = tissue thickness, and μ = Linear Attenuation Coefficient.
- Low-energy X-ray photons have a higher μ, meaning they are more readily attenuated by the patient.
- **<u>Example</u>**: An X-ray beam (I_0=1000 photons) passes through 5cm of tissue.
- Low Energy ($\mu=0.2\ cm^{-1}$): $I=1000\times e^{-(0.2\times5)}\approx368$ photons transmitted.
- High Energy ($\mu=0.1\ cm^{-1}$): $I=1000\times e^{-(0.1\times5)}\approx606$ photons transmitted.
- This mathematical difference explains exactly why the beam becomes "harder" as it penetrates deeper into tissue, leading to beam-hardening (cupping) artifacts.

Volume Averaging

- All CT examinations are performed by obtaining data for a series of slices through a designated area of interest (the anatomy and the pathology).
- Scanners allow the technologist to select slice thickness,
- Generally, the smaller the object being scanned, the thinner the CT slice required. Thicker CT slices increase the likelihood of missing very small objects.
- For example, if 10-mm slices are created, the area of pathologic tissue measures just 2mm, normal tissue represents 8mm and is averaged in with the pathologic tissue, potentially making the pathologic tissue less apparent on the image.
- This process is referred to as volume averaging, or partial volume effect.
- The volume averaging refers to the phenomenon where the reconstructed CT image represents an average value for a particular volume element (voxel) rather than the exact density of a specific material within that voxel. This happens because the X-ray beam used in CT scanning interacts with all materials within the voxel, not just a single point.

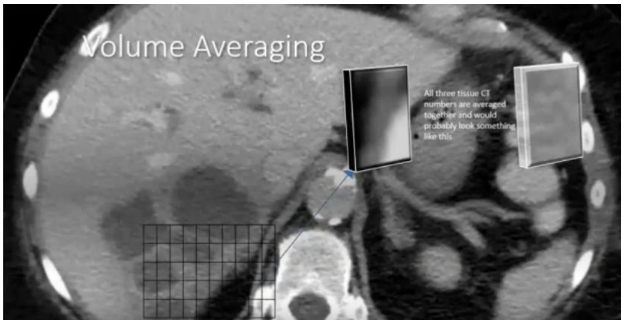
Volume Averaging

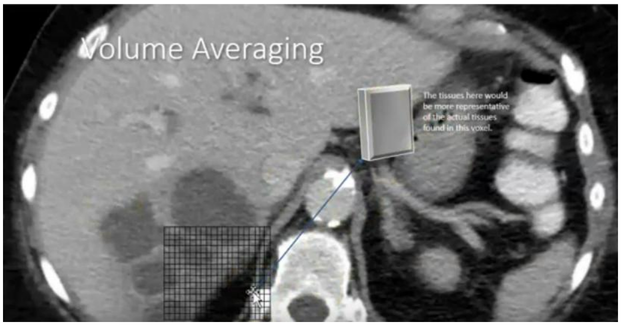
- **How volume averaging works:**
- During a CT scan, the X-ray beam penetrates the patient and is attenuated (weakened) by the tissues it encounters.
- The CT scanner measures the attenuation and reconstructs an image based on these measurements.
- However, the X-ray beam doesn't interact with a single point but rather with a small volume of tissue at each location.
- This volume, known as the **voxel**, is the basic unit of information in a CT image.
- If the voxel contains multiple tissue types with different densities (e.g., bone and muscle), the measured attenuation will reflect an average of their properties.

Volume Averaging

- *The impact of volume averaging :*
- It can blur the boundaries between tissues with different densities, making it difficult to distinguish fine details in the image.
- It can lead to inaccuracies in measured densities, especially for small structures or those with a mix of different materials within the voxel.
- *Factors affecting volume averaging:*
- Voxel size: Smaller voxels minimize volume averaging but require higher radiation doses and longer scan times.
- Tissue composition: Mixing materials of different densities within a voxel results in greater averaging.
- X-ray beam energy: Lower energy X-rays experience more interaction with tissue, hence more averaging.

Volume Averaging





Volume Averaging

- Thinner slices result in a higher radiation dose to the patient.
- If the scanned area is too large, a huge number of slices are produced.
- Scanning procedures are designed to provide the image quality necessary for diagnosis at an acceptable radiation dose.
- Generally, if the structures being investigated are very small (e.g., coronary arteries) and the region to be scanned is not extensive (the heart versus the entire abdomen), then slice thickness can be quite thin.
- If the structures being investigated span a long anatomical region (e.g., the abdomen), then the slice thickness can be 5 to 7 mm.

Volume Averaging

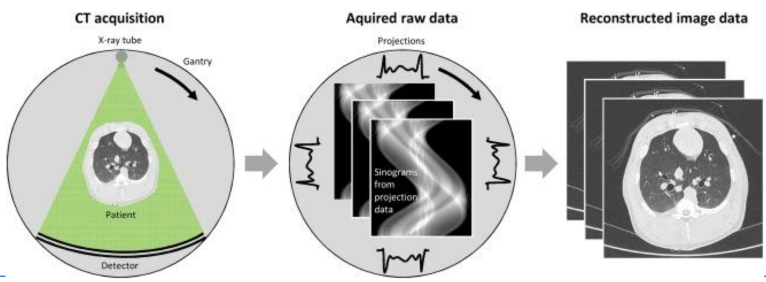
- Quantifying Volume Averaging in a Voxel, If the voxel contains multiple tissue types with different densities, the measured attenuation will reflect an average of their properties.
- The Hounsfield unit of a single pixel is the average of all data measurements within that pixel.
- Complex Mathematical Example: A thick slice setting creates a voxel that captures a boundary containing:
- 30% Bone (1000 HU), 50% Muscle (40 HU), 20% Fat (−100 HU)
- Calculation: $HU_{average} = (0.30\times1000)+(0.50\times40)+(0.20\times-100) = 300+20-20 = 300$ HU
- This type of averaging can lead to inaccuracies in the image, as the scanner outputs 300 HU for a pixel that actually contains three completely different tissues.

Volume Averaging: X and Y

- The larger the X and Y dimensions (i.e., the larger the pixel), the greater the chance that the pixel will contain tissues of different densities.
- Because the Hounsfield unit of a single pixel is the average of all measurements within that pixel, this type of averaging can introduce inaccuracies in the image.
- For example, imagine a pixel containing equal amounts of calcium (600 HU) and lung tissue (−600 HU).
- The resulting density of the specific pixel is the average of the two tissues, or 0 HU.

Raw Data and Image Data

- Raw data: All of the thousands of bits of data acquired by the system with each scan.
- Image reconstruction: creating an image by assigning a Hounsfield unit value for each pixel of the raw data to create an image.
- Image data: the data contained in an image.
- Prospective reconstruction: the reconstruction that is automatically produced during scanning.
- Retrospective reconstruction: the same raw data may be used later to generate new images.



Raw Data and Image Data

- Image reconstruction involves creating an image by assigning a Hounsfield unit value for each pixel of the raw data.
- The CT computer uses the following standard equation to assign these values based on the calculated linear attenuation coefficient (μ): $\mathrm{HU} = 1000 \ \mathrm{X} \ \frac{\mu_{tissue} - \mu_{water}}{\mu_{water}}$
- Standard References: Water (μ_{water}) is the baseline at 0 HU, and Air (μ_{air}) is −1000 HU.
- **Example:** If the CT scanner calculates the linear attenuation coefficient of a suspected tumor to be μ_{tissue}=0.20 cm^{-1} (assuming μ_{water}≈0.19 cm^{-1} and μ_{air}≈0):

$$HU = 1000 \times \frac{0.20 - 0.19}{0.19 - 0} \approx +52 \text{ HU}$$

- The system assigns this pixel a value of +52 HU, corresponding to soft tissue in the image.

Scanning modes: step and shot

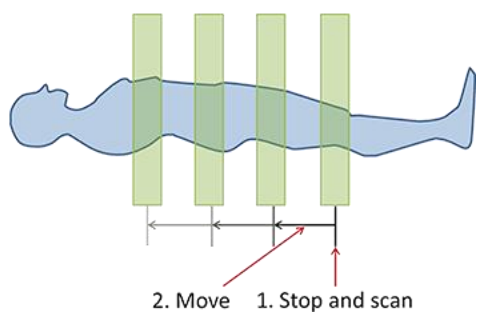
- In these modes:

1) The X-ray tube rotated 360° around the patient to acquire data for a single slice.

2) The motion of the X-ray tube was halted while the patient was advanced on the CT table to the location appropriate to collect data for the next slice.

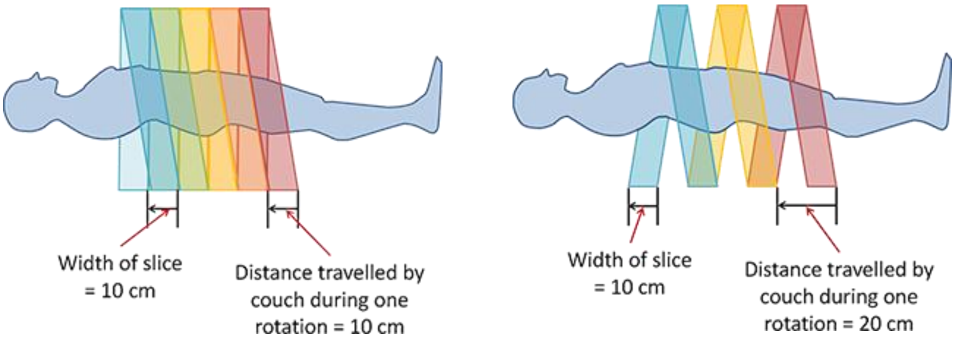
3) Steps one and two were repeated until the desired area was covered.

- The gantry motion had to be stopped before the next slice could be taken.



Scanning modes: Helical (Spiral)

- In 1990, the development of a continuous acquisition scanning mode was allowed, and is most often called spiral or helical scanning.
- Key among the advances was the development of a system that eliminated cables, enabling continuous rotation of the gantry.
- This, in combination with other improvements, enabled uninterrupted data acquisition along a helical path around the patient.



Scanning modes: Helical (Spiral)

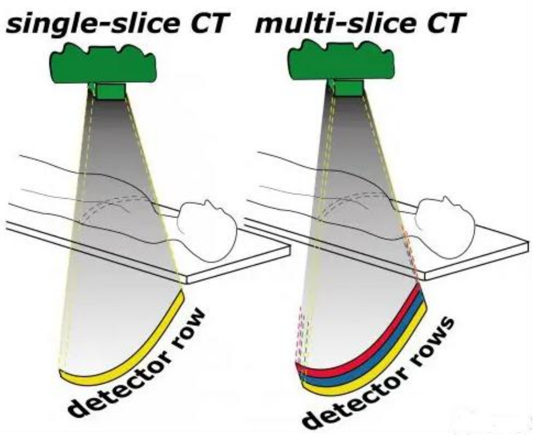
- Helical (Spiral) Scanning: The Concept of "Pitch"
- Helical scanning enables uninterrupted data acquisition along a helical path around the patient.
- A critical design parameter in this continuous acquisition scanning mode is Pitch, which defines the tightness of the X-ray spiral:

$$Pitch = \frac{\text{Table Feed per Rotation}}{\text{Nominal Slice Width}}$$

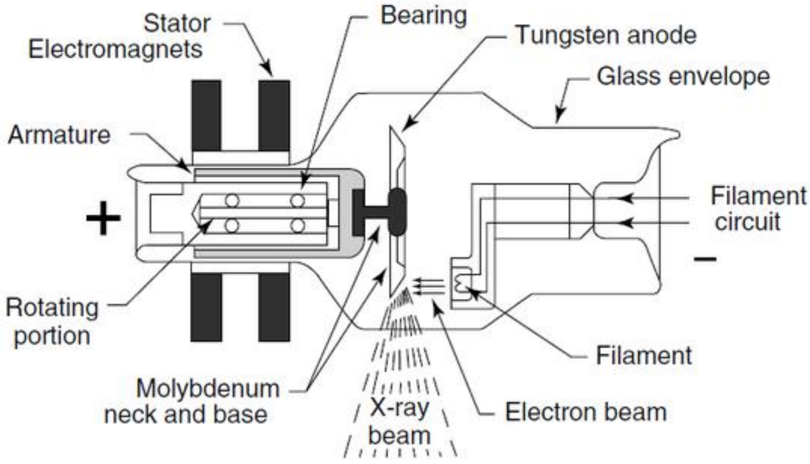
- Calculation from the Previous Diagram:
- Distance travelled by couch during one rotation = 20 cm, Width of slice = 10 cm,
- Pitch=20/10=2.0
- Design Implications:
- Pitch > 1: Faster scan, lower patient radiation dose, but increased risk of missing small details (spirals are stretched).
- Pitch < 1: Slower scan, higher patient dose, but higher image resolution (spirals overlap).

Multidetector Scanner

- The first helical scanners emitted X-rays that were detected by a single row of detectors, yielding one slice per gantry rotation.
- Further improvements equipped scanners with multiple rows of detectors, allowing data for many slices to be acquired with each gantry rotation.



Overview of CT System



Overview of CT System