CT Physics

Brant and Helms 2018

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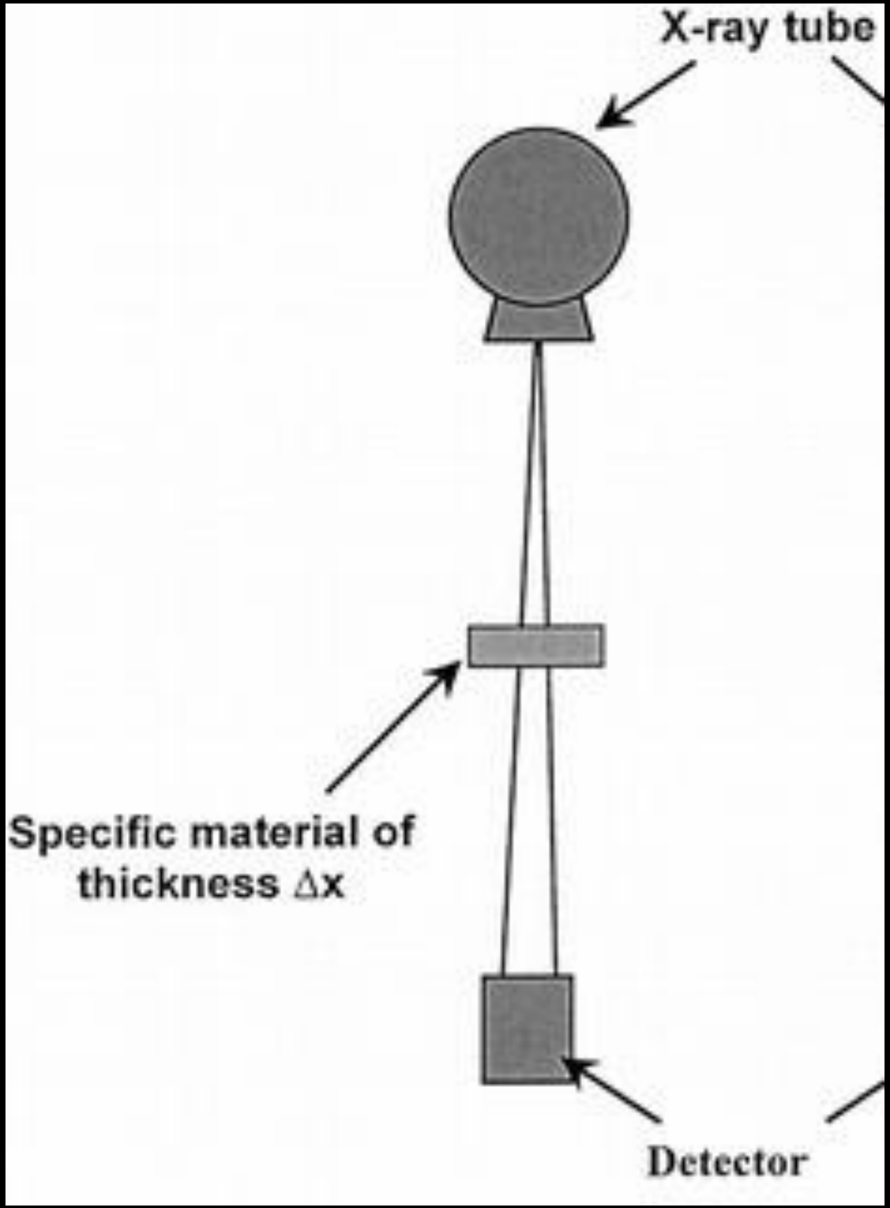
Outline

- Acquisition and Reconstruction
- Hounsfield units
- Image Display (windows and levels)
- Artifacts

Acquisition

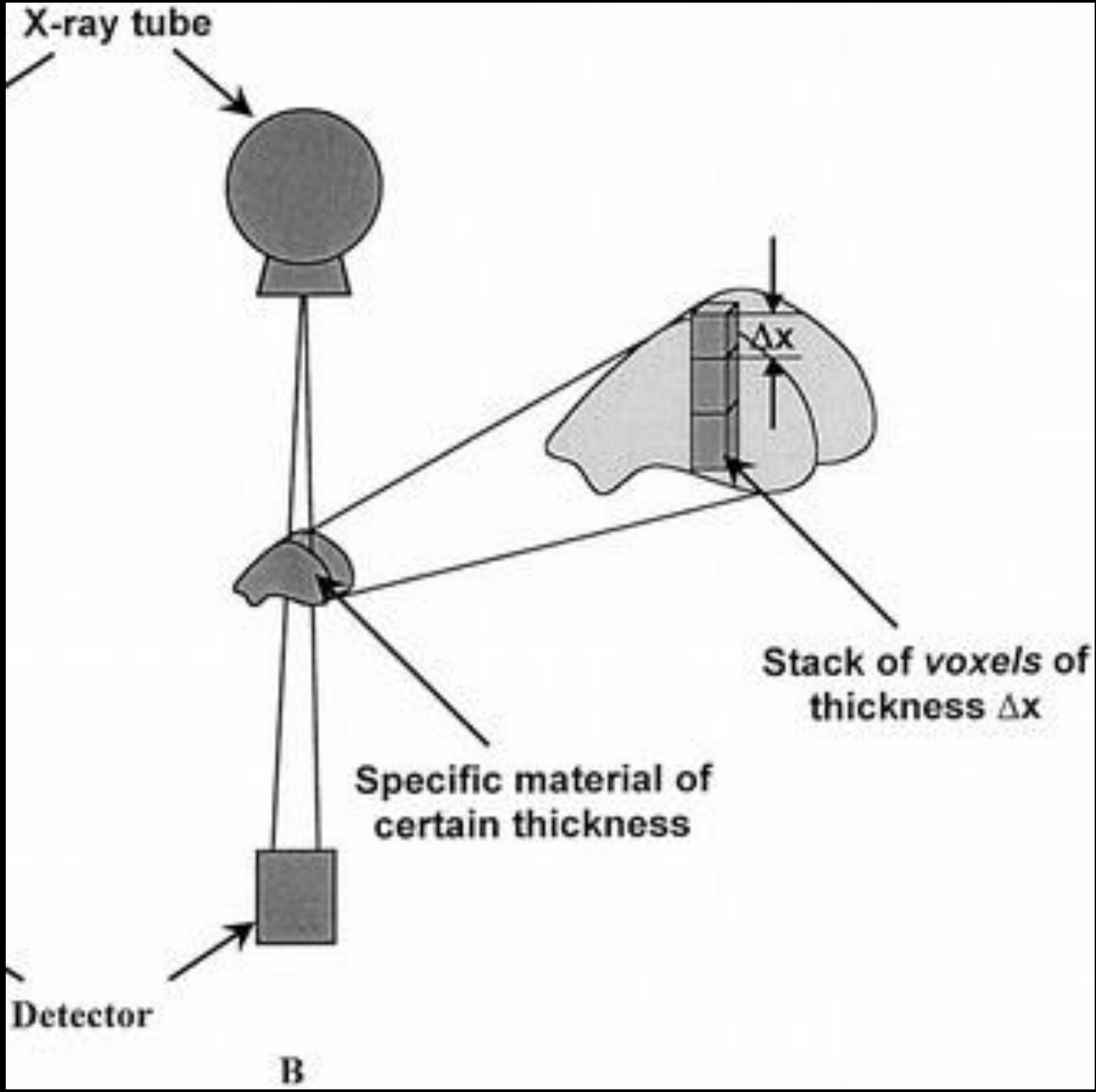


$$I_t = I_o e^{-\mu \Delta x}$$

- I_t is the x-ray intensity measured at the Detector
- I_o is the x-ray intensity at the source
- Δx is the thickness
- μ is the UNKNOWN linear attenuation coefficient of the material

→ Solve for μ

Acquisition

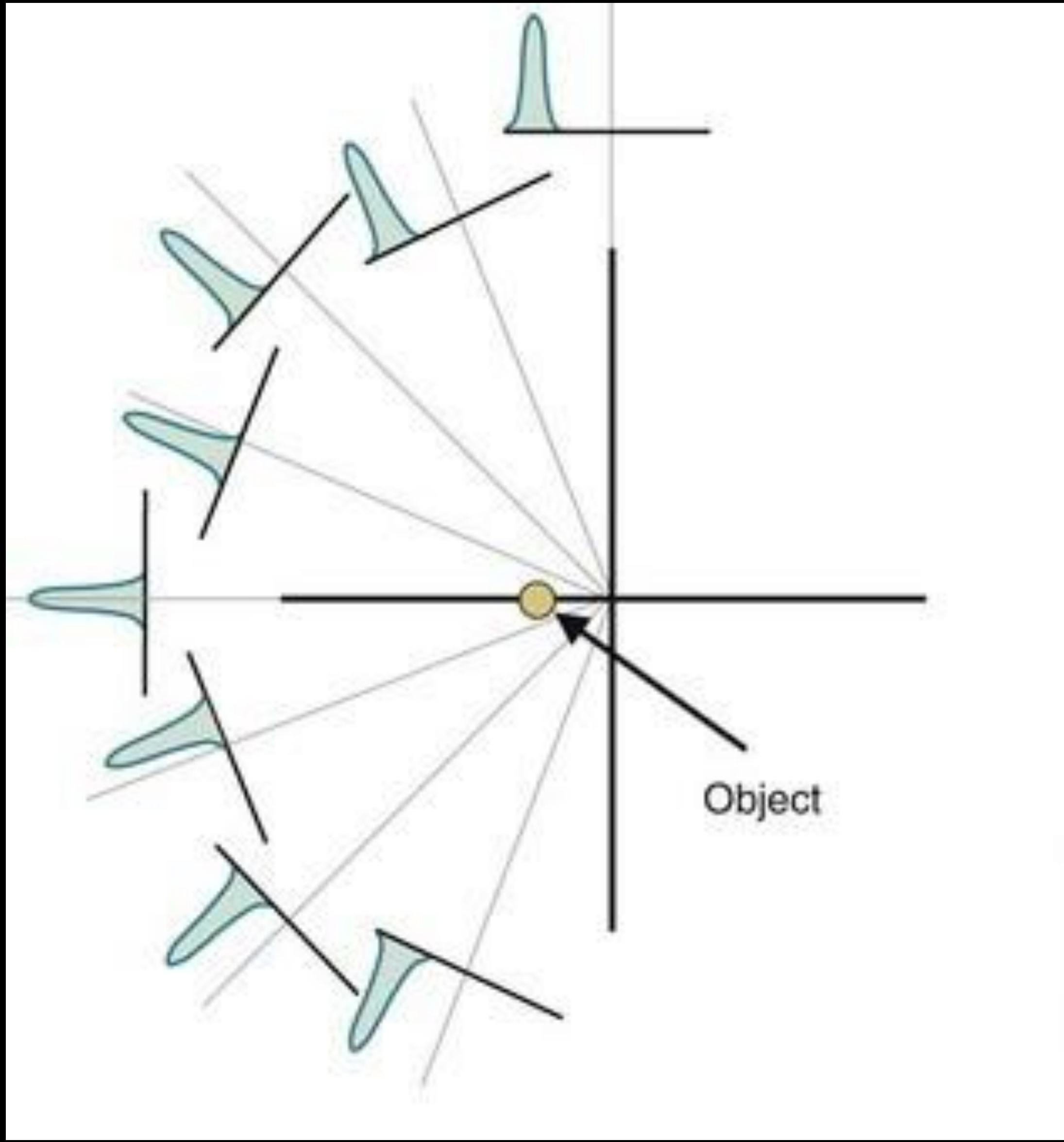


$$I_t = I_o e^{-\sum_{i=1}^{k} \mu_i \Delta x}$$

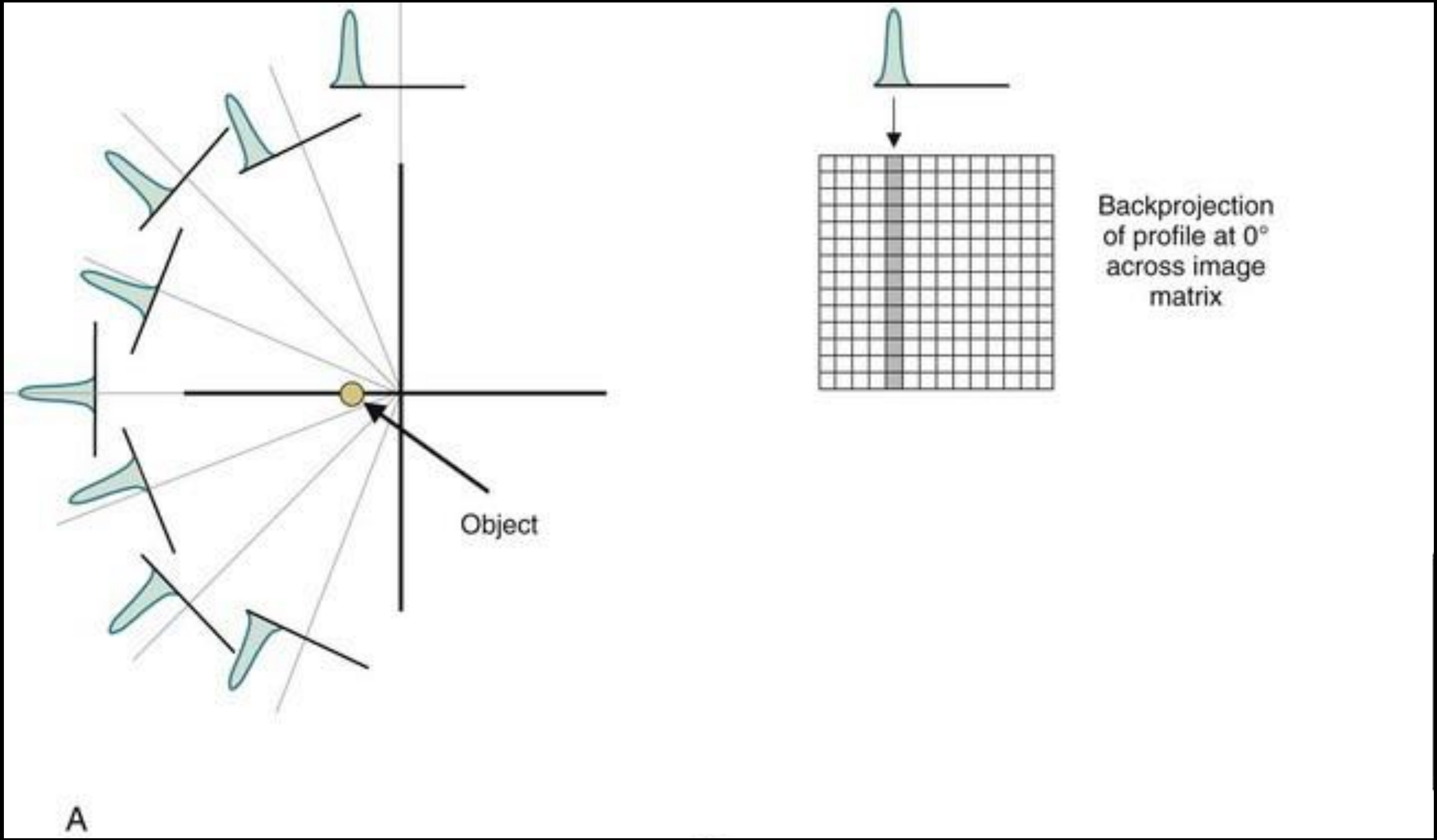
- In reality, our xray passes through multiple voxels each with an unknown μ_i
- Now we have 1 equation and multiple unknown variables, μ_i

→ cannot solve

Acquisition: multiple projections



Reconstruction: Filtered Back Projection



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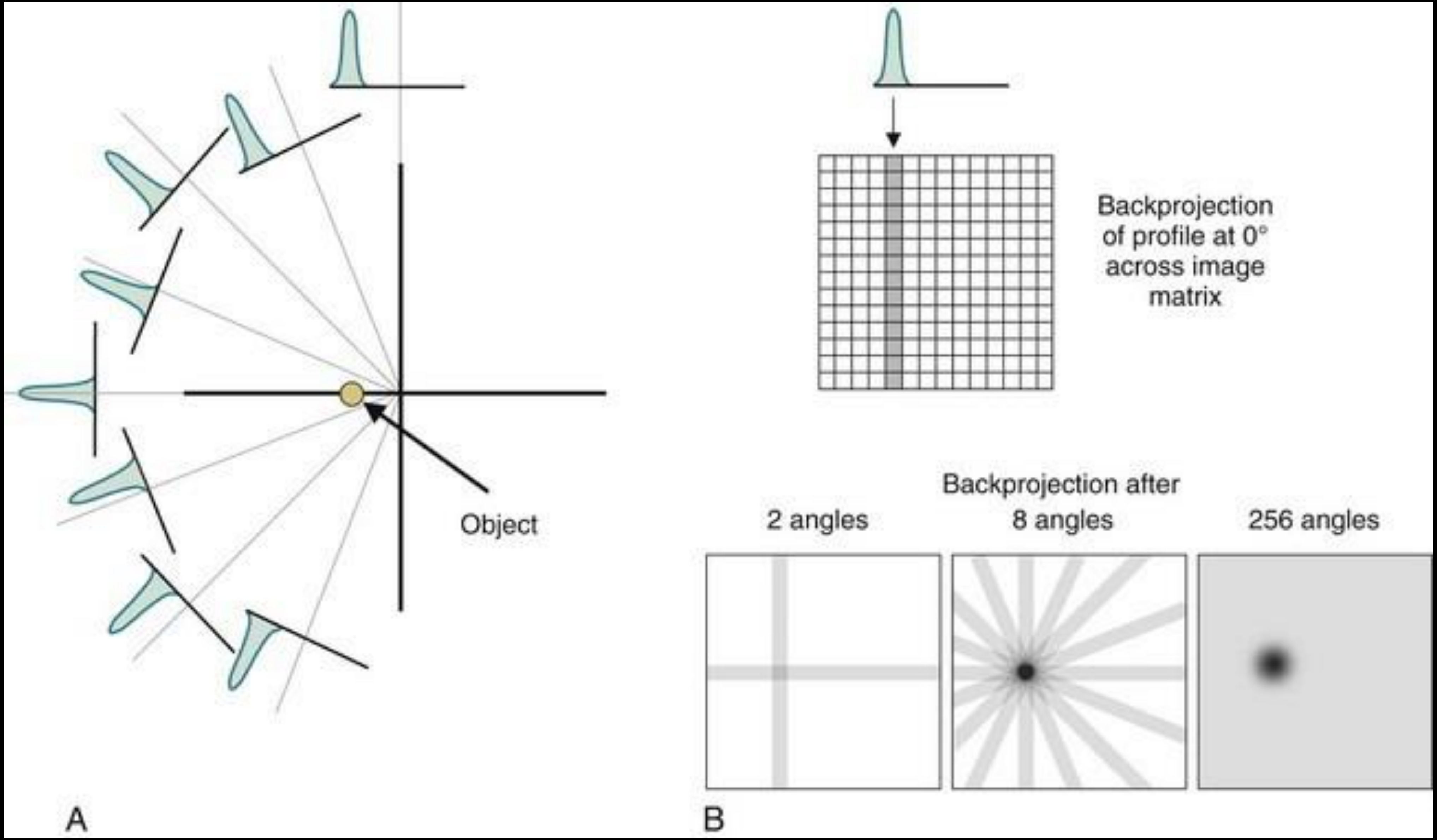

Reconstruction: Filtered Back Projection

- What does “Filtered” refer to in Filtered Back Projection?

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Reconstruction: Filtered Backprojection

- What does “Filtered” refer to in Filtered Backprojection?
- Projection data are multiplied by a mathematical reconstruction filter (MRF) prior to back projection
- Different filters (MRF) can be applied
  - ‘sharpen’ the image (ie. Bone)
  - ‘smooth’ the image (ie. Soft tissue)

Reconstruction: Hounsfield units

- The result of filtered back projection is a map of estimated attenuation values
- These values are scaled to produce Hounsfield units
- Hounsfield unit = $(\mu_i - \mu_w) * F$

  μ_i is the attenuation of the material of interest in a voxel

  μ_w is the attenuation of water

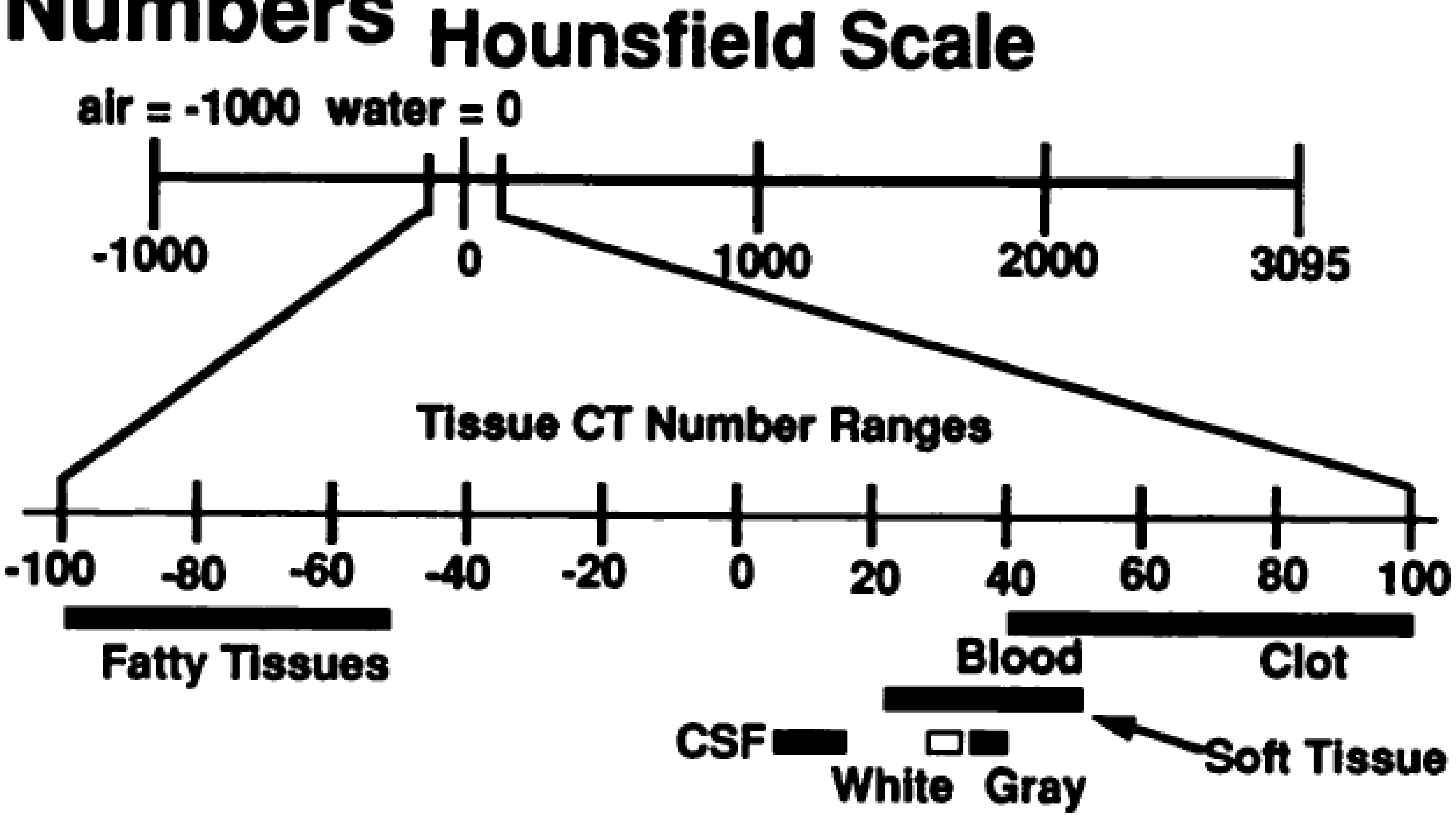
  F is a scaling factor
- Hounsfield units are also called “relative attenuation values” or “CT numbers”

Hounsfield units

- Water = 0
- Air = -1000

- At 120 keV:
  - Fat ≈ -100
  - Soft tissue ≈ 50
  - Bone > 1000

CT Numbers


Hounsfield Scale
air = -1000 water = 0
-1000
0
1000
2000
3095
Tissue CT Number Ranges
-100
-80
-60
-40
-20
0
20
40
60
80
100
Fatty Tissues
Blood
Clot
CSF
White
Gray
Soft Tissue

Hounsfield units (HU) vary with acquisition and reconstruction parameters

- HU depend on attenuation coefficients, μ

recall: $HU = (\mu_i - \mu_w) * F$

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- The attenuation of the xray depends the material, but also on KeV

Hounsfield units (HU) vary with acquisition and reconstruction parameters

- HU depend on Attenuation coefficients, μ

recall: $HU = (\mu_i - \mu_w) * F$

- Attenuation coefficients depend on the material, but also on KeV
- keV (kiloelectron volts) – voltage. Can think of this as the photon energy of the xrays

Hounsfield units (HU) vary with acquisition and reconstruction parameters

	Photon Energy (keV)			
Photon Energy	40	50	60[a]	80
Fat	–150	–110	–90	–70
Soft tissue	60	56	53	50
Cortical bone	3,800	2,600	4,000	2,100
Dilute iodine[b]	400	300	200	100

[a]Average energy expected for CT spectra obtained at 120 kV.
[b]Obtained by dividing the computed iodine HU by 1,000.

- Chart shows HU for different materials at different keV

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- Lower keV → Increases Contrast of the image

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- Lower keV → reduces radiation dose

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- Lower keV → less penetration (bad for larger patients)

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- kVp (peak keV of xray beam) is usually 80 - 140 keV

Hounsfield units (HU) vary with acquisition and reconstruction parameters

- Acquisition
  - keV

    Lower keV → Increases Contrast of the image

  - Resolution

    Larger voxels → more partial volume effects
    (ie. voxel more likely to contain mix of fluid, soft tissue)

    Voxel size (mm) = FOV (mm) / Matrix size (unit less)

Hounsfield units (HU) vary with acquisition and reconstruction parameters

- Acquisition
  - keV
  - *Resolution (partial volume effects) – practical consideration, not test answer*

    "Too small to characterize, but likely a benign cyst"
- Reconstruction
  - Filtering that's done during Filtered Back Projection

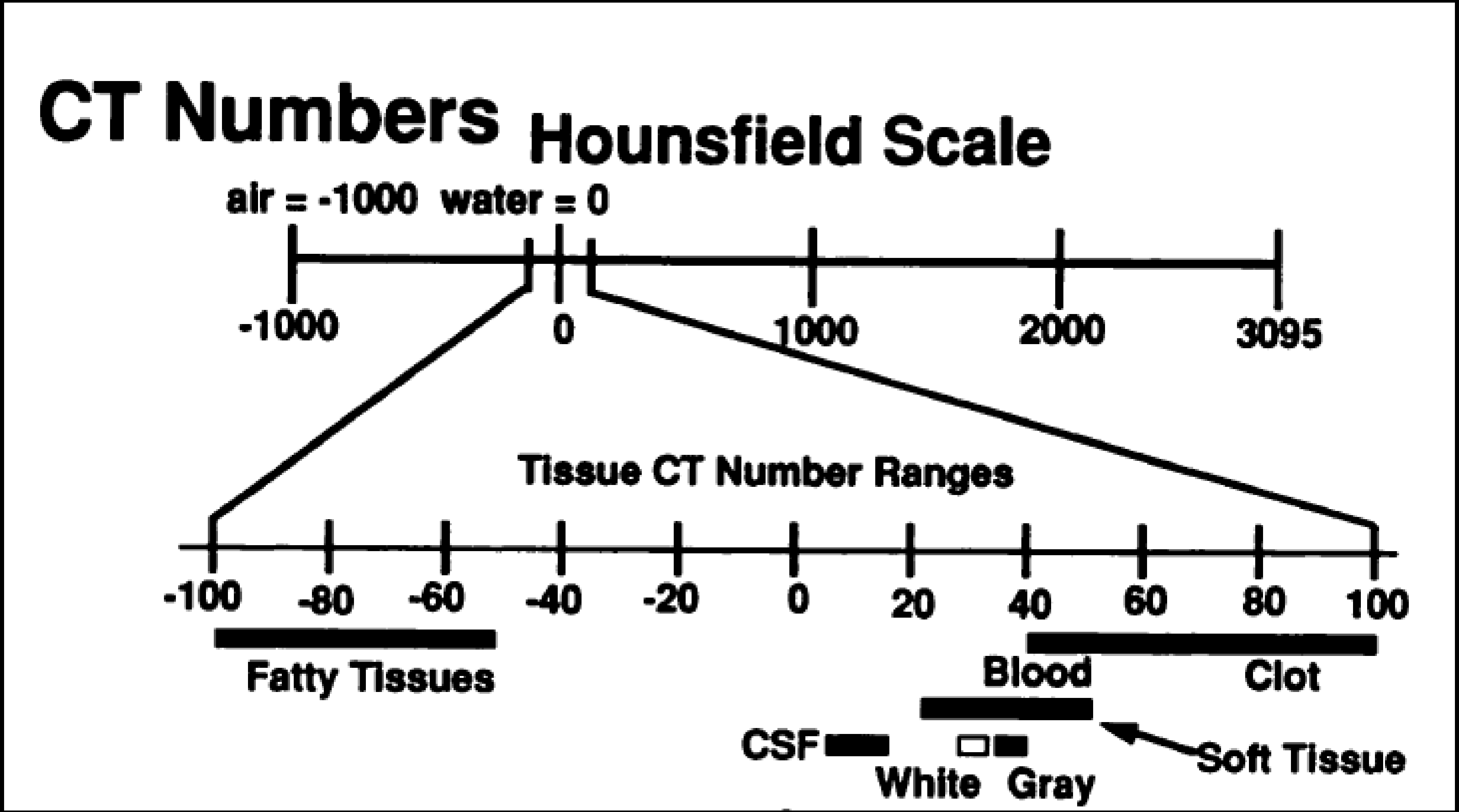
Outline

- Acquisition and Reconstruction
- Hounsfield units

→ Image Display (windows and levels)

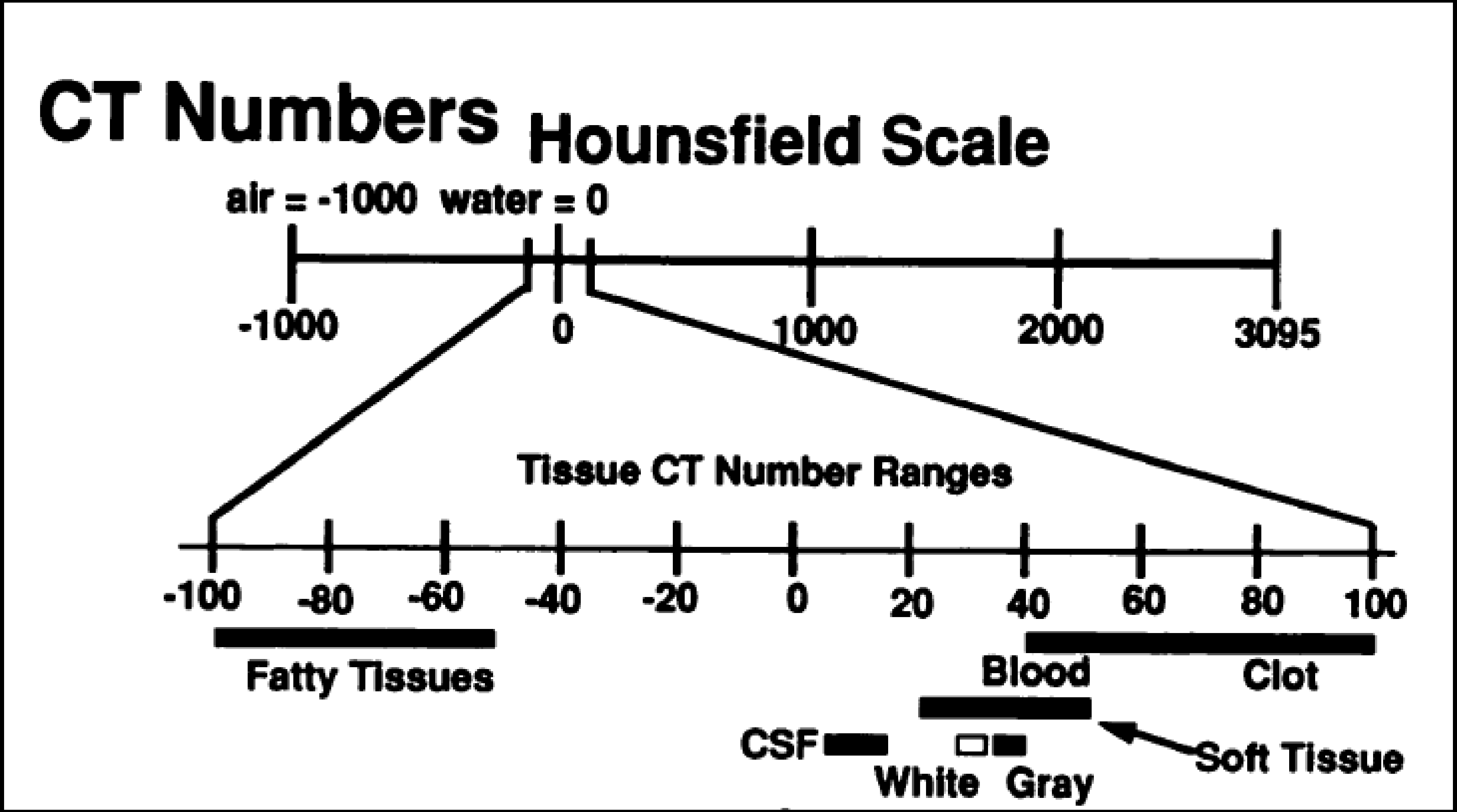
- Artifacts

Image Display : Windows and Levels



Range of possible HU = 4096 = 2^{12} (12 bits of memory allocated)

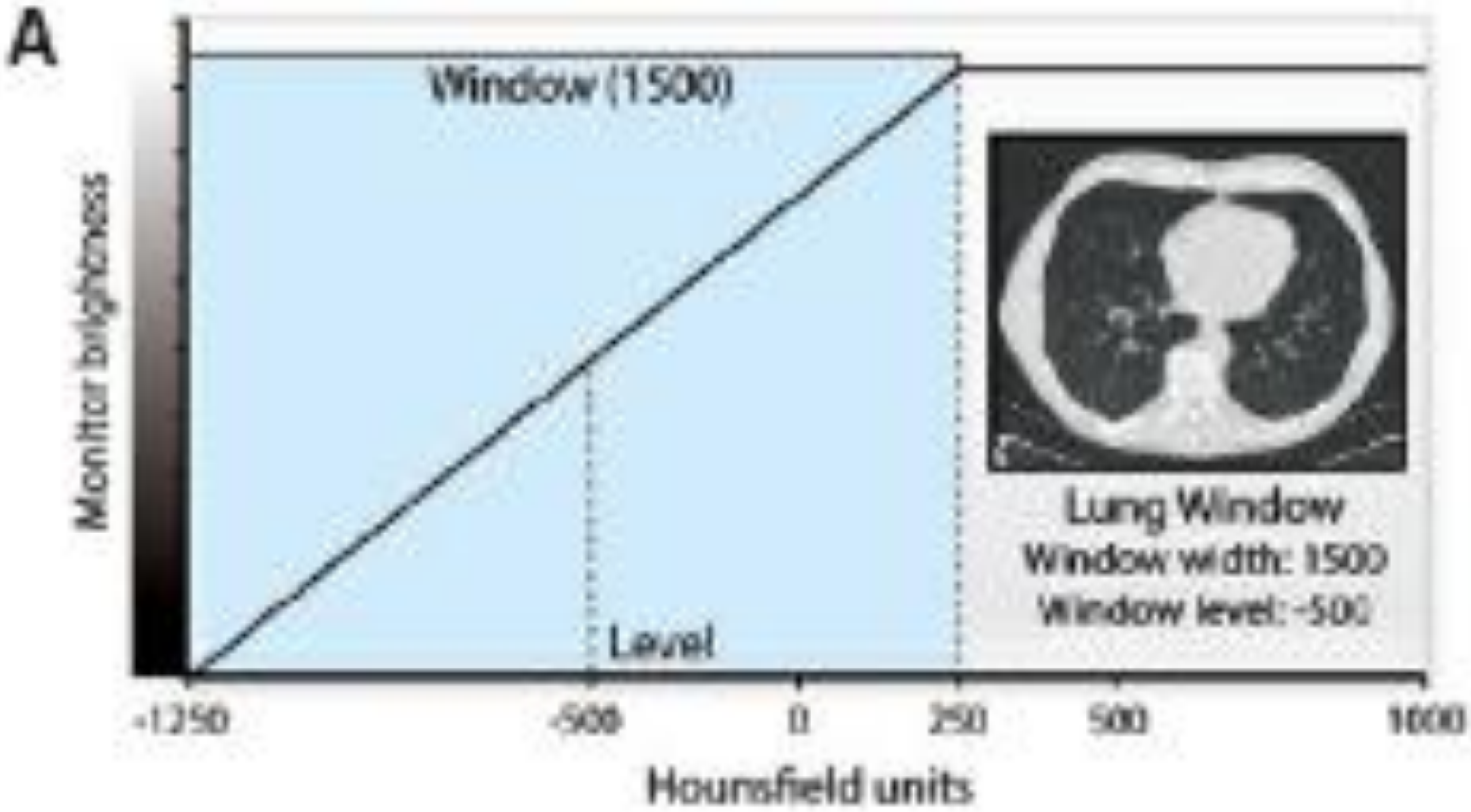
Image Display : Windows and Levels

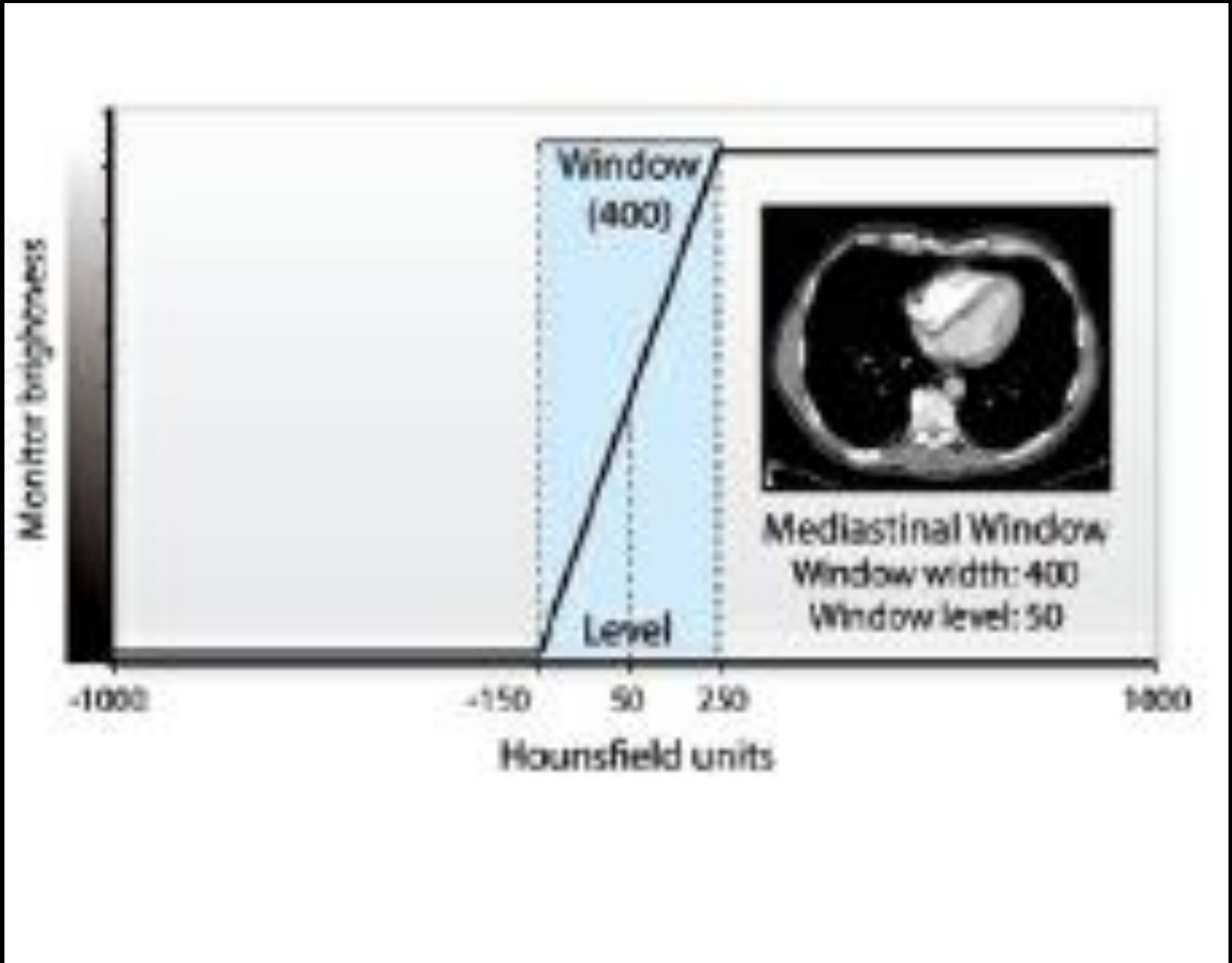


Human visual system cannot perceive 4096 shades of grey

Image Display : Windows and Levels

- Window
  - defines the range of HU that are mapped to displayed grayscale values
- Level
  - defines the center of that range


A
Window (1500)
Monitor brightness
Lung Window
Window width: 1500
Window level: -500
Level
-1250
-500
0
250
500
1000
Hounsfield units

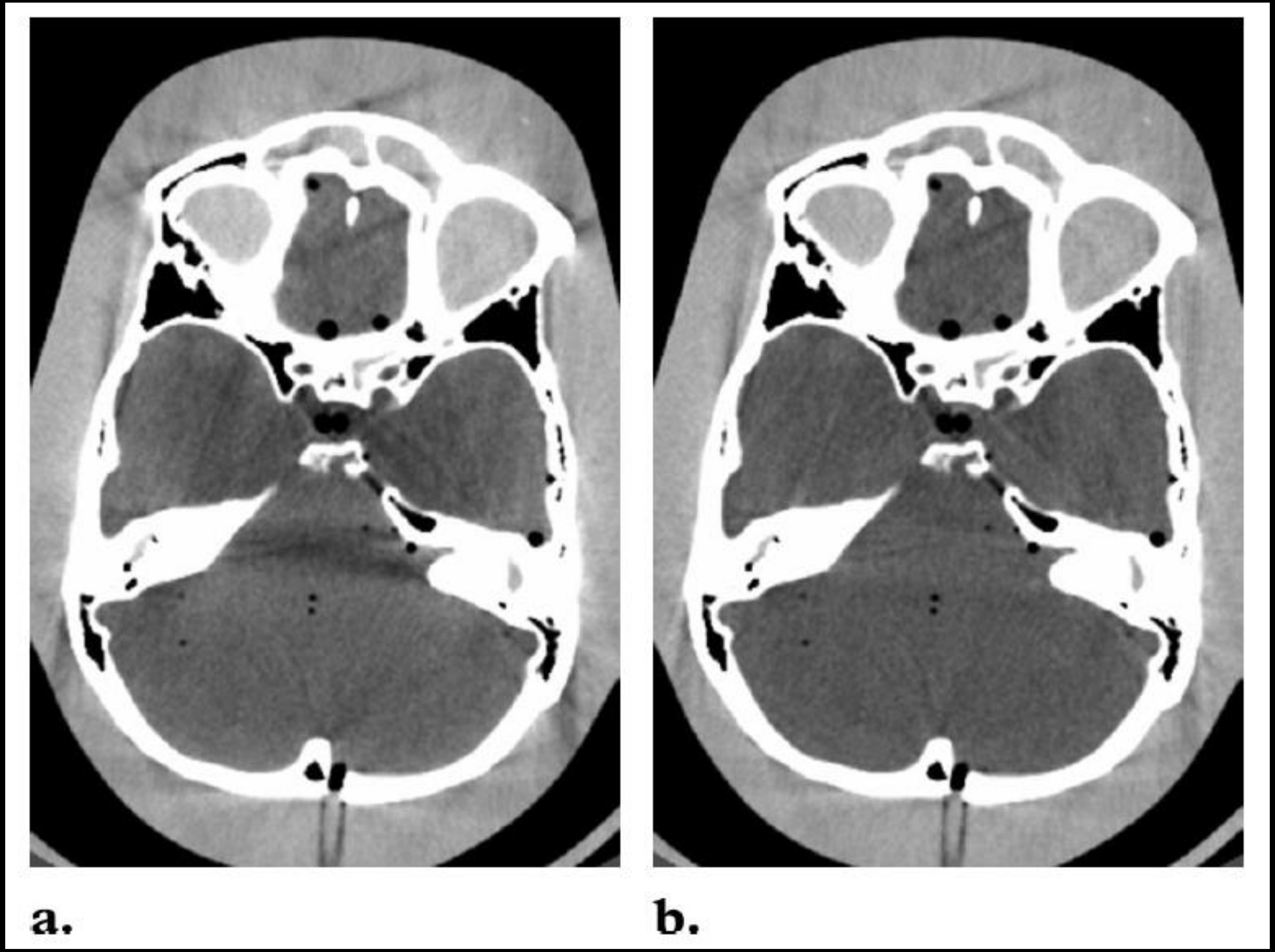


- Decreasing (narrowing) the window width → increases contrast
- Decreasing the level → increases brightness of image

Common Artifacts

- Beam Hardening
- Streak artifact
- Motion artifact

Beam Hardening



Streak and motion artifacts

References

- Huda, W. Review of Radiologic Physics, 4th ed. Lippincott Williams & Wilkins, Jan 20, 2016.
- Barnes, J. Radiographics. 1992. 12:825-837.
- Barrett, J, et al. Radiographics 2004; 24:1679–1691.
- Siegel MJ, et al. Radiology. 2004 Nov;233(2):515-22.