Imaging Physics – Computed Tomoography CT

Ayelet Akselrod-Ballin, PhD

Imaging Physics – CT

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- 02 | Contrast Phases
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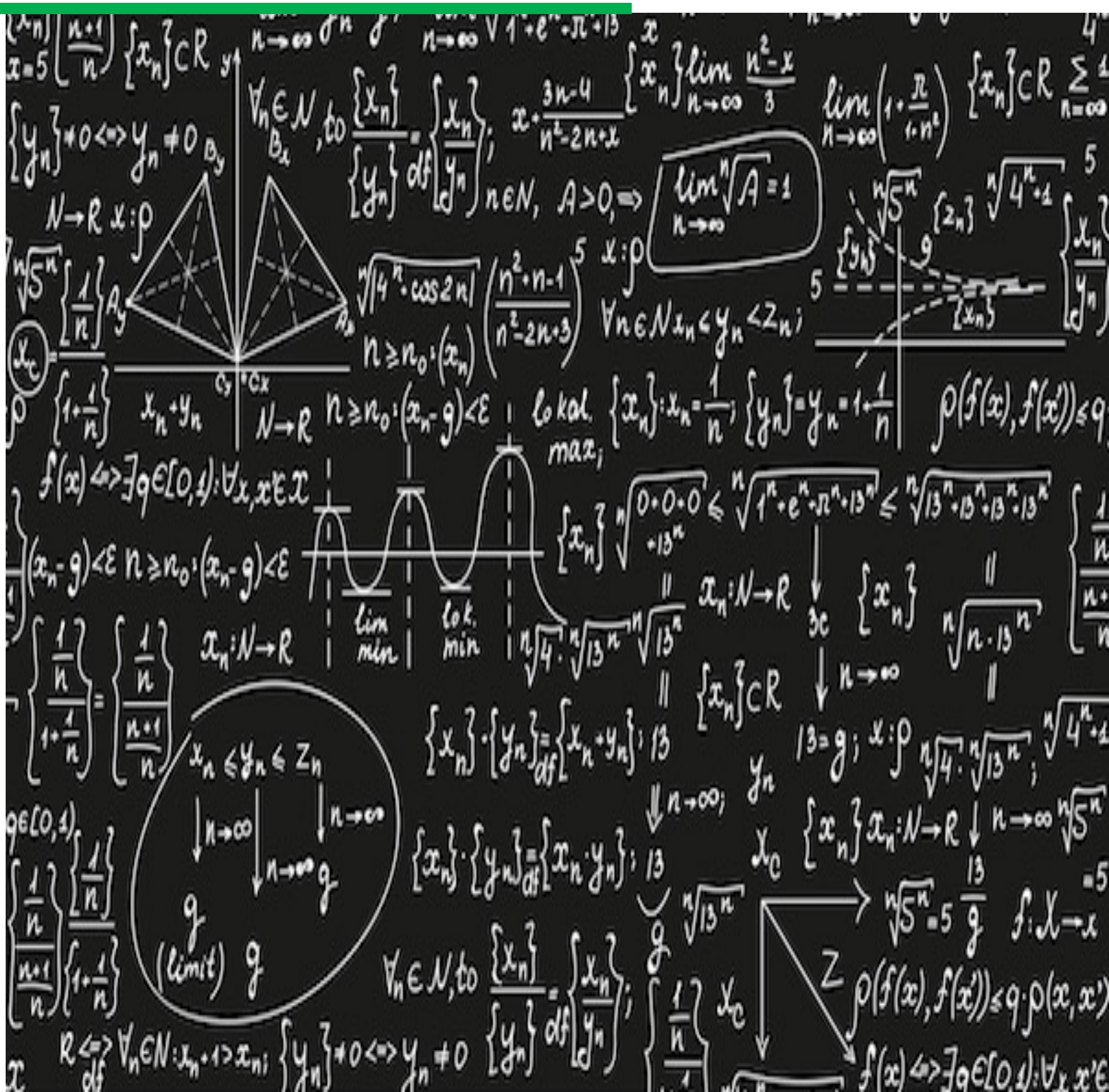
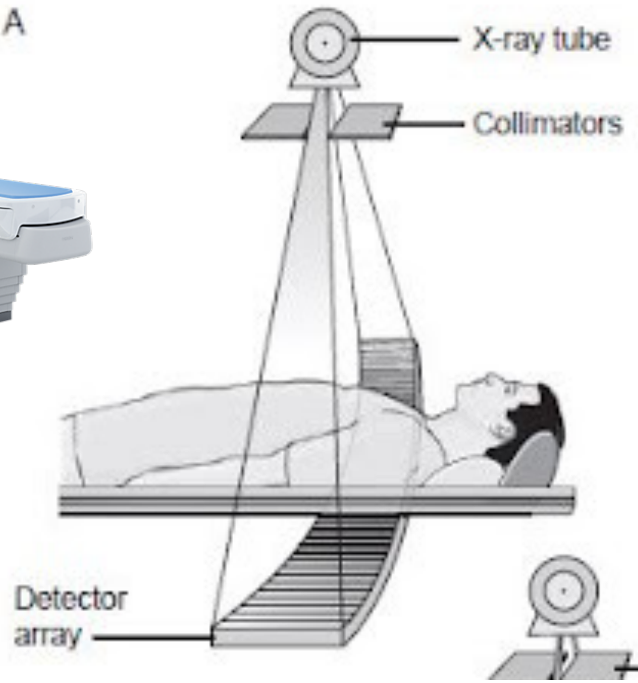
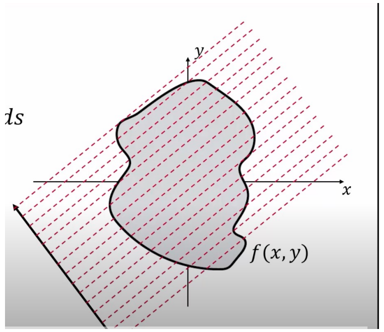
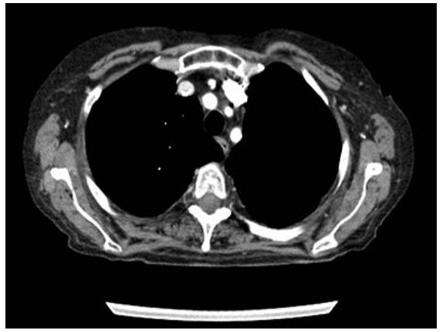


Introduction



- Transmission of X-ray made at several different angles or projections.
- The x-ray tube produces high energy photons that go through the body and the detectors measure the attenuated photon energy.
- monoenergetic x-rays trasversing matter are attenuated exponentially according to the formula $I = I_0 e^{-\mu x}$
- Various types of CT's have been designed – motion, geometric design detector type, etc.
- Acquisition modes: Parallel, Fan, Cone Beam

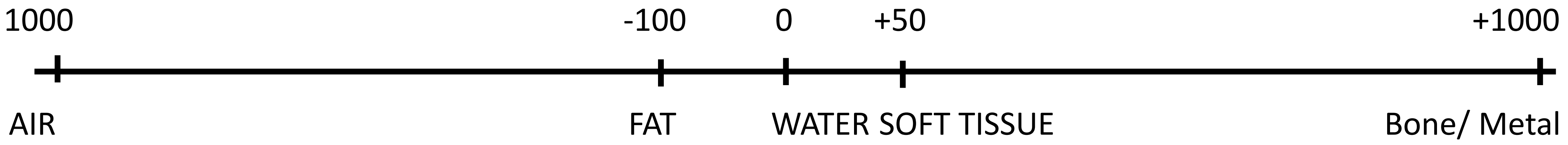




(1) Hounsfield Unit (HU)- Density

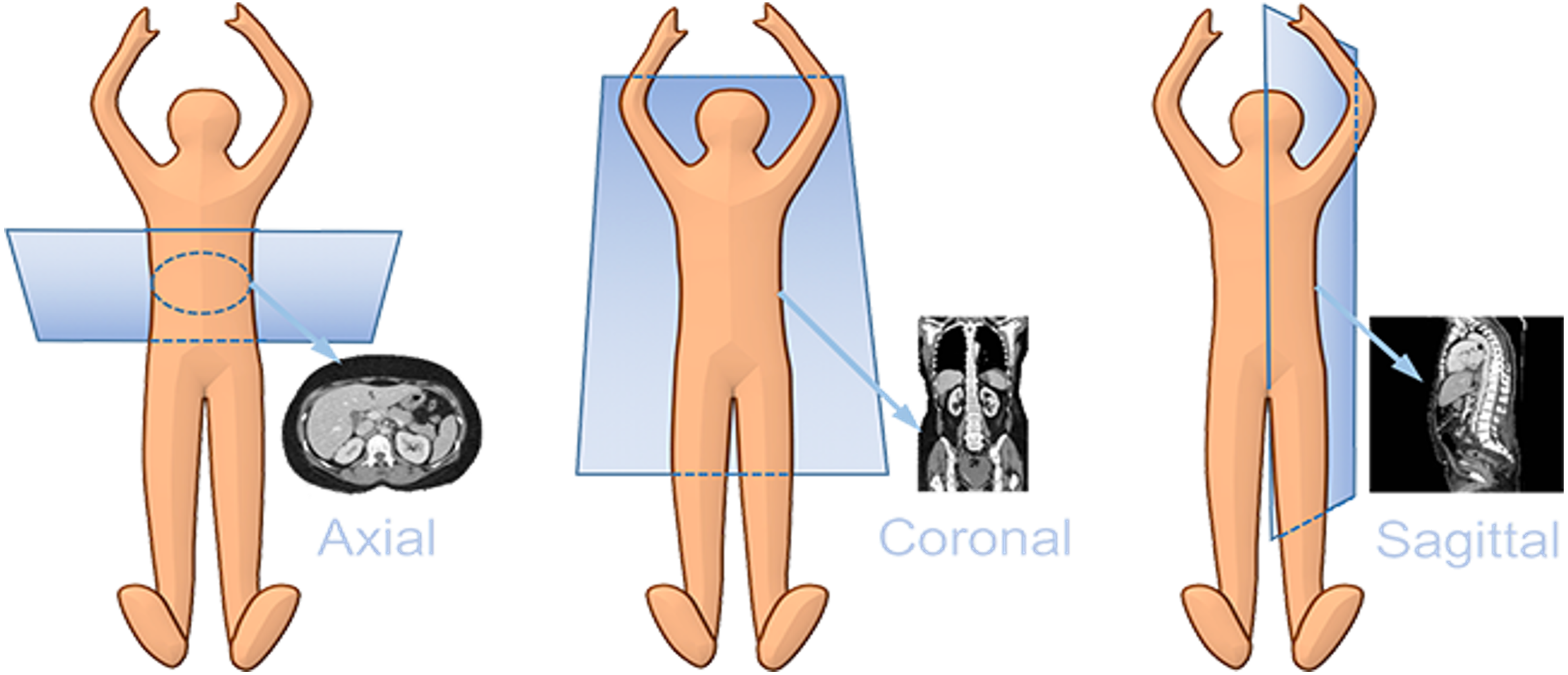
- Grey levels on CT images represent attenuation in each voxel
- The scale is expressed in HU. By convention Air =-1000, pure water =0
- Bone is 1000-3000 HU

$$HU = \frac{\mu_{object} - \mu_{water}}{\mu_{water}} \times 1000$$

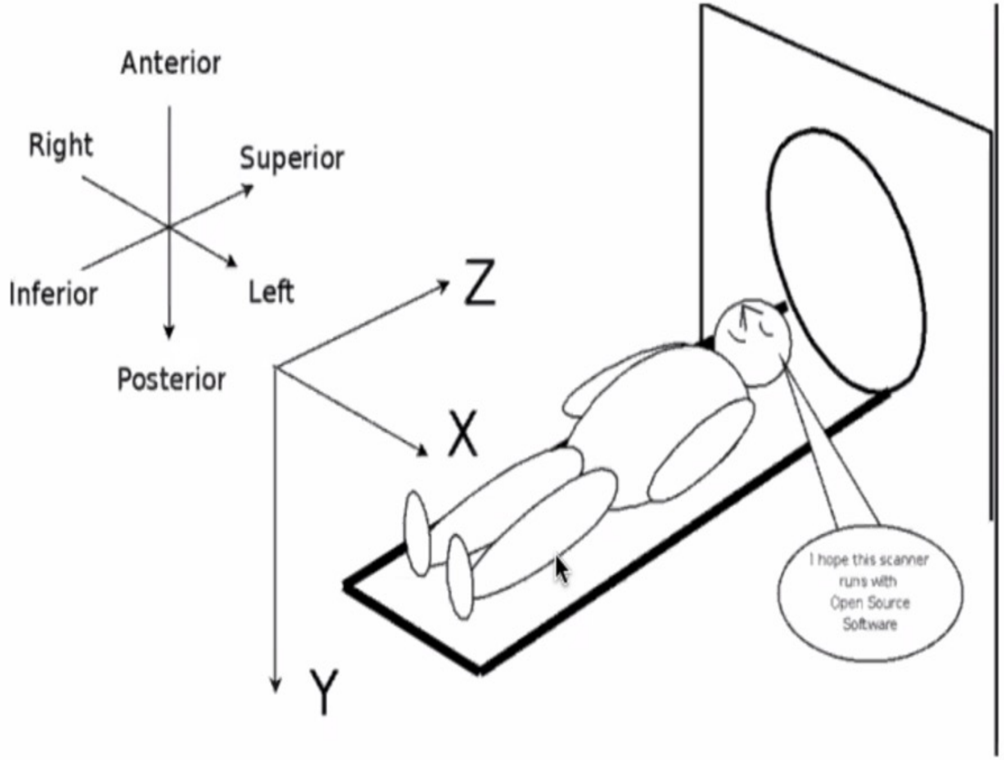


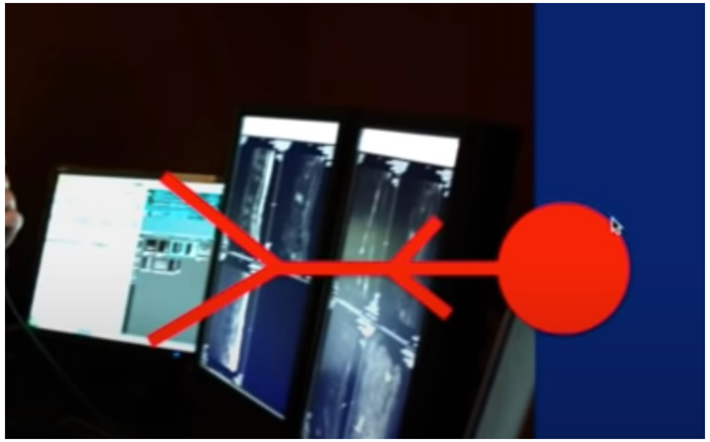
(2) CT Planes

Every CT scan consists of hundreds of thin **slices** along an axis. Scanners produce axial planes – other planes are generated by reformatting



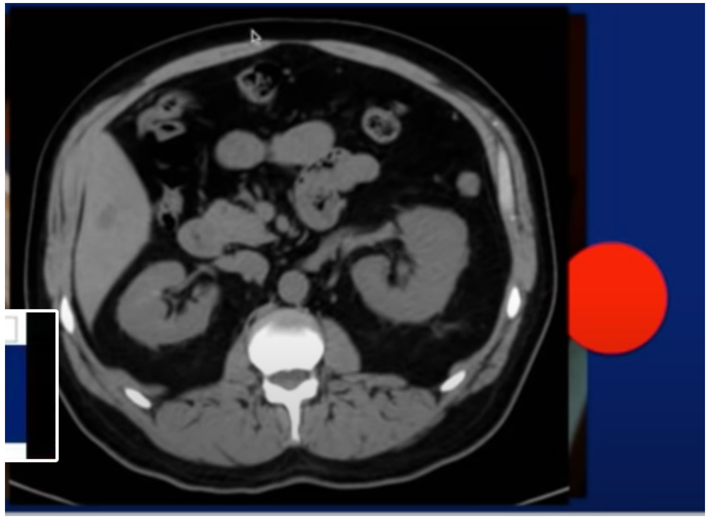
(3) Positioning





Anterior

R



L

Posterior

You picture the Head is in the screen and feets are toward you

https://www.navigatingradiology.com/

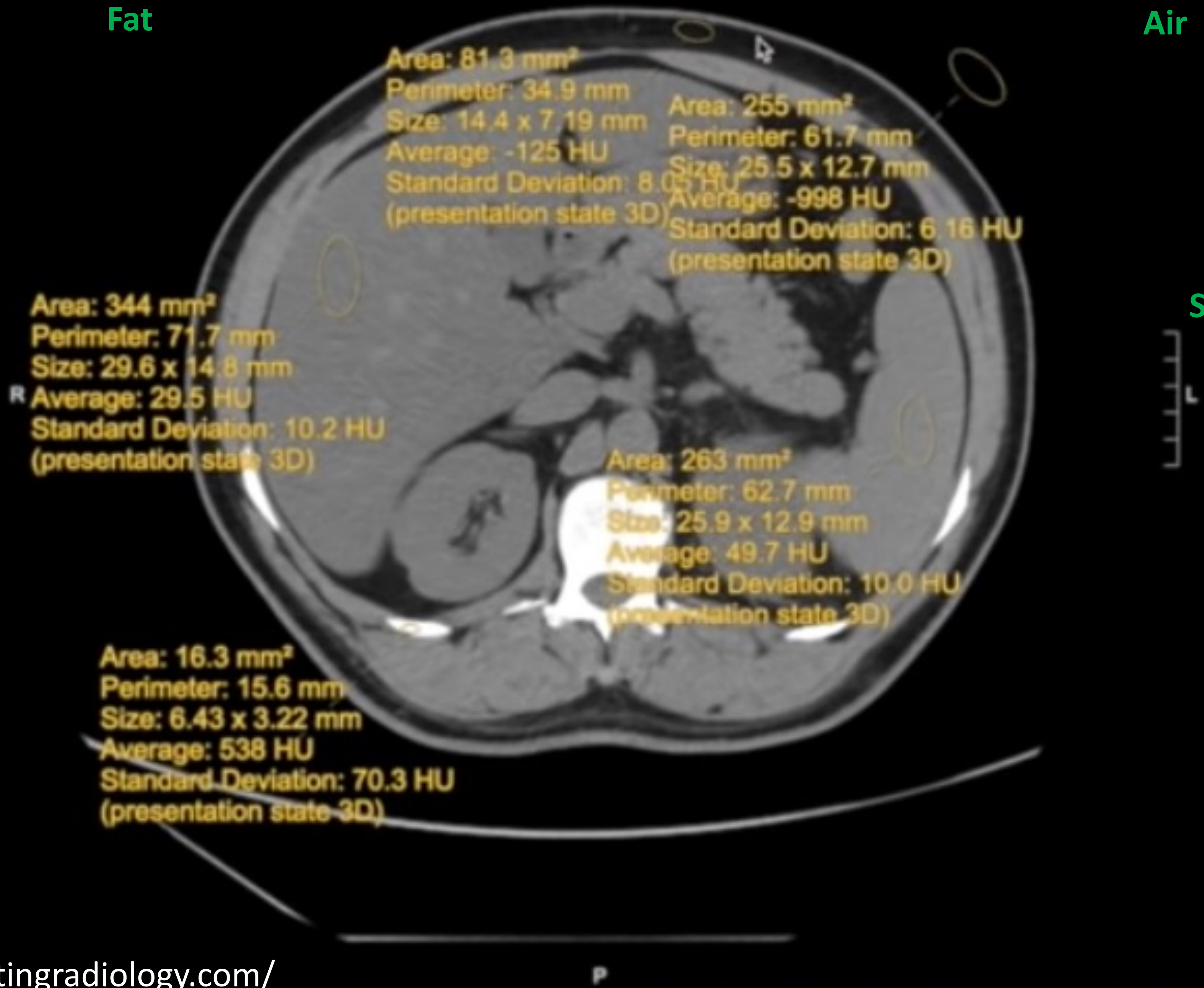
Fat

Air

Liver

Spleen

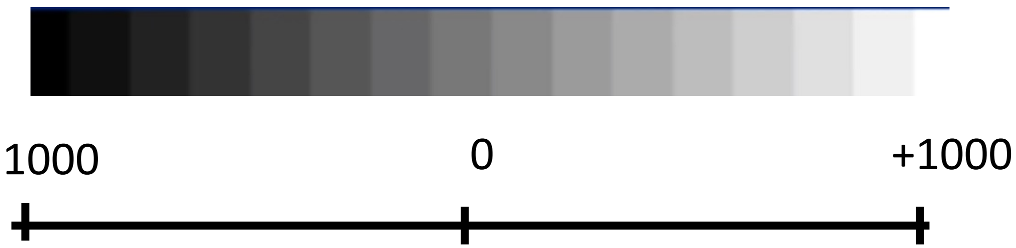
Rib



https://www.navigatingradiology.com/

(4) Window Width and Level

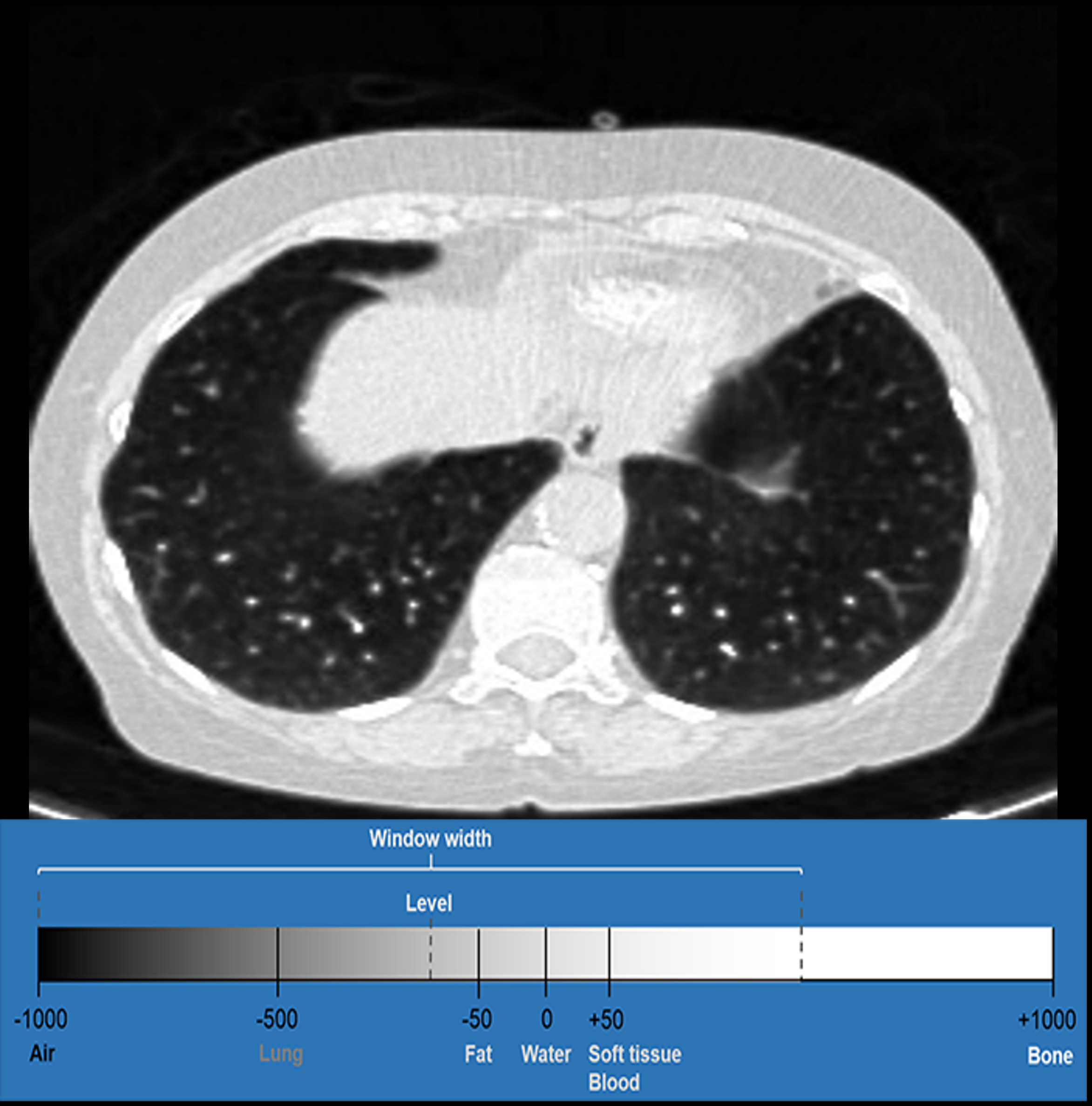
- Improves ability to diferentiate between subtle differences of signal and background
- Width: values below/above the lower/upper threshold are displayed as black/white
- Level corresponds the the number the distribution is centered upon
- Ball park numbers:
  - Soft tissue abdomen: W 350/ L50
  - Lung: W 1600 / L -600
  - Bone: W 2000 / L 500
  - Brain: W 70 / L 30
  - Stroke: W 30 / L 30
  - Blood: W 180 / L 80

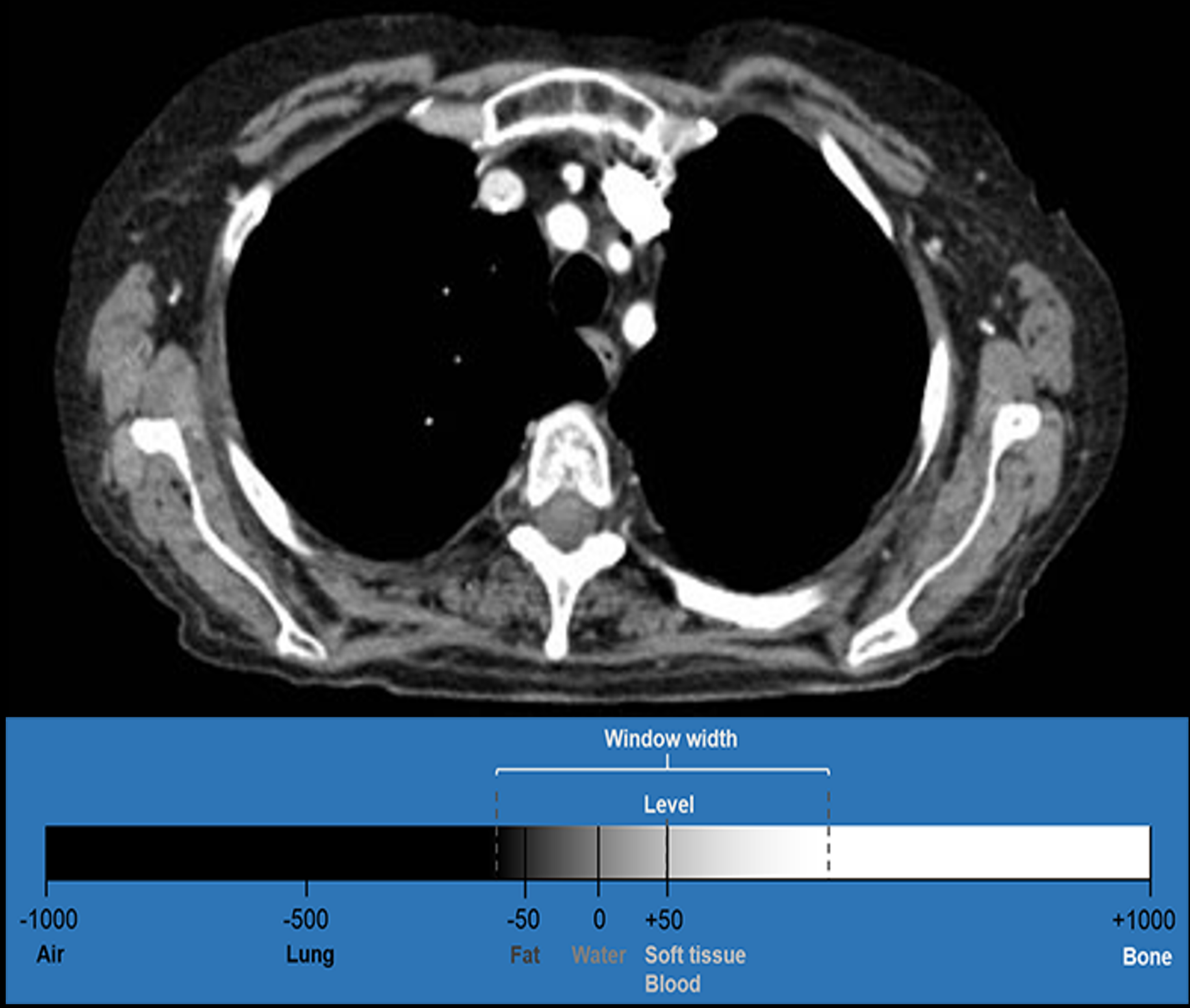


$$C = \frac{\mu_s - \mu_b}{\mu_b - \mu_l}$$

https://www.navigatingradiology.com/

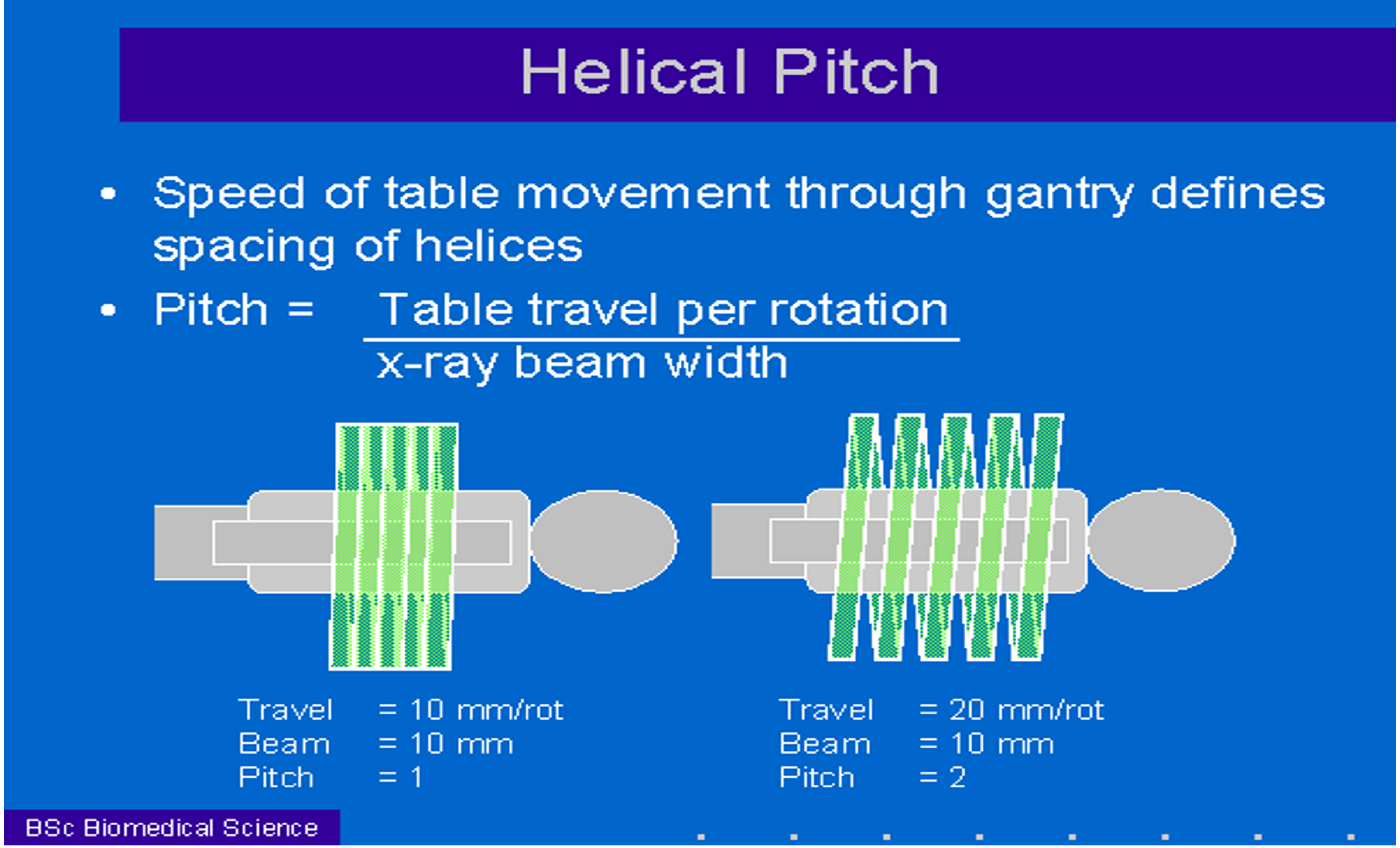
Chest CT - Different windows





(5) Acquisition parameters

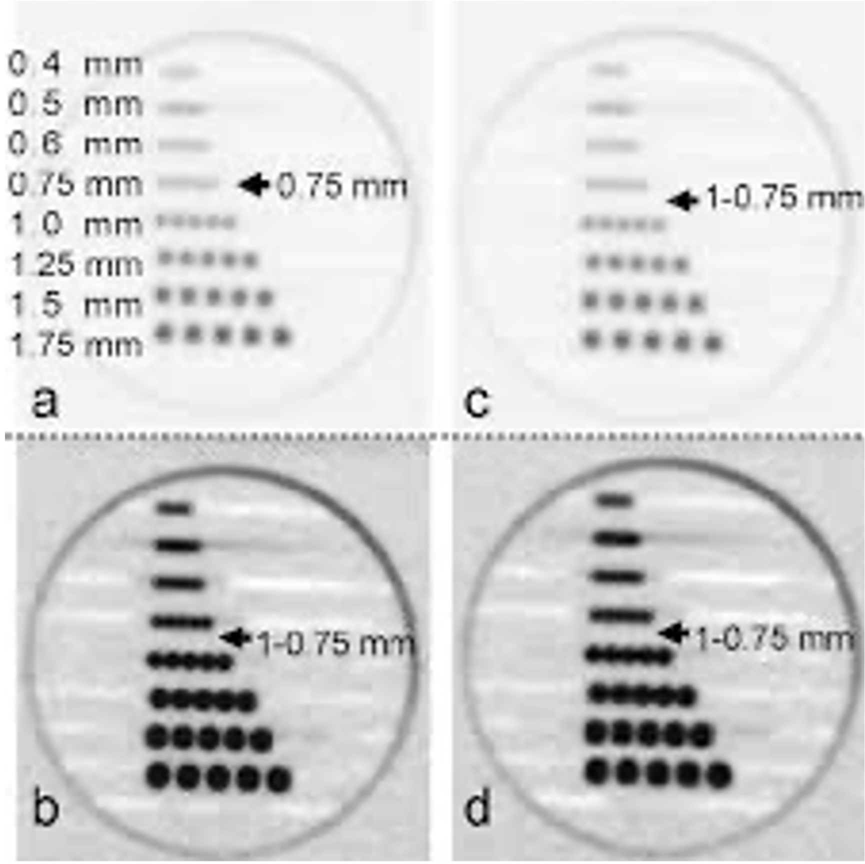
- Tube potential (80:140 kVp)
  - The voltage between the filament (cathode) and anode
  - Higher potential accelerated electorns more – giving them and X-rays more energy.
- Tube current (20:500 mA)
  - Current flowing through the tube filament
  - Larger current produces more elecctronns, and greater X-ray beam intensity.



- Spiral/ Helical scanner: This approach incorporated a moving table during the rotation of the x-ray tube.

❖ מהירות הסיבוב של השפופרת הנע בין 0.28 שניה ועד 2 שניות לסיבוב תלוי ביצרן.

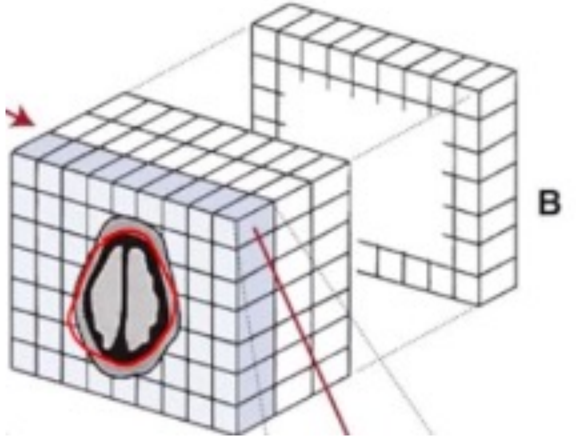
(6) Resolution



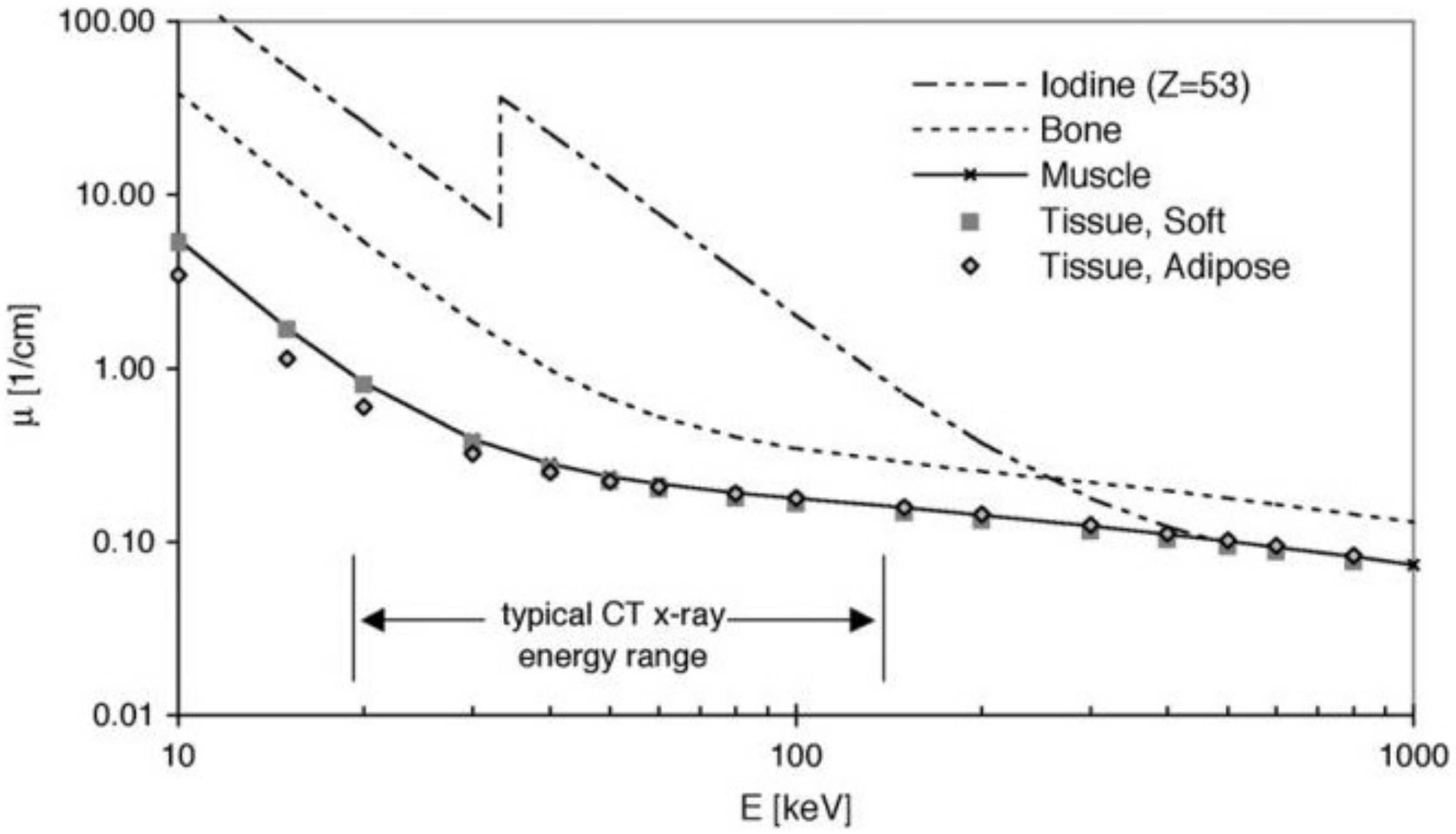
Spatial resolution in CT is the ability to distinguish between object or structures that differ in density.
A high spatial resolution is important for one to discriminate between structures that are located within a small proximity to each other.

Factors affecting CT spatial resolution

- field of view : as the FOV increases so do the pixel size; resulting in a decrease
- pixel size: the smaller the pixel size the higher the spatial resolution
- focal spot size: a larger focal spot will decrease the resolution
- magnification : increasing will decrease the resolution
- motion of the patient
- pitch : is inversely related to the resolution, the higher the pitch the less the resolution
- kernel : edge enhancement kernels will have a higher resolution than soft tissue kernels
- slice thickness : the larger the slice thickness the lower the resolution
- detector size : increase in detector size decreases resolution



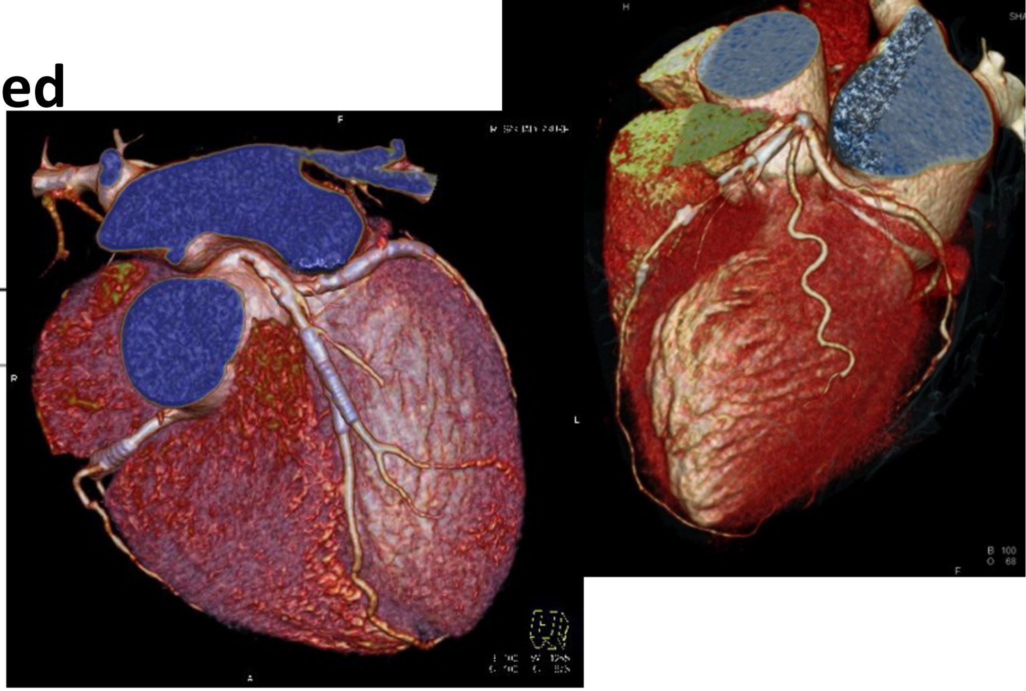
https://radiopaedia.org/articles/spatial-resolution-ct



Linear attenuation coefficient versus x-ray energy. For CT imaging, the body is imaged with x-rays in the range of 20–140 keV. In this range, soft tissues have little variation in their attenuation coefficients, leading to low soft tissue contrast and the need for contrast agents such as iodine.

Medical Imaging – vol 1, J. Beutel, H.Lundel, R.L. Van Metter, SPIE press , 2000

Table 1 **Temporal:** **# detectors, Table speed, Turn speed**



Spatial, contrast, and temporal resolutions of cardiac imaging methods

	Spatial resolution (FWHM), mm	Contrast resolution	Temporal resolution
CT	0.5-0.625	Low to moderate	83-135 ms
MRI	1-2	High	20-50 ms
Catheter angiography	0.16	Moderate	1-10 ms
PET	4-10[*]	Very high, varies[†]	5 s to 5 min[*]
SPECT	4-15[*]	Very high, varies[†]	15 min[§]
Echocardiography	~0.5-2[‡]	Low to moderate	>200 frames/s (<5 ms)

FWHM, full width at half maximum; PET, positron emission tomography; SPECT, single photon emission tomography.

[*]Depends on resolution versus noise tradeoff; higher count studies can be reconstructed with better resolution. Dedicated preclinical systems offer substantially improved resolutio (<2 mm).

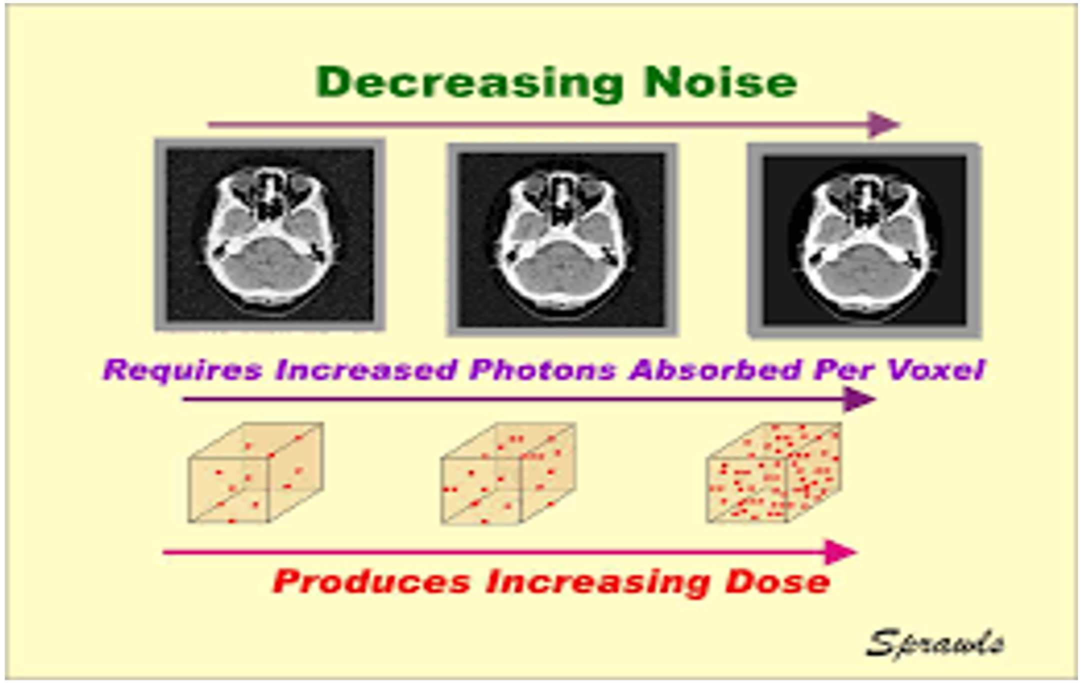
[†]Varies with specificity of radiotracer.

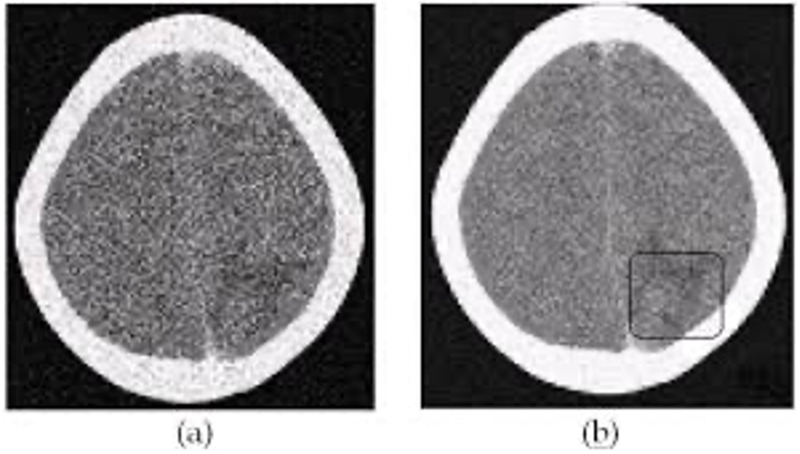
[‡]Intravascular ultrasound scanning can have a spatial resolution of 0.15 mm.[1]

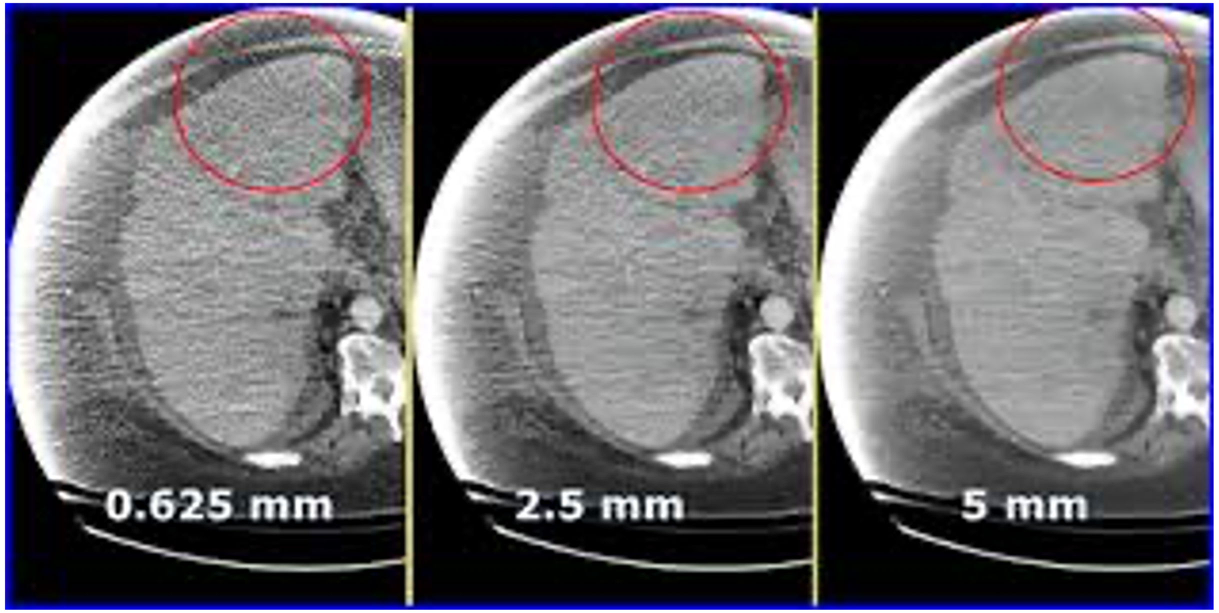
[§]General purpose SPECT systems; Novel dedicated cardiac cameras offer improved temporal resolution on the order of 10 seconds to 5 minutes.[2]

Example: An Important area of development is for heart scanning, due to temporal constraints of the beating heart. One solution adequate gating of the cardiac and respiratory cycles in synchrony with the data acquisition scheme.

(7) Artifacts:



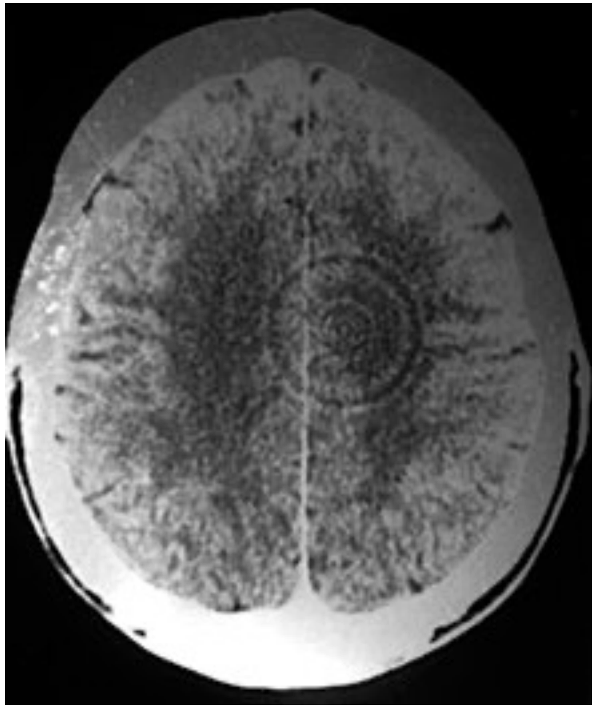




Noise – affected by the # of photons per voxel.
Higher/lower radiation doses result in higher-resolution images/increased image noise and unsharp images.

Artifacts

- Streak artifact: are often seen around materials that block most X-rays, such as metal or bone. Numerous factors contribute to these streaks: under sampling, photon starvation, motion, beam hardening, and Compton scatter.
- Partial volume effect: This appears as "blurring" of edges. It is due to the scanner being unable to differentiate between a small amount of high-density material (e.g., bone) and a larger amount of lower density (e.g., cartilage).
- Ring Artifact: The image of one or many rings appear within an image. They are usually caused by the variations in the response from individual elements in a two-dimensional X-ray detector due to defect or miscalibration.



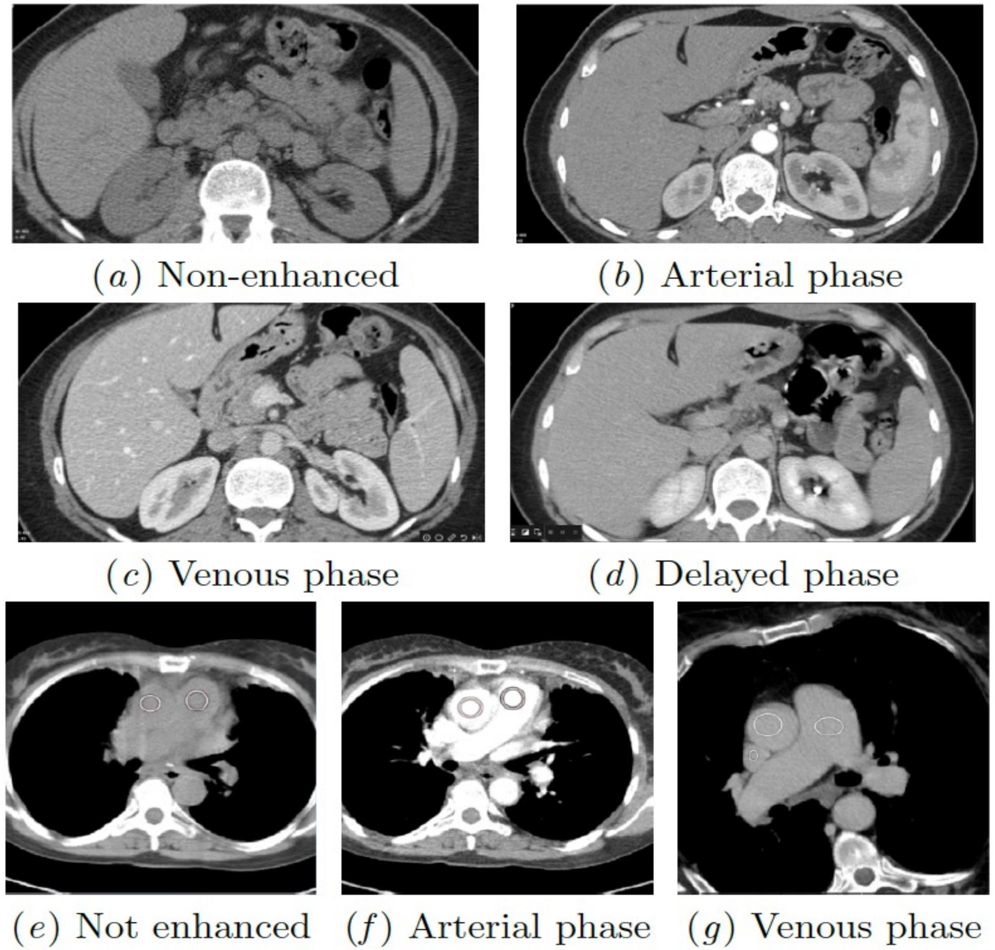
https://en.wikipedia.org/wiki/CT_scan

Maximum Intensity Projection (MIP)

- The voxel with the highest attenuation is displayed. Therefore, high-attenuating structures such as blood vessels filled with contrast media are enhanced.

IV Contrast

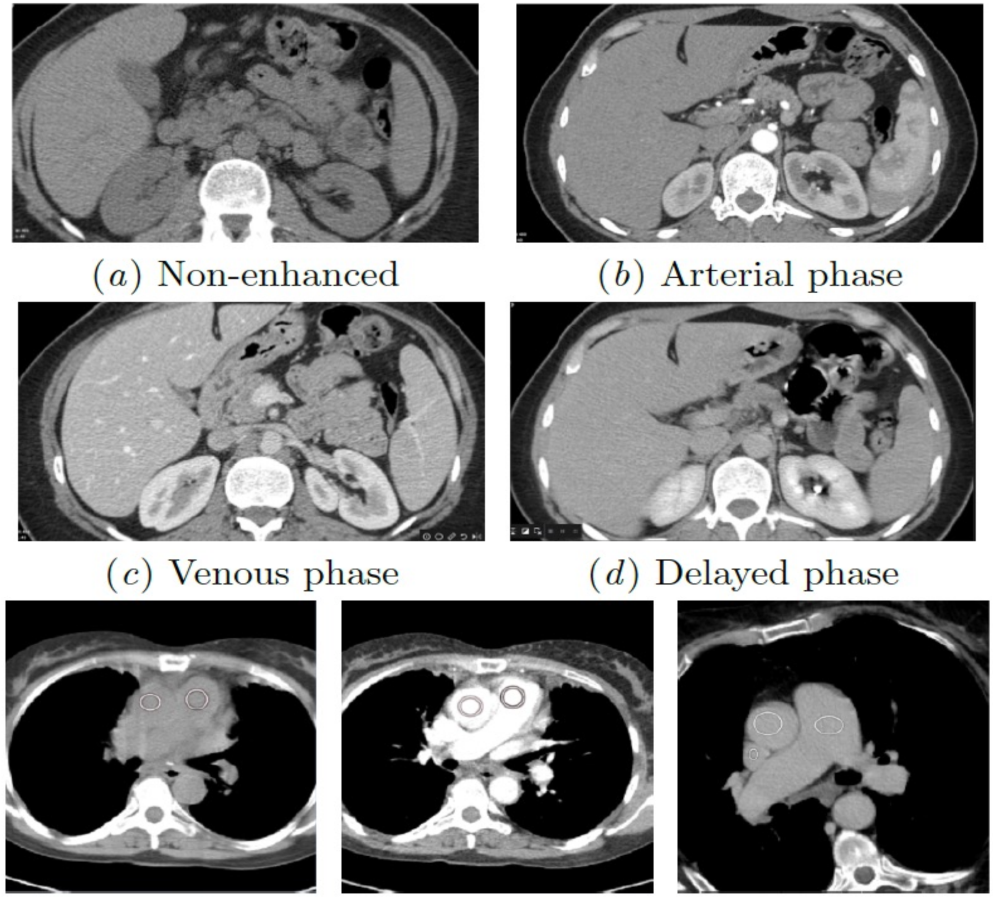
- Inject Iodinated contrast intravenously, wait and image
- The waiting time will determine the phase / where the contrast is in the body.
- Common phases are:
  - Arterial phase: Contrasts predominantly In the arteries
  - Portal venous system: general abdomen organs
  - Delayed: Through the kidneys and then collecting system



d) Contrast enhancement phases in CT abdomen and (e)-
'T chest

R Muhamedrahimov, et al. [Learning Interclass Relations for Intravenous Contrast Phase Classification in CT] Medical Imaging with Deep Learning, 507-519

Contrast



(a) Non-enhanced (b) Arterial phase (c) Venous phase (d) Delayed phase (e) Not enhanced (f) Arterial phase (g) Venous phase

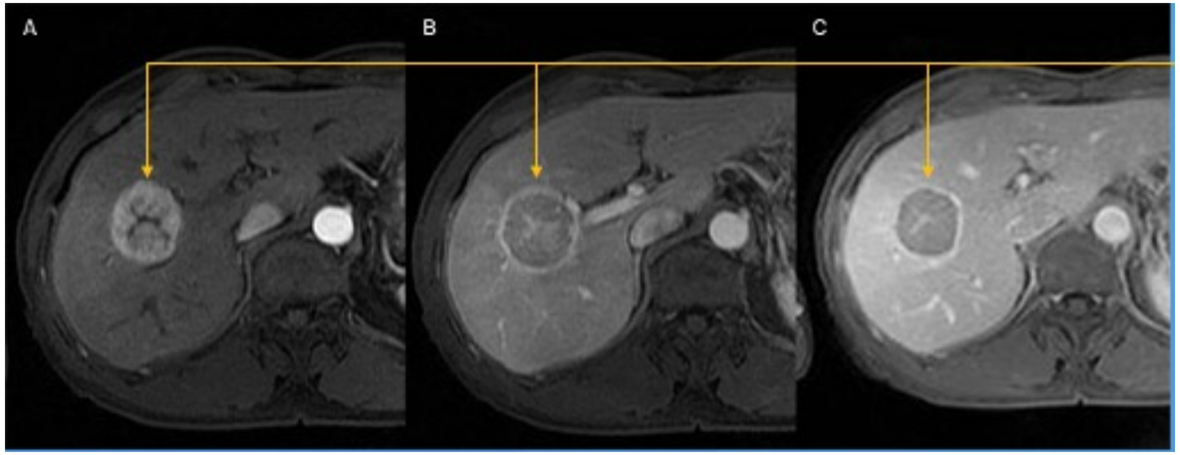
d) Contrast enhancement phases in CT abdomen and (e)-
'T chest

Scroll through the images to see the enhancement in the different phases.

- **Non-enhanced CT (NECT)**
  Helpful in detecting calcifications, fat in tumors, fat-stranding as seen in inflammation like appendicitis, diverticulitis, omental infarction etc.
- **Early arterial phase -** 15-20 sec p.i. or immediately after bolustracking
  This is the phase when the contrast is still in the arteries and has not enhanced the organs and other soft tissues.
- **Late arterial phase** - 35-40 sec p.i. or 15-20 sec after bolustracking. Sometimes also called "arterial phase" or "early venous portal phase", because some enhancement of the portal vein can be seen. All structures that get their bloodsupply from the arteries will show optimal enhancement.
- **Hepatic or late portal phase** - 70-80 sec p.i. or 50-60 sec after bolustracking. Although hepatic phase is the most accurate term, most people use the term "late portal phase". In this phase the liver parenchyma enhances through bloodsupply by the portal vein and you should see already some enhancement of the hepatic veins.
- **Nephrogenic phase -** 100 sec p.i. or 80 sec after bolustracking. This is when all of the renal parenchyma including the medulla enhances. Only in this phase you will be able to detect small renal cell carcinomas.
- **Delayed phase** - 6-10 minutes p.i. or 6-10 minutes after bolustracking. Sometimes called "wash out phase" or "equilibrium phase". There is wash out of contrast in all abdominal structures except for fibrotic tissue, because fibrotic tissue has a poor late wash out and will become relatively dense compared to normal tissue. This is comparable to late enhancement of infarcted scar tissue in cardiac MRI.

Functional information – Liver Cancer

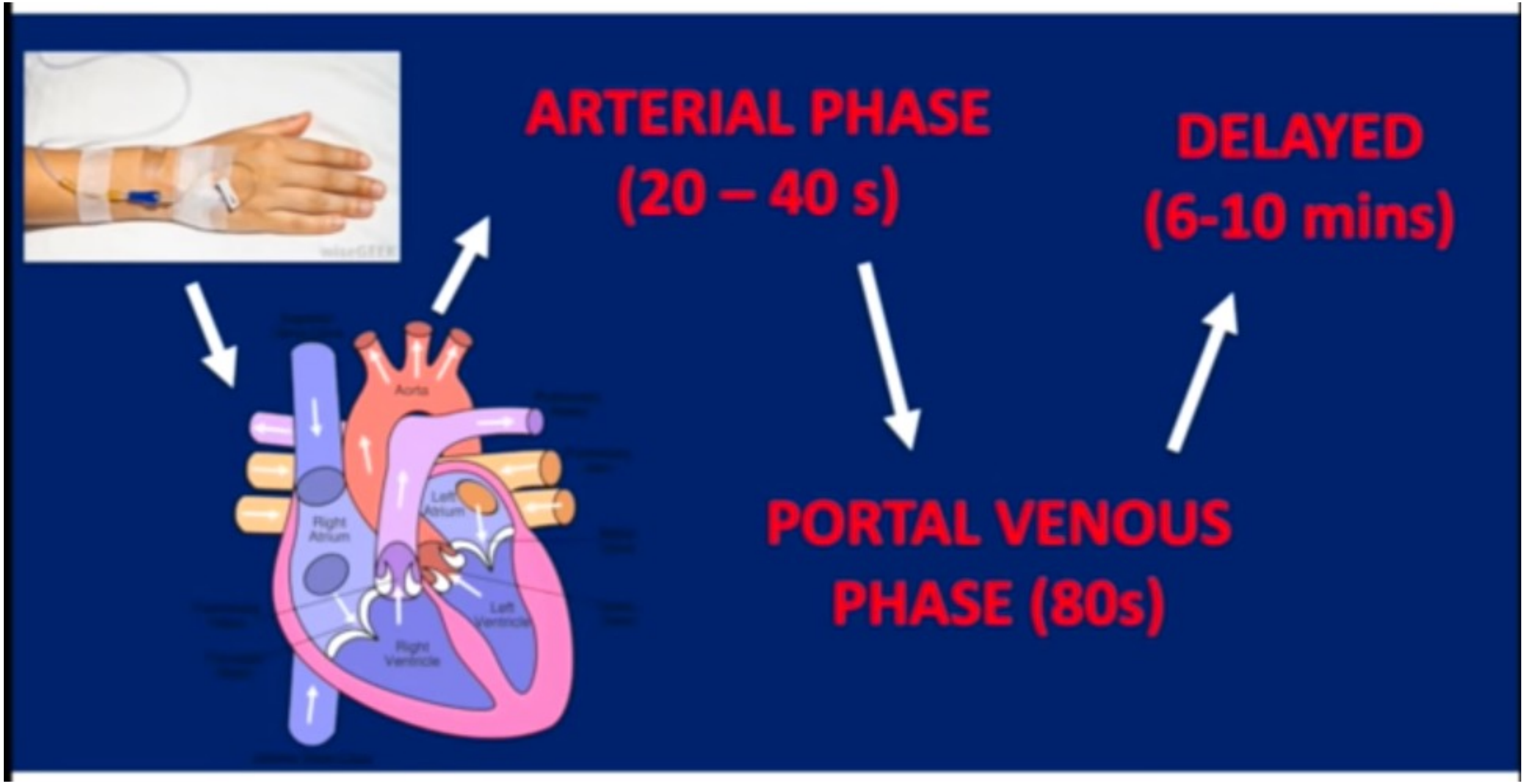
Radio contrasts for X-ray CT's are, in general iodine-based. This is useful to highlight structures such as blood vessels that otherwise would be difficult to delineate from their surroundings. Using contrast material can also help to obtain functional information about tissues.



Arterial (20 sec) Portal Veoius (70 sec) Delayed (4min)

Temporal (and spatial) patterns of wash in and wash out of contrast agent provide signature of lesion types

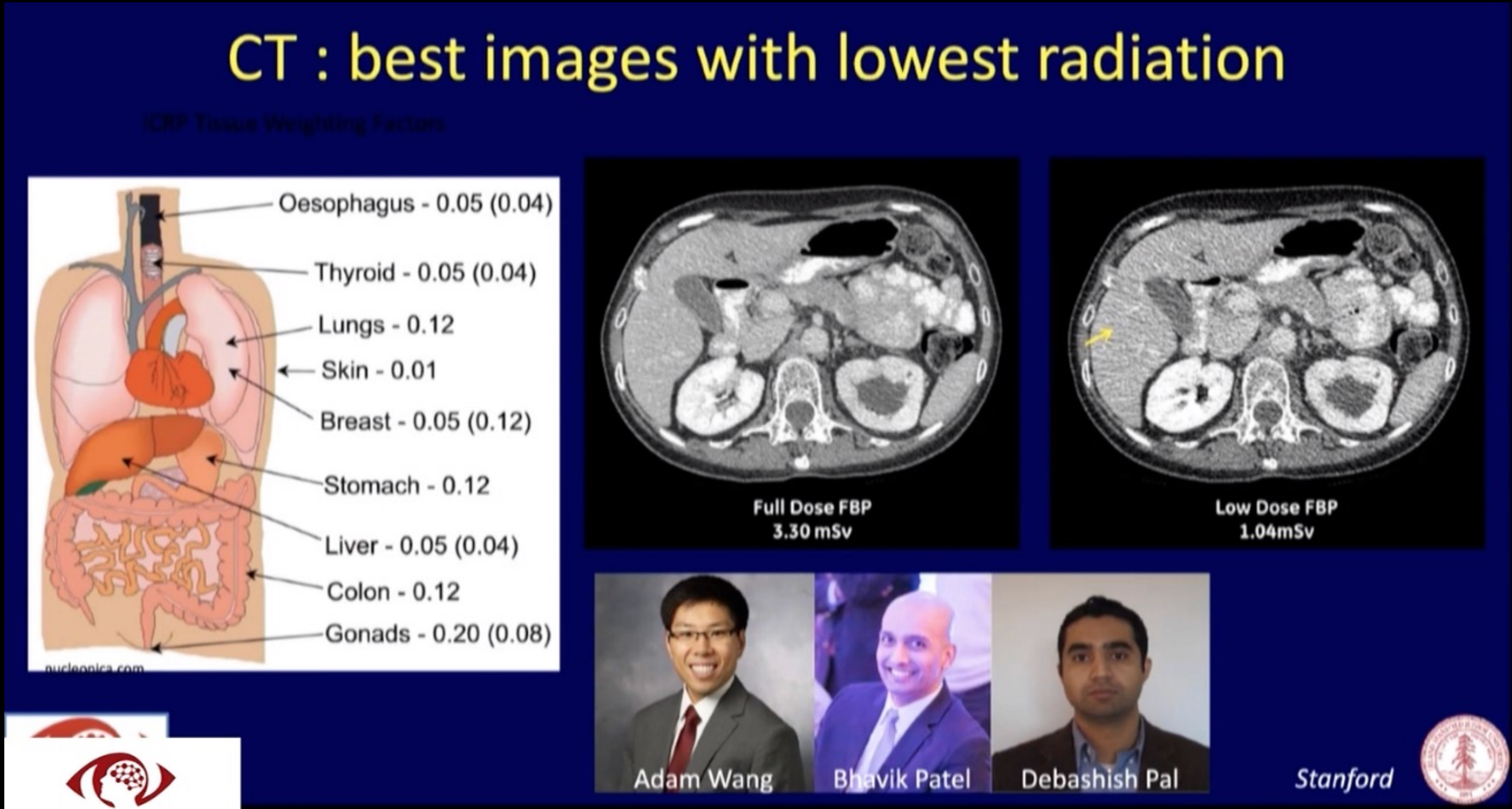
CTA



CT angiography is a contrast CT where images are taken with a certain delay after injection of radiocontrast material. The contrast material is radiodense causing it to light up brightly within the blood vessels of interest.

https://www.navigatingradiology.com/

Low Dose


CT : best images with lowest radiation
Oesophagus - 0.05 (0.04)
Thyroid - 0.05 (0.04)
Lungs - 0.12
Skin - 0.01
Breast - 0.05 (0.12)
Stomach - 0.12
Liver - 0.05 (0.04)
Colon - 0.12
Gonads - 0.20 (0.08)
nucleonica.com
Full Dose FBP
3.30 mSv
Low Dose FBP
1.04mSv
Adam Wang
Bhavik Patel
Debashish Pal
Stanford