PI Session: 2020.11.13_CPR_Radiology: Thorax_Preparatory_Marcus John Julius, M.D.

Objectives: At the end of this session, students will be able to:
1. Discuss the contribution of beam intensity, voltage, tube current, and exposure time in the creation of a radiographic image
2. Differentiate the four cardiac chambers on frontal (PA/AP) and lateral chest radiographs
3. Compare and contrast PA and AP chest radiographs with respect to geometric parameters of magnification
4. Describe the physiologic mechanism essential to the production of a ventilation/perfusion (V/Q) scan
5. Explain the role of sonography in assessment of the thorax
6. Illustrate the components of a CT imaging unit
7. Compare and contrast axial scanning and helical/spiral scanning in CT imaging
8. Differentiate and categorize the hallmark types of matter with respect to Hounsfield units (HU)
9. Describe the concepts of window width (WW) and window level (WL) with respect to CT image processing
10. Differentiate between lung, bone, and soft tissue algorithms on chest CT imaging (in the assessment of normal chest CT anatomy)

General radiology

PHYSICS

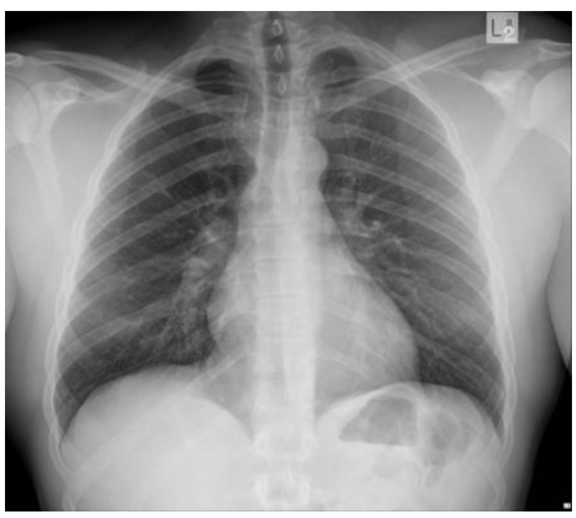
-X-ray beam intensity (i.e. x-rays/mm^2) is called Air kerma ($K_{air)}$
-Kerma: *Kinetic energy released per unit mass*
-Air kerma from an x-ray source obeys the inverse square law
-Decreases with the square of the distance from the source
-Air kerma may be measured at different sites
-*Entrance* ($K_{air)}$ is a measure of the x-ray intensity incident on the patient
-($K_{air)}$ at the *image receptor* is a measure of the x-ray intensity that is incident on the image receptor (i.e. used to generate a radiographic image)
-($K_{air)}$ at the *image receptor* is much lower than entrance ($K_{air)}$
-(<1%) of entrance $K_{air)}$
-Beam intensity is reduced by patient attenuation, increased distance from x-ray tube, and grid losses
-Grids (placed between the patient and the image receptor) are used in an attempt to remove scatter radiation arising from the patient (prior to its arrival at the receptor)

-X-ray beam quantity
-X-ray beam intensity is directly proportional to tube current (mA)
-X-ray beam intensity is directly proportional to exposure time (s)
-Note: Again, the *product* of tube current (mA) and exposure time (s) is **mAs**
-Therefore, the x-ray beam intensity, ($K_{air)}$ is directly proportional to mAs.
-Altering mAs affect beam *quantity*, but not beam quality (i.e. energy)
-When more x-rays are required, this is generally achieved by increasing the mAs
-More often performed by increasing tube current (mA), rather than increasing the exposure time.
-Longer exposure times lead to patient motion and image blurring

-X-ray beam quality
-X-ray quality refers to x-ray beam penetration (and relates to average x-ray beam energy)
-Associated with tube voltage (and kVp)

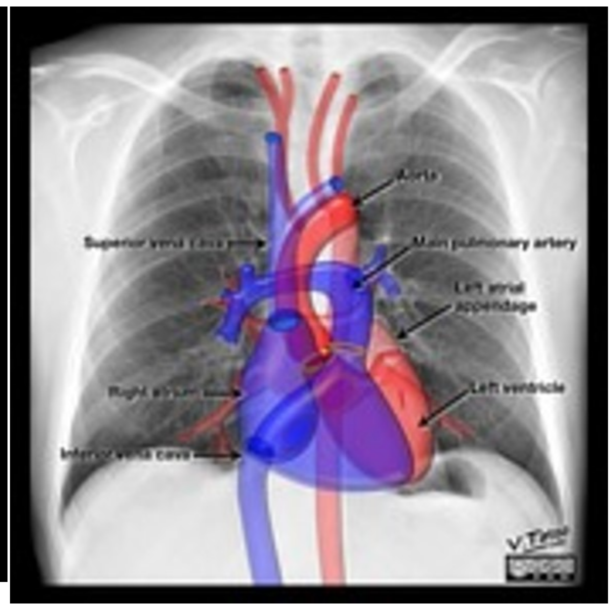
-When tube voltage is changed, x-ray beam energy is altered
-Increasing tube voltage increases the average x-ray photon energy
-Decreasing tube voltage decreases the average x-ray photon energy
-Altering x-ray photon energy alters its interaction with matter (see: X-ray interaction with matter section)
-Penetration
-Scatter
-Absorption
-Altered interaction with matter will alter image characteristics
-Alteration of image contrast

-Note: When tube voltage is changed, there is also an effect on x-ray *quantity*
-In radiography, x-ray beam intensity/quantity, $\mathrm{Kerma}_{air)}$, is proportional to the *square* of the tube voltage (i.e. kV^2)
-Thus, altering the tube voltage changes both the *quality* (i.e. energy) **and** *quantity* (i.e. intensity) of the x-ray beam
-An example:
-Increasing the kV by 15% requires cutting the mAs in half (in order to maintain the same x-ray *quantity*, $\mathrm{Kerma}_{air)}$, at the receptor site)



NORMAL ANATOMY
-Based on geometric principles, *two imaging planes, obtained orthogonal/perpendicular to one another, define three dimensions.*
-*AP (anterior-posterior) projection* is an image exposed from an anterior x-ray source (with image detector positioned posterior the body part) (**see image to the right)**
-The film is labelled and interpreted as if the patient is facing you.

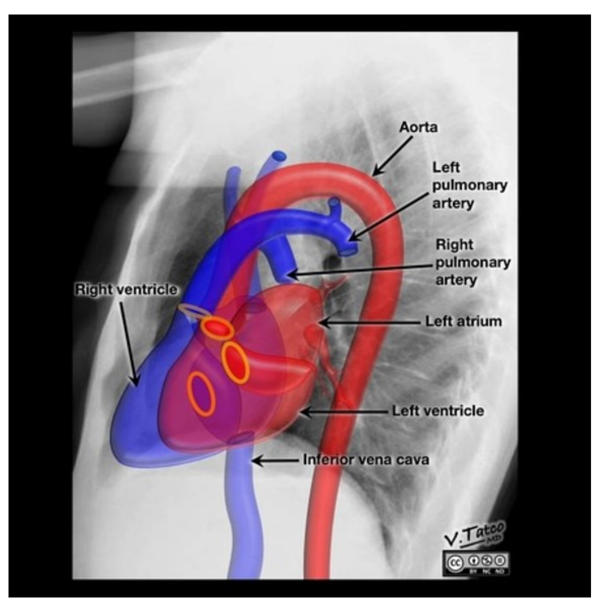
-<u>PA (posterior-anterior) projection</u> is an image exposed from a posterior x-ray source (with image detector positioned anterior to the body part) **(see images below).** The film is labelled and interpreted as if the patient is facing you.



-The heart is positioned closer to the detector on the PA view. Based on geometric principles, the heart is less magnified on this projection (than on AP view)

-*<u>Lateral projection</u>* is an image of the chest exposed from a source on right side of the chest (with the image detector positioned on the left side of the chest) **(see images below)**
-The heart is closer to the detector on the left lateral view, leading to less magnification

-**<u>NOTE</u>**: AP and lateral views are orthogonal to one another (and allow us to assess the body part in 3-dimensions)



Nuclear Medicine

INTERACTION WITH MATTER (NUCLEAR MEDICINE

-**Physiologic mechanisms of radiopharmaceuticals**

-Ventilation/perfusion imaging (V/Q scan) (**see image below**)

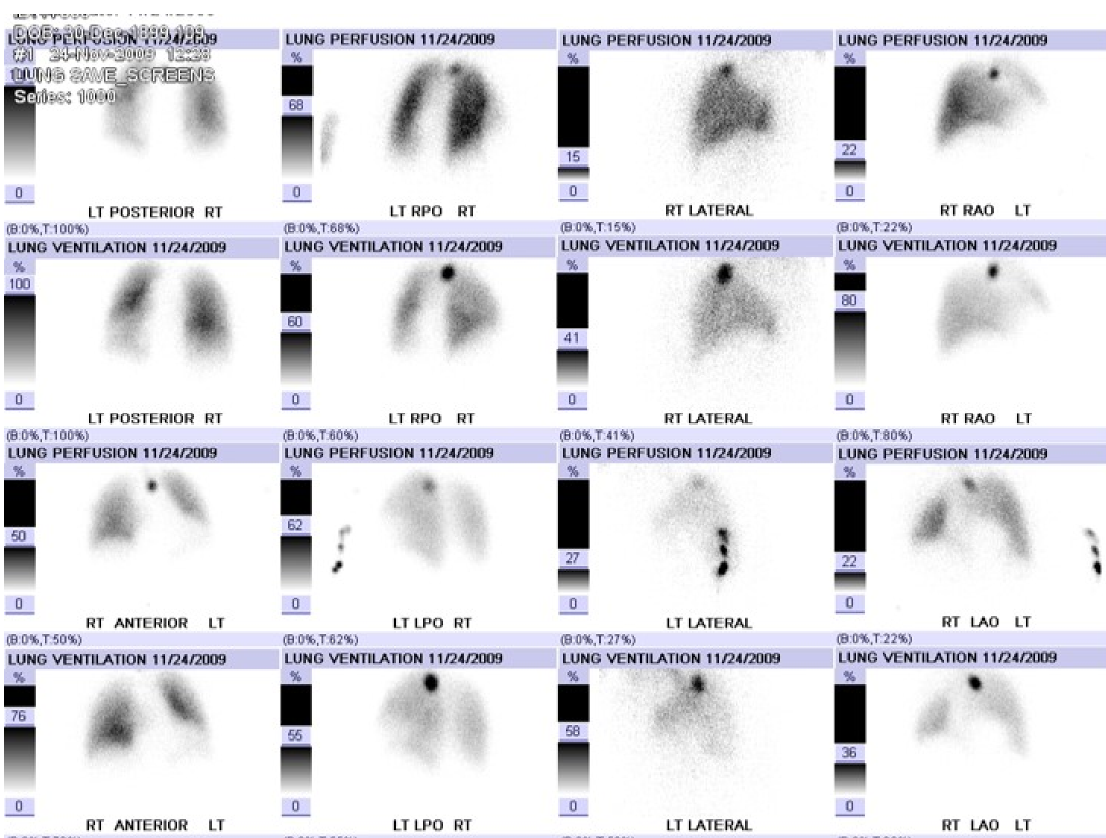
- *Capillary blockade*: Tc-99m-labelled macro-aggregated albumin (MAA) particles
  - -Perfusion portion of lung scan (V/Q scan)
    - -Size: 10 micrometers<x< 90 micrometers
    - -Number: 200,000<x< 500,000
    - -'Diagnostically useful *embolization*'

-*Compartmental localization*: Tc-99m-labelled DTPA aerosol
- -Ventilation portion of lung scan (V/Q scan)
  - -Utilized to functionally visualize lung parenchyma

NORMAL ANATOMY:

(Ventilation/Perfusion, V/Q, scan)

-Different projections
- -Anterior
- -Posterior
- -Lateral (Right/Left)
- -Anterior Obliques (RAO/LAO)
- -Posterior Obliques (RPO/LPO)



Ultrasonography

ULTRASOUND INTERACTION WITH MATTER

-Attenuation

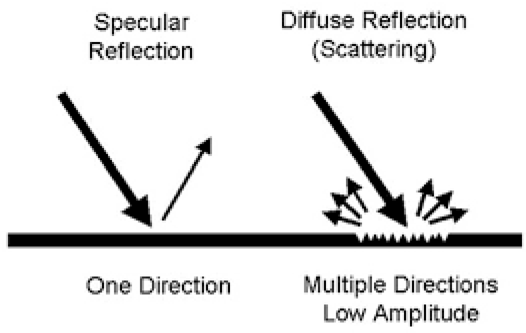
-Weakening of sound wave by *scatter* and *absorption*

-Scatter (non-specular reflections)

-Diffuse echoes from the small, irregular surfaces of objects

-Majority of echoes in ultrasound imaging are from these non-specular reflections (vs specular reflection from smooth surfaces)

-Source of 'speckled' texture artifact



-Absorption

-Absorbed sound wave energy is converted to heat

Note: Attenuation increases with increasing frequency

1. Ultrasound (with its higher frequency than audible sound) is more attenuated than audible sound
2. In soft tissues, a linear relationship exists between frequency and attenuation (i.e. At 1 MHz, soft tissue attenuation is 1dB/cm. At 5 MHz, soft tissue attenuation is 5 dB/cm)
   a. Decibels (dB) are a measurement of relative sound intensity (on a logarithmic scale)
3. For bone, attenuation (in dB/cm) increases as frequency *squared*
4. For fluids, little absorption and almost no scatter nor reflection occurs.

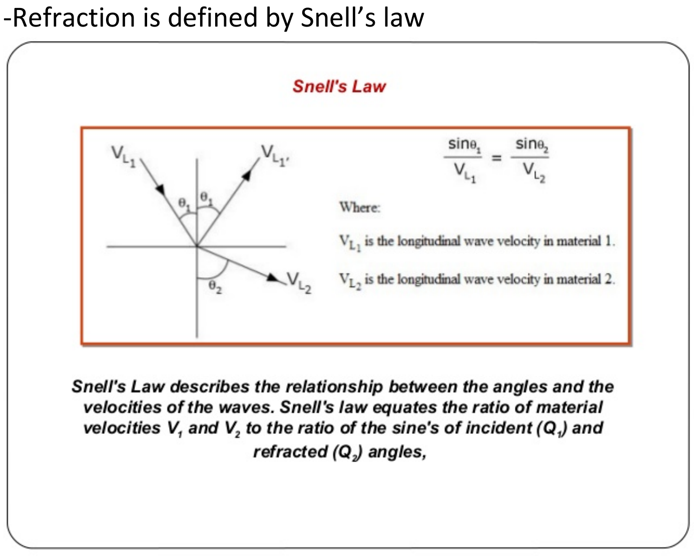
Note: Higher frequency transducers are used for superficial imaging (i.e. good resolution but relatively poor depth penetration)

Note: Lower frequency transducers are used for deeper penetration (i.e. good depth penetration but relatively poor resolution)

-Refraction

-As an ultrasound beam passes from one medium to another medium (each of differing acoustic velocities), the beam changes direction.

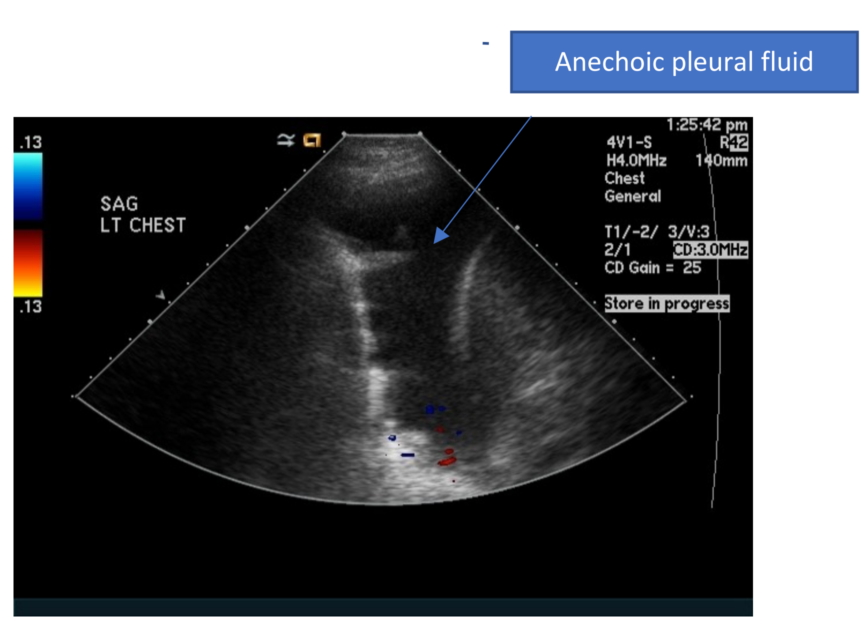
-Refraction is defined by Snell's law



-Since ultrasound units assume straight wave propagation, refraction creates *artifacts* (when transmitted and/or reflected waves strike a tissue-tissue interface at non-perpendicular angles)

Note: In the thorax, US is often utilized to assess for fluid in the pleural space (**see image to the right**).

Note: US of lung parenchyma is a technique utilized in bedside and emergent examinations. This technique and its imaging features will be reviewed during future clinical imaging sessions).



COMPUTERIZED AXIAL TOMOGRAPHY

-**PHYSICS**:

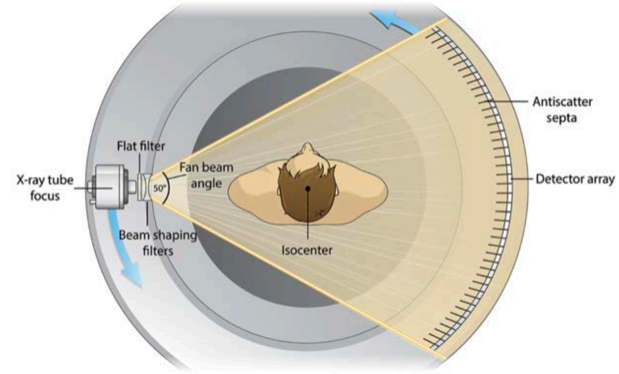
-Components of X-ray tube and detector array (in a CT unit)

-*X-ray tube*: source of x-rays

-*Filters*: tailors the beam quality (by absorbing low energy x-rays)
shapes the beam (which is referred to as 'fan-shaped' beam)

-*Anti-scatter septa*: positioned between detector elements

-*Detector array*: scintillators (produce light when x-ray photons are absorbed)



-*Image acquisition*

-Axial scanning: table and patient are stable, while x-ray tube rotates through 360 degrees (then table moves an increment…followed by another tube rotation)

-At each tube location, each detector measures the x-ray transmission through the patient (referred to as a ray)

-Projection: All rays for a given tube angular position (i.e. 1000 rays)

-Rotation: A 360-degree path around the patient (i.e. 1000 projections)

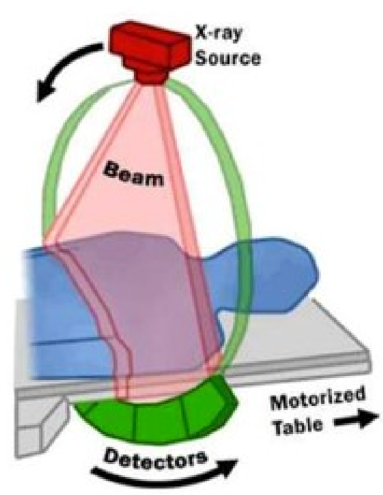
-Sinogram: Plot of projections -VS- tube angles

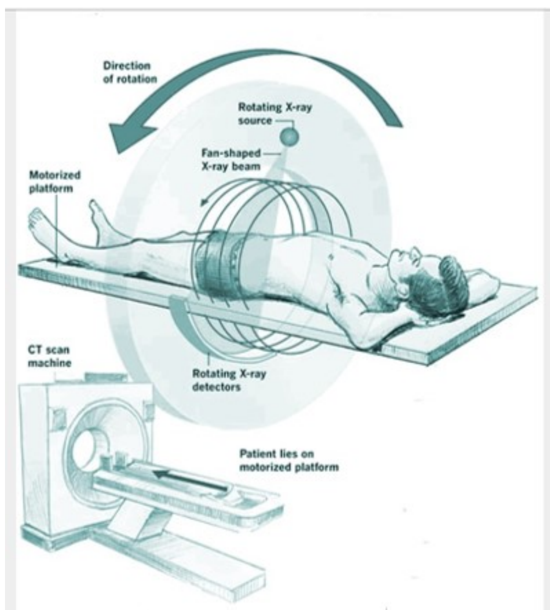
-Helical/spiral scanning: table/patient move linearly, while x-ray tube rotates thorough 360 degrees

-Pitch: Table incremental distance (during a 360-degree rotation)/beam width

-Projection: At any given positions along patient's long axis (i.e. z-axis), helical imaging provides 1 out of 1000 projections (with other data obtained using *interpolation algorithms* from other projections)

-Reduces total CT scan time (compared with axial scanning)





-*Image reconstruction*

-Actual reconstruction techniques (i.e. filtered back projection and iterative reconstruction) are beyond the scope of this course.

-Knowledge of the *display* of the data (i.e. native axial images), however, is vital.

-Tomography: Imaging by sectioning (in this case, axially, from head-to-toe)

-Patient is usually positioned supine (i.e. 'face-up') on the CT table, feet toward us.

-Envision the patient 'facing you' (i.e. if they were to sit up)

-Examples of normal CT anatomy will be provided throughout the course

CT IMAGING INTERACTION WITH MATTER

-Since CT imaging utilizes x-rays, the very same concepts involving x-ray interaction with matter hold true for CT imaging.

- The more readily x-rays pass through matter, the less than are attenuated.

-Gas permits x-rays to pass through most readily

-The more readily x-rays are removed from a beam as it passes through matter (i.e. by photoelectric effect and scatter), the more they are attenuated.

-Dense materials and materials of higher atomic number attenuate the x-ray beam

-Hounsfield units (HU) or CT numbers: the attenuation of a material relative to the attenuation of water (0 HU)

-Negative HU: matter attenuates x-rays LESS THAN water

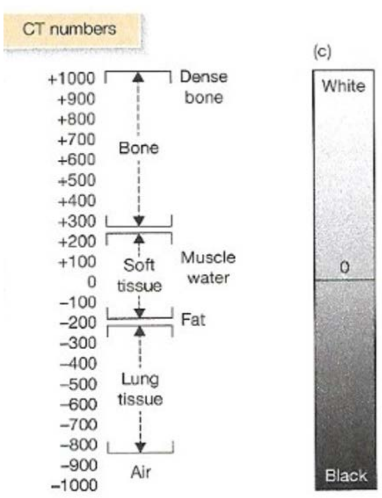
-Air: (-1000 HU)

-Fat: (-100 HU)

-Positive HU: matter attenuates x-rays MORE THAN water

-Soft tissue: (+ 50 HU)

-Bone (+1000 HU)



-Spectrum from black…to…white on film or detector (based on x-ray interaction with matter): *Subjective*

Gas <Fat <Water/soft tissue < Bone < Metal

-CT spectrum from negative HU to positive HU: *Objective*

Gas (-1000 HU) <Fat (-100 HU) < Water (0 HU) <Soft tissue (+50 HU) <Bone (1000 HU) < Metal (**>**1000HU)

-CT Post-processing: **Windowing**

-Most common post-processing operation in CT

-CT image gray scale is manipulated with respect to the CT numbers (i.e. HU) of the image

-Assists with *image contrast* and *image brightness*

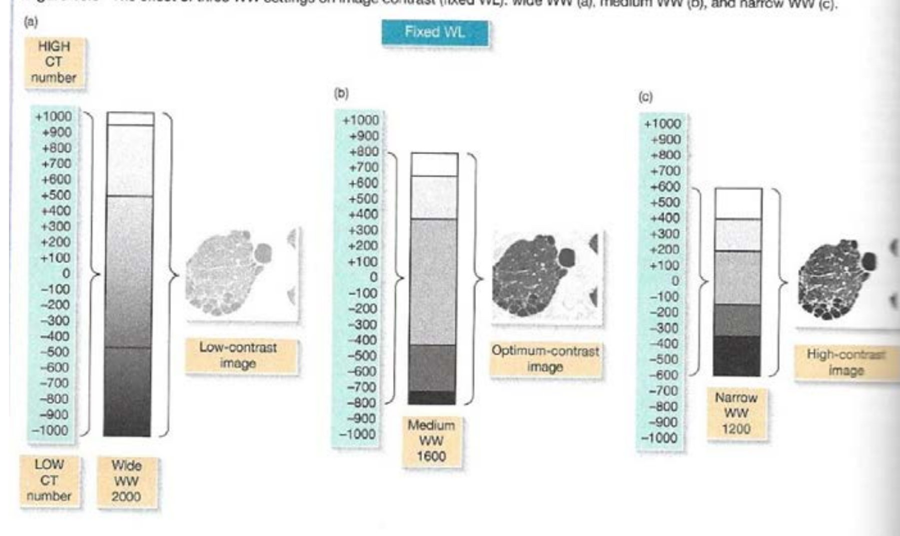
-*WW:* Window width (range of CT numbers in the image)

-Maximum shades of gray that are displayed in the image (i.e. determines *image contrast*)

-Wide window width: Many shades of gray (but creates lower contrast)

-Narrow window width: Fewer shades of gray (but creates higher contrast)

Figure 13.3 The effect of three WW settings on image contrast (fixed WL): wide WW (a), medium WW (b), and narrow WW (c).



-*WL:* Window level (center of the range of the CT numbers in the image)

-Determines the *brightness* or *darkness* of the image

-Location of the center of the range of CT numbers on the gray scale

-Increasing the WL causes the image to appear darker (as more of the lower CT numbers are displayed)

-'Bone window'

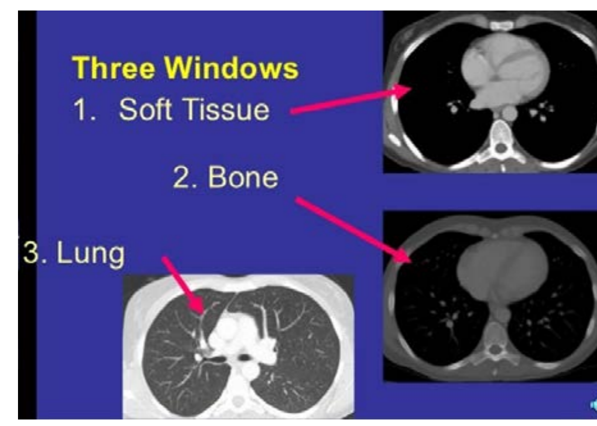
-Bone is white (while most of the remaining image is 'dark')

-Decreasing the WL causes the image to appear brighter (as more of the higher CT numbers are displayed)

-'Lung window'

-Lung is dark (while most of the remaining image is 'bright')

Note: 'Soft tissue window' is in between bone and lung windows (with respect to 'brightness')



-**Note:** Window width and window level *both* contribute to tissue appearance.

Table 13.1 Typical WW and WL values for different tissues.

Tissues	Window Width	Window Level
Temporal bone	3000	500
Spine	1600	300
Soft tissue (orbits)	400	30
Soft tissue (chest)	400	40
Abdomen	400	50
Brain (posterior fossa)	100	40
Soft tissue (cervical and thoracic spines)	500	60
Brain	80	40
Lung	1500	−400

TERMINOLOGY

-***Density***: root word

-hypodense (or of decreased density): lower HU

-hyperdense (or of increased density): higher HU

-***Attenuation***: root word

-decreased attenuation: lower HU

-increased attenuation: higher HU

ADVANTAGES OF CT IMAGING

-Optimal soft tissue differentiation

-Excellent osseous detail

-Submillimeter imaging with potential for multiplanar reconstruction

-3-dimensional imaging

-Fast scanning techniques

DISADVANTAGES OF CT IMAGING

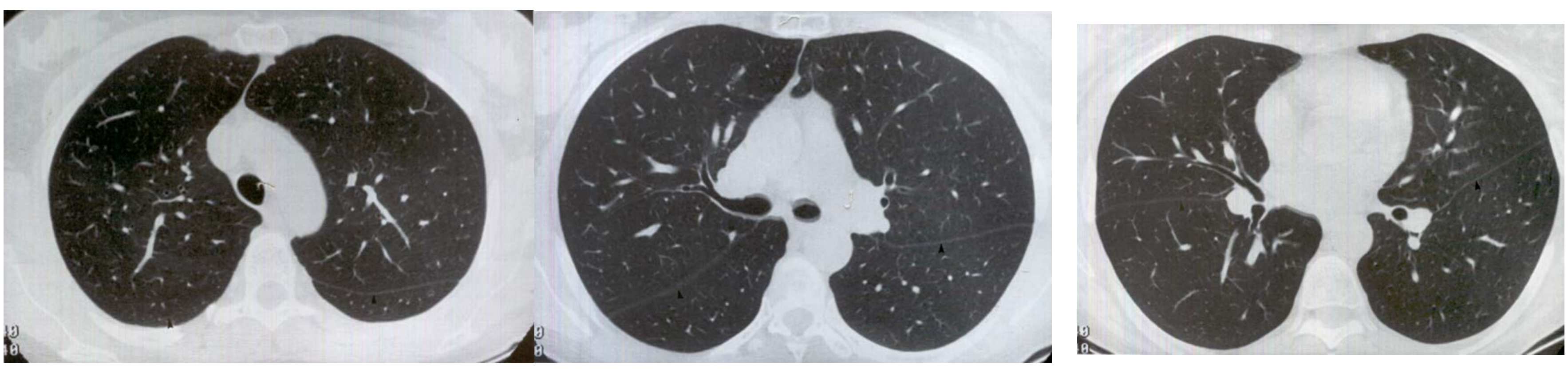
-Exposure to ionizing radiation

-Cost

EXAMPLES OF NORMAL CT THORACIC ANATOMY

Chest CT (soft tissue window)

Left, Level of Aortic arch *Center, Level of Pulmonary arteries* *Right, Level of heart*



Chest CT (Lung window)

Left, Level of distal trachea *Center, Level caudal to carina* *Right, Level of lobar and segmental bronchi*

References

-Clinical Radiology: The Essentials. Daffner et al. 4th ed. (Chapters 1, 2, 4, and 11).

-Primer of Diagnostic Imaging. Weissleder et al. 4th ed. (Chapter 1).

-CT at a Glance. Seeram et al. (Chapters 1-4, 7, and 8)

Note: Unless otherwise specified, all graphics are from Review of Radiologic Physics. Huda. Fourth edition.

Note: Medical images are from anonymized patient or online archives.

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