

MODERN TECHNICAL EDUCATION SOCIETY

RADIOLOGY



PART ONE

Ordering Schemes

The following is a list of patient symptoms accompanied by the imaging studies that may be beneficial for arriving at an accurate diagnosis. Please understand that there may never be universal consensus among clinicians about the imaging study that is best in any given clinical circumstance. The following recommendations are based on my own clinical experience as well as guidelines from current literature. When in doubt, always consult with the radiologist.

Ordering Schemes

BODY AREA	SYMPTOM/CONDITION	IMAGING STUDIES
Brain	Aneurysm	MRI/MRA Catheter cerebral angiography
	Difficulty speaking	Noncontrast head CT and/or Cranial MRI with diffusion imaging
	Double vision	Pre- and postcontrast MRI (attention orbits, optic nerves, tracts, and optic radiations)
	Fever/headache	Pre- and postcontrast CT and/or Pre- and postcontrast MRI
	Hearing loss	CT of temporal bones and/or Cranial MRI attention IACs
	Hemorrhagic stroke	Noncontrast head CT followed by MRI
	Ischemic stroke	Noncontrast head CT (may miss stroke in first 24 hours) MRI with diffusion imaging Perfusion imaging (MRI)
	Mastoid infection/tumor	CT of temporal bones
	Memory loss	Pre- and postcontrast CT and/or Cranial MRI
	Middle-ear infection	CT of temporal bones

	Multiple sclerosis	Pre- and postcontrast MRI
	ringing in the ears	Pre- and postcontrast MRI (attention internal auditory canals)
	Seizure	Cranial MRI (attention medial temporal lobes) and PET
	Severe headache	Pre- and postcontrast CT or Pre- and postcontrast MRI
	Stiff neck	Noncontrast head CT Pre- and postcontrast MRI
	Trauma	Noncontrast head CT
	Vascular malformation	MRA and/or Catheter cerebral angiography
Visual field defect	Pre- and postcontrast MRI (attention orbits, optic nerves, tracts, and optic radiations)	
	Weakness/paralysis	Head CT and/or Cranial MRI with diffusion imaging
Head	Acute sinusitis	No imaging indicated Exceptions: suspect brain abscess, tumor, nonresponse to therapy
	Facial bone trauma	X-ray and/or noncontrast facial bone CT
	Nasal bone trauma	X-ray
	Orbital trauma	X-ray and/or Noncontrast orbit CT
	Skull fracture	Head CT with bone window settings Skull X-ray
	Unresolving sinusitis	Sinus CT
Neck	Enlarged thyroid	Nuclear thyroid uptake/scan and Ultrasound
	Epiglottitis	AP and lateral neck X-ray
	Lymphadenopathy	CT or MRI
	Mass unknown etiology	CT (without/with contrast) or MRI
	Retropharyngeal abscess	CT
	Salivary gland mass	CT or MRI

	Sialolithiasis	CT (without/with contrast)
	Stridor	AP and lateral neck X-ray
	Thyroid nodule	Nuclear thyroid uptake/scan and Ultrasound
	Vocal nodule	CT
Chest	Aortic aneurysm	Chest CT/CTA/angiography
	Aortic dissection	Aortic MRI or chest CT and/or angiography Transesophageal echography
	Chest pain	Chest X-ray Expiratory PA if suspect pneumothorax CTA if suspect PE
	Cough/fever	Chest X-ray
	Dyspnea	Chest X-ray
	Esophageal rupture	Chest CT
	Hemoptysis	Chest CT
	Lung nodule/mass	Chest CT followed by PET
	Occupational exposure	Chest X-ray Chest CT (high resolution)
	Orthopnea	Chest X-ray
	Pleural effusion	Chest X-ray with decubitus Ultrasound (guided thoracentesis) Chest CT (malignant effusion)
	Trauma	Chest X-ray/Chest CT
	Unresolving cough	Chest CT
	Wheezing	Chest X-ray Expiratory if suspect foreign body
Esophagus	Cancer	Esophagram and CT thorax
	Diverticulum	Esophagram
	Dysphagia	Esophagram/CT
	Foreign body	Esophagram
	Reflux/heartburn	Esophagram
Abdomen	Adrenal pathology	Abdomen CT with contrast
	Ascites	Abdomen CT or Abdominal ultrasound

Bleeding, GI	Nuclear RBC study (0.1 cc/min rate of blood loss) Angiography (1.0 cc/min blood loss)
Cholecystitis	Ultrasound/HIDA scan
Cirrhosis	Hepatic CT Ultrasound for ascites Esophagram for varices
Colon obstruction	Abdominal X-ray Barium enema (water soluble)
Crohn's disease	CT, MRI, or small bowel follow-through
Epigastric pain	Abdomen CT or abdomen ultrasound
Flank pain	Noncontrast renal CT Renal ultrasound Intravenous pyelogram
Gallstone	Ultrasound
Hemangioma (liver)	Hepatic CT (hemangioma protocol) Nuclear SPECT imaging MRI
Intussusception	Air-only enema (children) Barium enema (adults)
Jaundice	Abdomen CT or Abdominal ultrasound and/or Nuclear HIDA scan Magnetic resonance cholangiogram ERCP
Meckel's diverticulitis	Abdomen-pelvis CT Pertechnetate scintigraphy Tc-99m
Pain (nonspecific)	Acute abdominal series Abdomen CT if persistent
RLQ pain (appendicitis)	Ultrasound (children) Abdomen CT (adults)
RUQ pain	GB ultrasound
Small bowel obstruction	Abdomen X-ray Small bowel follow-through
Splenic trauma	Abdomen CT
Trauma	Abdomen CT

		Ultrasound (if patient is unstable)
Pelvis	Dysmenorrhea	Pelvic ultrasound
	Hip pain (AVN)	X-ray followed by hip MRI
	LLQ pain (diverticulitis)	Abdomen-pelvis CT
	Pelvic pain	Pelvic ultrasound Pelvic CT or MRI
	Prostate cancer staging	Pelvic MRI
	Trauma	X-ray and CT
	Uterine cancer staging	Pelvic MRI
Scrotum	Pain/swelling/mass	Scrotal ultrasound
	Testicular torsion	Scrotal ultrasound with Doppler
Perineum	Pain/trauma/infection	Pelvic CT
Shoulder	A-C separation	X-ray (option: weight holding)
	Brachial plexopathy	MRI
	Clavicle fracture	X-ray
	Dislocation	Shoulder X-ray
	Glenoid labrum tear	MRI arthrography
	Glenoid/scapular fracture	CT with 3D reconstruction
	Persistent pain	MRI (option MR arthrography)
	Recurrent dislocation	MRI
	Rotator cuff tear	MRI
	Trauma	X-ray CT for fracture MRI for soft tissue injury
Upper arm	Mass (soft tissue or bone)	MRI
	Trauma or foreign body	X-ray
Elbow	Mass or infection	MRI, bone scan (three phase)
	Tendon/ligament tear	MRI
	Trauma or foreign body	X-ray CT for complex fractures
Forearm	Mass or infection	MRI
	Trauma or foreign body	X-ray
Wrist	Carpal tunnel syndrome	MRI

	Ligament disruption	MRI
	Soft tissue injury, Mass or Infection	MRI
	Trauma or foreign body	X-ray CT Nuclear imaging for occult fracture
Hand	Infection	MRI Three-phase nuclear bone scan Nuclear white blood cell scan
	Soft tissue injury, Mass	MRI
	Trauma or foreign body	X-ray
Hip	Acetabulum fracture	X-ray, CT with 3D reconstruction
	Infection	MRI Three-phase nuclear bone scan Nuclear white blood cell scan
	Legg-Perthes	MRI
	Pain (AVN)	MRI
	Trauma	X-ray, MRI, nuclear bone scan, CT
Femur	Infection	Three-phase nuclear bone scan or white cell study (nuclear)
	Mass	MRI
	Trauma	X-ray
Knee	Baker's cyst	Ultrasound or MRI
	Infection	MRI Three-phase nuclear bone scan Nuclear white blood cell scan
	Ligament/meniscus tear	MRI
	Swelling/effusion	MRI
	Trauma	X-ray CT for tibial plateau fracture
	Tumor	X-ray and MRI
Lower leg	Infection	MRI Three-phase nuclear bone scan Nuclear white blood cell scan
	Mass	MRI
	Trauma/foreign body	X-ray

Ankle	Avascular necrosis	MRI
	Infection	MRI Three-phase nuclear bone scan Nuclear white blood cell scan
	Ligament injury	MRI
	Mass	MRI
	Tendonopathy	MRI
	Trauma	X-ray CT if complex fracture
Foot	Infection	MRI Three-phase nuclear bone scan Nuclear white blood cell scan
	Ligament injury	MRI
	Mass	MRI
	Morton's neuroma	MRI
	Plantar fasciitis	MRI
	Tarsal coalition	CT with 3D reconstruction
	Trauma	X-ray CT if calcaneus fracture
Toe	Infection	MRI Three-phase nuclear bone scan Nuclear white blood cell scan
	Mass	MRI
	Trauma	X-ray
Vascular	Aneurysm or AVM	CTA, MRA, and/or angiography
	Deep vein thrombosis	Doppler ultrasound Magnetic resonance venography
	Hypertension	Renal scan and flow study and Renal CTA or Renal MRA
	Peripheral vascular disease	CTA, MRA, and/or angiography (claudication)

CT/MRI Comparison

	MRI BEST	MRI = CT	CT BEST
Head and neck	Vascular lesions Seizures	Hydrocephalus Headache screening	Acute hemorrhage Head trauma

	Acoustic neuroma Primary neoplasia Metastasis Infections Pituitary lesions Multiple sclerosis Neuro-degenerative Venous thrombosis Dementia Congenital anomaly	Cerebral infarction Parathyroid Nasopharynx Salivary glands	Orbits Paranasal sinuses Calcified lesions Middle ear Acute headache Larynx
Thorax	Cardiac masses	Aortic dissection Pericardium Mediastinum	Hilar mass Lung nodule COPD Pulmonary fibrosis Asbestosis Pneumoconiosis Persistent pneumonia Pulmonary embolism Pleural effusion Mesothelioma
Abdomen	Hemangioma Venous thrombosis Hemochromatosis	Liver metastasis Renal tumors Aortic disease Hemangioma	Liver Spleen Pancreas Kidney Adrenal Trauma Lymphadenopathy Abscess
Pelvis	Uterine fibroid Endometrium* Prostate cancer*	Cervical cancer* Rectal cancer* Ovarian cancer* Bladder cancer*	Adenopathy Diverticulitis Appendicitis
Musculo-Skeletal	Hip AVN Marrow disorders Shoulder Knee Bone neoplasm Soft tissue neoplasm TMJ Osteomyelitis Ankle Elbow Wrist/hand		Joint fracture Joint loose body

	Ligaments		
	Cartilage		
Spine	Congenital anomaly	Lumbar radiculopathy	Spondylosis
	Radiculopathy	Spinal stenosis	Bone abnormality
	Myelopathy	Vertebral fracture	Spinal trauma
	Neoplasia		
	Syrinx		
	Spinal cord		
	Scar vs. HNP		
	Infection		

* Cancer staging.

PART TWO

Imaging Overview

CHAPTER ONE X-RAYS

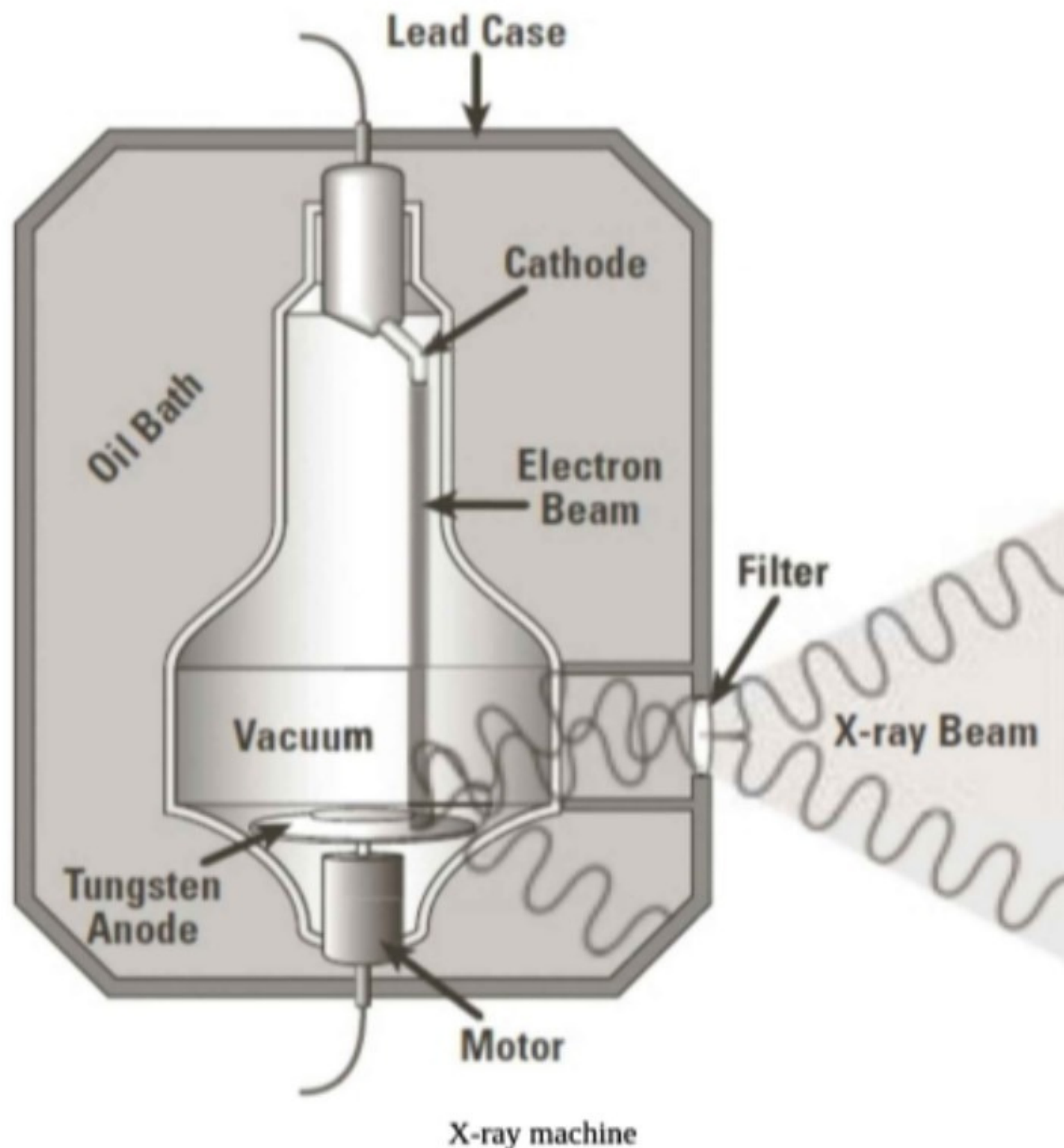
1.0 Goals: Understanding and working with X-rays

Objective questions:

- 1.1 What is an X-ray?
- 1.2 How can X-rays produce images of internal structures of the body?
- 1.3 What are the five basic radiographic densities?
- 1.4 What are the three key elements of radiation safety?
- 1.5 What is a safe dose of radiation?
- 1.6 What can happen when people are exposed to radiation?
- 1.7 Are there special considerations for children?
- 1.8 How do I order an X-ray?
- 1.9 How do I develop a differential diagnosis?
- 1.10 Is there an optimal way to view a radiograph?
- 1.11 What is the basic analysis of any structure or mass?

1.1 What Is an X-ray?

X-rays are a form of electromagnetic energy formed when high-speed electrons bombard a tungsten anode target. Like light energy, these useful rays have properties of waves and particles. However, X-rays have a much shorter wavelength than visible light, allowing them to penetrate matter.



1.2 How can X-rays produce images of internal structures of the body?

Differences in body tissue densities are what allow us to “see” inside the body by creating a shadowgram. The body is composed of tissues containing many different elements, which vary by atomic number (the number of protons in the nucleus). The higher the atomic number, the denser the element and the more effectively the X-ray is blocked. Therefore, specific shadows of internal body structures become visible because they contain varying types of elements. For example, when an X-ray strikes the calcium in cortical bone, it is blocked, and on the radiographic image the bone will appear white. When an X-ray strikes a less dense element like nitrogen, it passes all the way through. Therefore, the air-containing lungs will appear darker, approaching black on the radiographic image. When a fracture extends through bone, the fracture line will be dark while the intact bone will remain white.

1.3 What are the five basic radiographic densities?

- Metal (Bright white)
- Mineral (White)
- Fluid/soft tissue (Gray)
- Fat (Dark gray)
- Air (Black)

KEY POINT

The higher the atomic number of the matter, the more the X-rays will be blocked from reaching the film. (N = atomic number = number of protons in the atom of an element.)



Metal and mineral density



Calcified liver cyst

1.4 What are the three key elements of radiation safety?

The first element of radiation safety is *time*. As health care providers, we must limit the amount of time that we and our patients are exposed to radiation. The second element of safety is *distance*. The energy and therefore potential damage caused by X-rays are inversely proportional to the distance squared. The farther we are from the source of radiation, the safer we are. The third element of safety is *shielding*. By covering the body with a protective metallic shield, we can effectively limit the dose of radiation to that part of the body.

The three elements of radiation safety

Time (Reduce to a minimum the time you spend around an X-ray source)

Distance (X-ray dose is inversely proportional to the distance squared)

Shielding (Aprons composed of metal that block X-rays)

1.5 What is a safe dose of radiation?

There is no dose of radiation that is considered perfectly safe. We are all exposed to

ambient radiation in the environment. It comes from the sun and other celestial bodies and from the ground, including a well-known source—radon. Unnecessary exposure from imaging studies is a preventable hazard. Always consider risk versus benefit when requesting any test utilizing radiation.

1.6 What can happen when people are exposed to radiation?

X-rays can dislodge electrons from the shell of an atom. This results in the production of an ion (free radical). A free radical is an unstable molecule with an extra electron. Free radicals become stable by donating their extra electron to other molecules within cells of the body. This process permanently damages protein, DNA and other vital molecules. Among the ill effects reported from radiation exposure are birth defects, cancer and cataracts. For more information about radiation damage, dosages, and ways to protect yourself and your patients, please visit the Web site of the Nuclear Regulatory Commission, <http://www.nrc.gov>.

1.7 Are there special considerations for children?

Children are more vulnerable to radiation because of their rapidly dividing cells and incompletely differentiated cells. I always insist that my own children be well covered by a protective apron whenever they have an X-ray study. To be sure that your pediatric, adolescent, and young adult patients are shielded, always indicate on the order that shielding is requested. Technologists are taught to do this, but a reminder never hurts. Gonadal shielding should be used for anyone in the reproductive age group. This age range may be from 10 to 70—ask the patient! When in doubt, always shield. For medical personnel (and that includes students, interns, and residents), I recommend using a thyroid shield in addition to a protective body apron.

1.8 How do I order an X-ray?

It is important for completeness and accuracy that physician orders follow a reproducible sequence. In the list of orders, lab and X-ray can be grouped together under the umbrella of diagnostic studies. Please note that you will be asked to provide a diagnosis when you order a study. The more information you provide, the more likely we will be to arrive at the correct imaging diagnosis.

Example

1. Admit to the service of Dr. Smith
2. Admitting diagnosis: Pneumonia and dehydration
3. Activity: Bathroom privileges with assistance
4. Diet: Regular diet
5. Diagnostic studies:
 - Laboratory
 - Imaging:
 - PA and lateral chest X-ray, rule out pneumonia

1.9 Is there an optimal way to view a radiograph?

The conventional way to view any radiograph is as if you are looking at the patient

from the front, in the anatomic position. Your hospital or clinic may have a picture archival and communication system (PACS). With this system, the X-ray images will appear on a computer screen. Strive to view these digital images in a dark, quiet environment. If you are viewing conventional X-ray films, always use a dedicated view box. Holding films up to an overhead light is a great way to miss something important. You and I are responsible for everything on the film, so be sure to look at all of the structures and each corner of the image.

To get the optimal ratio of light coming from the image relative to the background, a darkened room is critical. This is why movie theaters become nearly pitch-black before the movie begins. Light pollution can severely impair your ability to perceive an abnormality.

Once you have identified the shadow of a structure, whether it is a normal anatomic structure or pathology, carefully examine it for size, shape, position, and density. The questions you must ask yourself are: Is this structure normal anatomy? Is this structure abnormally large or small? Can its borders be recognized so that a measurement of size can be made? What is the shape of the structure? Where is it located, and is this a normal position? What is the radiographic density of the structure (remember the five basic radiographic densities)?

Basic concept: Analysis of any structure or mass on a radiograph

1. Size of the structure
2. Shape or contour of a structure
3. Position of the structure
4. Density of the structure

Note: In general, a mass or nodule is more likely to be benign if it is small, smoothly margined, and calcified. A mass or nodule is more likely to be malignant if it is large, irregular in contour, and dense but not calcified.

1.10 How will I know if the X-ray is of diagnostic quality?

As physicians, we are responsible not only for the pathology present on an X-ray, but also for ensuring good-quality images through feedback to and supervision of the technologists who perform the studies. An overpenetrated (overexposed) radiograph is too dark. X-rays can penetrate through subtle pathology and obscure an important finding. A malignant pulmonary nodule may be difficult or impossible to see if the film is overpenetrated. An underpenetrated (underexposed) radiograph can make normal structures such as bronchovascular structures in the lungs look like pathology. The image is too light or white-looking. Sometimes a patient suspected to have congestive heart failure based on an underpenetrated radiograph may be treated for CHF unnecessarily.

The patient should be orthogonal to the X-ray beam on a PA or AP view. This means that the beam enters the patient at 90 degrees and there is no patient rotation. On a well-positioned PA chest X-ray, the spinous process at T1 should be equidistant from the medial ends of the clavicles.

Watch out for artifacts. Objects in clothing and hair and on the skin create shadows that can mimic pathology. A patient who was sent for a chest X-ray was chewing a piece of gum, which he put on his upper back for safe keeping. The resulting nodular-appearing opacity caused quite a stir until the patient was examined and the cause of the "lesion" was revealed.



Overpenetrated chest X-ray



Optimally penetrated chest X-ray

1.11 How can I develop a differential diagnosis?

Occasionally (not often enough, as far as I'm concerned) a diagnosis is obvious. The late Dr. Felson, a brilliant mind in radiology, called these recognizable X-ray findings "Aunt Minnie." Aunt Minnie is the relative whom we may see once every 10 years, but whose appearance is so characteristic that we know her the minute we see her. There is an excellent Web site for radiology education called <http://AuntMinnie.com>. Examples of Aunt Minnie include such entities as calcification of the gallbladder wall in the condition known as porcelain gallbladder, or laminated calcified gallstones or a staghorn renal calculus. Most of the time we must create a list of possible diagnoses. Radiographic findings are not specific. To arrive at the correct diagnosis, history, physical, laboratory, and imaging data must be correlated.

For guiding students through the general disease categories to be considered in a differential diagnosis,

I like the mnemonic "VITAMINS D and C":

V = Vascular

I = Infection or Inflammation

T = Trauma

A = Autoimmune or Allergic

M = Metabolic
I = Idiopathic or Iatrogenic
N = Neoplastic
S = Structural
D = Developmental
C = Cardiac

Picture this. Your attending physician catches you off guard and asks for the differential diagnosis for a patient with an unusual pain pattern and symptom complex. Your answer may go like this:

I've been thinking about that, Dr. Smith. I believe we have to consider the possibility of a vascular cause. Of course, an *infection* such as TB, the "great masquerader," should be considered, but bacterial, fungal, and viral etiologies are contained in my differential thinking. Has this patient experienced *trauma*? I always think of *autoimmune* processes in cases such as these. The endocrine system can produce a variety of *metabolic* disorders that must be considered. Have we thought about the possibility of an *iatrogenic* drug reaction? Primary and metastatic *neoplasm* can present with similar symptoms. I learned that *structure* and function are inseparably related. I would also consider a congenital or *developmental* cause in this case. If all else fails, let's make sure there is not a *cardiac* origin.



Cortical buckle fracture of the radius with ulnar styloid avulsion

CHAPTER TWO COMPUTED TOMOGRAPHY

2.0 Goals: Understanding how CT works: its uses, strengths, and weaknesses

Objective questions:

- 2.1 What is CT?
- 2.2 How does CT work?
- 2.3 What are Hounsfield units?
- 2.4 Are there limitations to CT?
- 2.5 What are window settings and how are they used?
- 2.6 What parts of the body are best studied with CT?
- 2.7 What is contrast CT?
- 2.8 What are 3D CT and sagittal and coronal reconstruction?
- 2.9 What is CTA?
- 2.10 What are the benefits of CT compared to plain radiography?
- 2.11 What are the benefits of CT compared to MRI?

2.1 What is CT?

Computed tomography (CT) provides us with images (tomograms) showing slices through the body. We can vary the thickness of these slices so that, in effect, we are looking at thin two-dimensional pictures representing a volume of tissue. *Computed axial tomography* (CAT) is a synonym for CT. It refers to the axial plane, the most common plane of CT imaging.

2.2 How does CT work?

CT uses X-rays to produce an image. The same basic principles apply to CT as to all other X-ray studies. X-rays are blocked (attenuated) by tissues depending upon their density (atomic number). Air is black on CT and minerals are white.

To obtain a slice, an X-ray source rotates around the body in an arc while an X-ray detection source rotates opposite the source on the opposite side of the body. The computer analyzes the number and density of the transmitted X-rays, calculates the coordinates, and assigns a gray scale to individual picture elements (pixels) that will make the final picture.

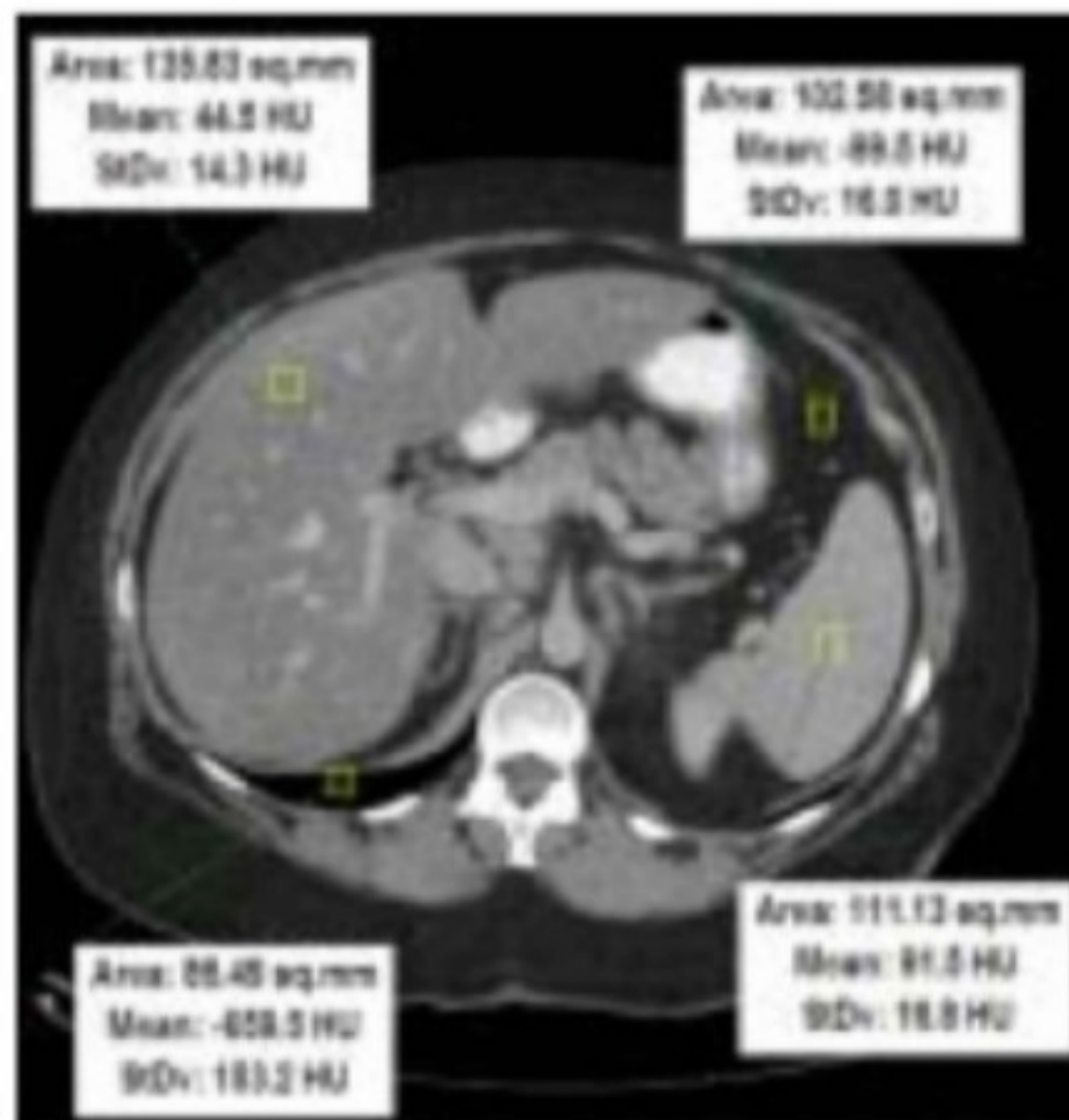
2.3 What are Hounsfield units?

Sir Godfrey Hounsfield was instrumental in the development of computed tomography.

His name is used for the numbers associated with the gray scale produced during CT scanning. All CT scanners are programmed such that water appears dark on the image; its attenuation value in Hounsfield units (HU) is 0. From this central point, HU range from calcium at approximately +1,000 HU to air at approximately -1,000 HU.

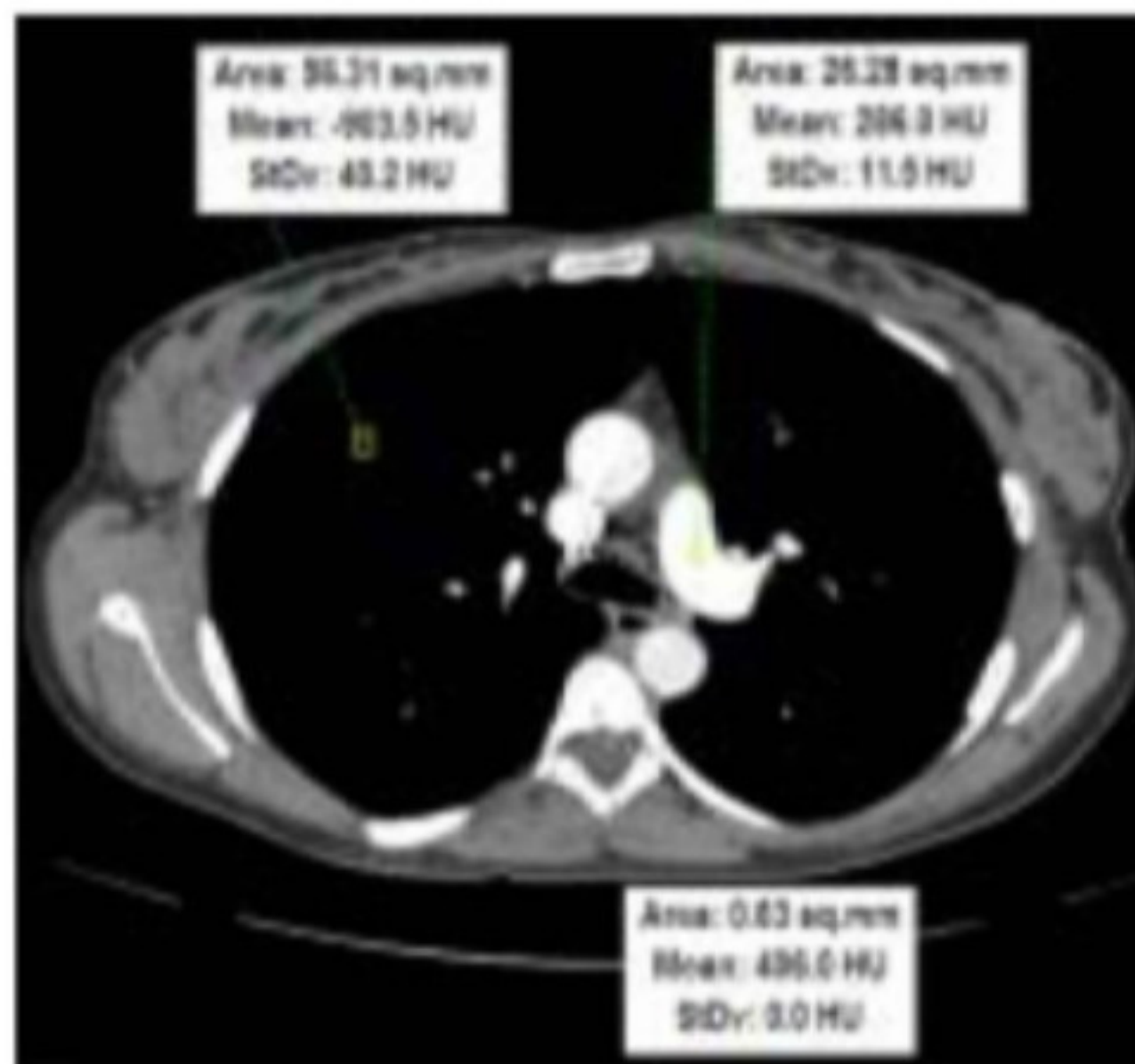
Common CT-assigned attenuation values:

Air = -1,000 HU or less (black)
Fat = -5 to -50 HU (dark gray)
Water = 0 HU (gray)



CT-assigned attenuation values

Soft tissue = +40 to +80 HU (light gray)
Calcium (stone) = +100 to +400 HU (gray white)
Cortical bone = +1,000 HU (white)



CT-assigned attenuation values: *Lung* = -903.5 HU *Contrast* = 286.0 HU *Bone* = 406.0 HU

2.4 Are there limitations to CT?

CT cannot distinguish soft tissue structures as well as MRI can. For example, the ligaments and menisci of the knee are not different enough in their attenuation values to allow us to delineate them easily or demonstrate specific pathology.

Metal can create a “starburst artifact” that blurs the image. This can happen around the maxillary area and mandible due to dental fillings, as well as around the hip when a prosthesis is present.

CT is limited in the posterior fossa of the brain because of the dense bone in the petrous ridges and the skull base. A “beam-hardening artifact” limits our ability to detect subtle pathology in the brain stem area.

In addition, CT is less sensitive than MRI in the detection of white matter disease of the brain.

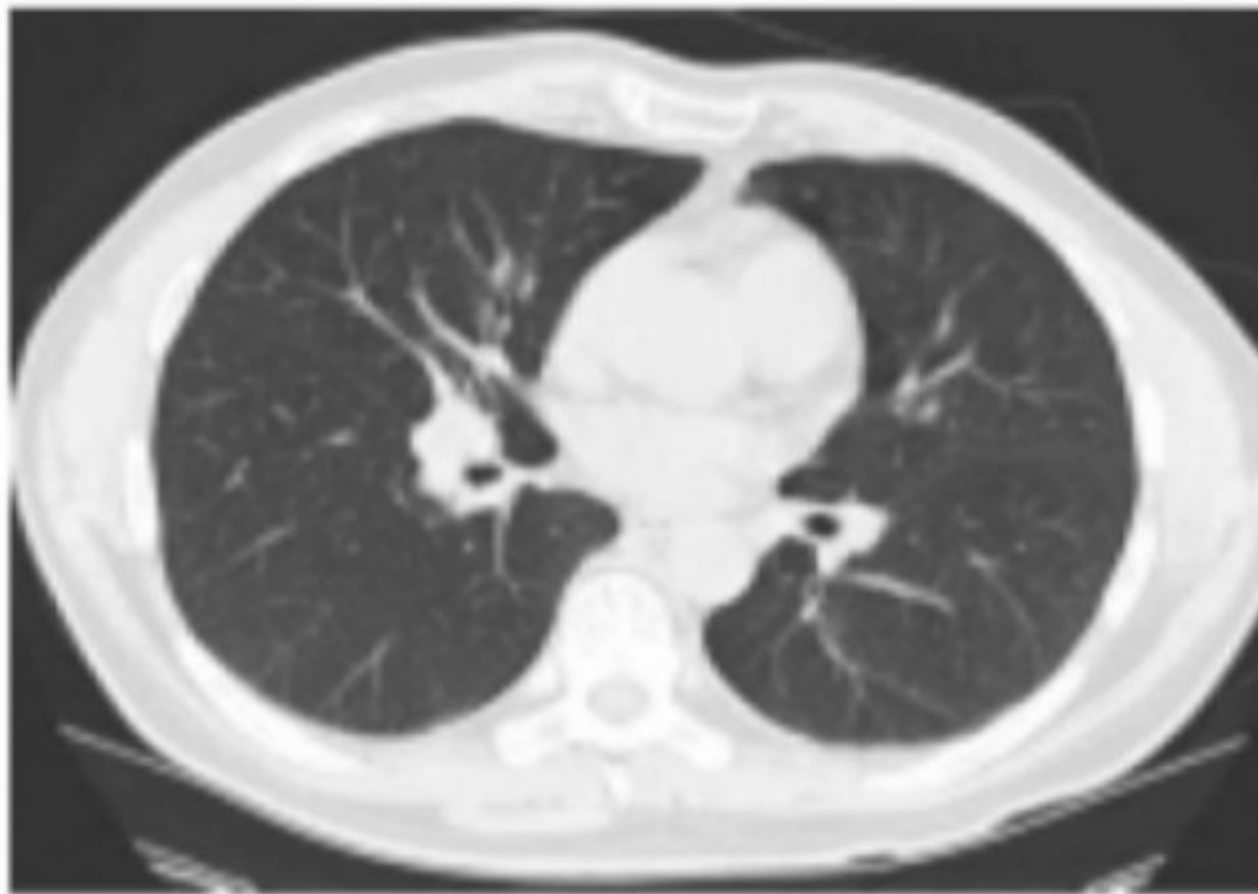


Metal artifact

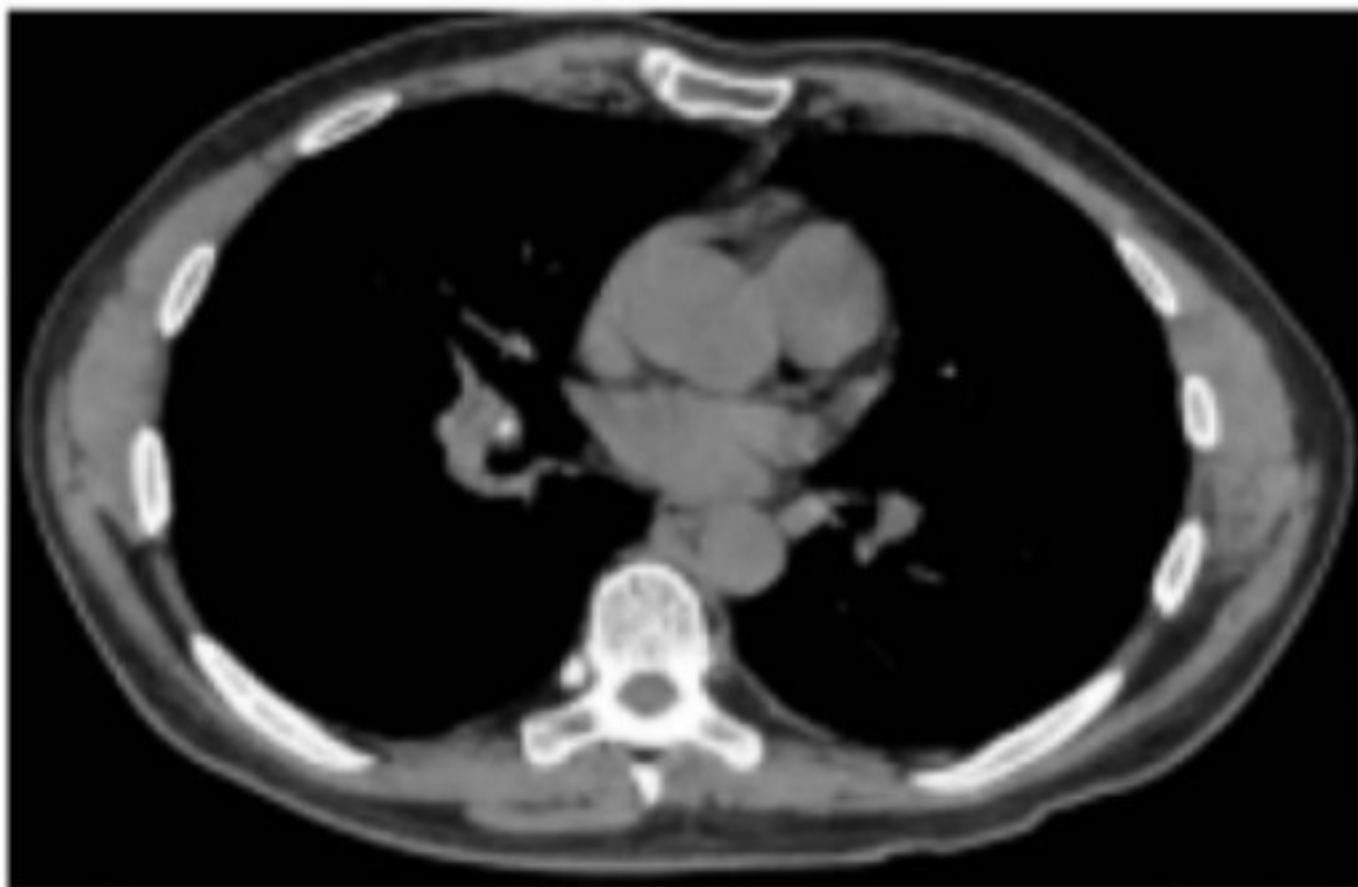
2.5 What are window settings and how are they used?

Digital technology such as CT, MRI, and digital radiography provides the opportunity for computer-aided manipulation of the image. *Window widths* and *window levels* are used to optimize visualization of specific structures. The window level is the midpoint of the gray scale. The window width is the number of gray shades. If the window level is set to 0 and the window width is set to 1,000, the gray scale is from -500 to +500.

The most obvious example of windowing and leveling technique is chest CT. To evaluate the mediastinum, the window level is set to soft tissue density and the window width is set moderately narrow to allow for optimal contrast. To evaluate the lungs, the window level is set closer to air density and the window width is set relatively wide to allow detailed assessment of the air-bearing lung parenchyma.



CT lung window setting



CT mediastinal window setting

2.6 What parts of the body are best studied with CT?

CT can be used from head to toe.

Head: An excellent screening modality for cranial trauma, suspected intracranial bleeding, or stroke

Paranasal sinuses

Neck

Facial bones

Chest

Abdomen

Pelvis

Knee: for evaluation of tibial plateau fractures; not good for cartilage or ligament injury evaluation

Hip: specifically for assessment of acetabulum fracture