MI

Medical Imaging

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Acronyms

^{18}FDG	18-fluorodeoxyglucose
AP	anteroposterior
ARDS	acute respiratory distress syndrome
AV	arteriovenous
AXR	abdominal x-ray
BOOP	bronchiolitis obliterans organizing pneumonia
CNS	central nervous system
CSF	cerebrospinal fluid
CT	computed tomography
CTA	computed tomographic angiogram
CVD	collagen vascular disease
CVP	central venous pressure
CXR	chest x-ray
DEXA	dual-energy x-ray absorptiometry
DMSA	dimercaptosuccinic acid
DSA	digital subtraction angiography
DTPA	diethylene triamine pentaacetic acid
DWI	diffusion-weighted image
ECD	ethyl cysteinate dimer
ERCP	endoscopic retrograde cholangio-pancreatography
FLAIR	fluid-attenuated inversion recovery
GI	gastrointestinal
GPA	granulomatosis with polyangiitis
HCC	hepatocellular carcinoma
HIDA	hepatobiliary iminodiacetic acid
HMPAO	hexamethylpropyleneamine oxime
HSG	hysterosalpingogram
IBD	inflammatory bowel disease
ICV	ileocecal valve
IPF	interstitial pulmonary fibrosis
IVP	intravenous pyelogram
KUB	kidneys, ureters, bladder
LA	left atrium
LV	left ventricle
MAA	microaggregated albumin
MAG3	mertiatide
MCA	middle cerebral artery
MR	magnetic resonance
MRA	magnetic resonance angiogram
MRCP	magnetic resonance cholangiopancreatography
MRI	magnetic resonance imaging
MS	multiple sclerosis
MUGA	multiple gated acquisition
PA	posteroanterior
PBD	percutaneous biliary drainage
PET	positron emission tomography
PFT	pulmonary function test
PICC	peripherally-inserted central catheter
POCUS	point-of-care ultrasound
PTA	percutaneous transluminal angioplasty
PTC	percutaneous transhepatic cholangiography
RA	right atrium
RAIU	radioactive iodine uptake
RV	right ventricle
SPECT	single photon emission computed tomography
SVC	superior vena cava
TB	tuberculosis
TNK	tenecteplase
tPA	tissue plasminogen activator
TRUS	transrectal ultrasound
TVUS	transvaginal ultrasound
U/S	ultrasound
VCUG	voiding cystourethrogram
V/Q	ventilation/perfusion

Imaging Modalities

X-Ray Imaging
- x-rays, or Röentgen rays, are a form of electromagnetic energy of short wavelength
- as x-ray photons traverse matter, they can be absorbed (a process known as "attenuation") and/or scattered
- the density of a structure determines its ability to attenuate or "weaken" the x-ray beam
  - air < fat < water < bone < metal
- structures that have high attenuation (e.g. bone) appear white on the resulting images

Plain Films
- x-rays pass through the patient and interact with a detection device to produce a 2-dimensional projection image
- structures closer to the film appear sharper and less magnified
- contraindications: pregnancy (relative)
- advantages: inexpensive, non-invasive, readily available, reproducible, fast
- disadvantages: radiation exposure, generally poor at distinguishing soft tissues

Fluoroscopy
- continuous x-rays used for guiding angiographic and interventional procedures, in contrast examinations of the GI tract, and in the OR for certain surgical procedures (e.g. orthopedic, urological)
- on the fluoroscopic image, black and white are reversed so that bone and contrast agents appear dark and radiolucent structures appear light
- advantages: allows for real-time visualization of structures
- disadvantages: increased radiation dose; however, the use of pulsed fluoroscopy has reduced fluoroscopy time by 76% and radiation dose by 64% as compared with continuous fluoroscopy

Computed Tomography
- x-ray beam opposite a detector moves in a continuous 360º arc as patient is advanced through the imaging system
  - subsequent computer assisted reconstruction of anatomical structures from the axial plane
- attenuation is quantified in Hounsfield units:
  - subsequent computer assisted reconstruction of anatomical structures from the axial plane
  - adjusting the "window width" (range of Hounsfield units displayed) and "window level" (midpoint value of the window width) can maximally visualize certain anatomical structures (e.g. CT chest can be viewed using "lung", "soft tissue", and "bone" settings)
- contraindications: pregnancy (relative), contraindications to contrast agents (e.g. allergy, renal failure)
- advantages: delineates surrounding soft tissues, excellent at delineating bones and identifying lung/liver masses, may be used to guide biopsies, spiral/helical multidector CT has fast data acquisition and allows 3D reconstruction, CTA is less invasive than conventional angiography
- disadvantages: high radiation exposure, soft tissue characterization is not as good in comparison with MRI, IV contrast injection, anxiety of patient when going through scanner, higher cost, and less available than plain film

Typical Effective Doses from Diagnostic Medical Exposures (in adults)*

Diagnostic Procedure Type	Equivalent Number of Chest X-Rays	Approximate Equivalent Period of Natural Background Radiation** (~3 mSv/yr)
X-Ray		
Skull	5	12 d
Cervical spine	10	3 wk
Thoracic spine	50	4 mo
Lumbar spine	75	6 mo
Chest (single PA film)	1	2 d
Shoulder	0.5	1 d
Mammography	20	7 wk
Abdomen	35	3 mo
Hip	35	3 mo
Pelvis	30	10 wk
Knee	0.25	<1 d
IVU	150	1 yr
Dual-energy x-ray absorptiometry (without/with CT)	0.5/2	<1 d/4 d
Upper GI series	300	2 yr
Small bowel series	250	20 mo
Barium enema	400	2.7 yr
CT		
Head	100	8 mo
Neck	150	1 yr
Spine	300	2 yr
Chest	350	2.3 yr
Chest (pulmonary embolism)	750	5 yr
Coronary angiography	800	5.3 yr
Abdomen	400	2.7 yr
Pelvis	300	2 yr
Radionuclide		
Brain (^{18}FDG)	705	4.7 yr
Bone (^{99m}Tc)	315	2.1 yr
Thyroid (^{99m}Tc)	240	1.6 yr
Thyroid (^{123}I)	95	8 mo
Cardiac rest-stress test		
(^{99m}Tc 1-d)	470	3 yr
(^{99m}Tc 2-d)	640	4 yr
Lung ventilation (^{133}Xe)	25	2 mo
Lung perfusion (^{99m}Tc)	100	8 mo
Renal (^{99m}Tc)	90-165	7-13 mo
Liver-spleen (^{99m}Tc)	105	8.4 yr
Biliary tract (^{99m}Tc)	155	1 yr

*Source: *Radiology* 2008;248:254-263
**Calculated using average natural background exposure in Canada (Health Canada: http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/expos-eng.php)

Ultrasound

- high frequency sound waves are transmitted from a transducer and passed through tissues; reflections of the sound waves are picked up by the transducer and transformed into images
- reflection (or "echo") occurs when the sound waves pass through tissue interfaces of different acoustic densities
- structures are described based on their echogenicity; hyperechoic structures appear bright (U/S reflected) whereas hypoechoic structures appear dark (U/S waves not reflected back but pass through)
- higher U/S frequencies result in greater resolution but greater attenuation (i.e. deeper structures more difficult to visualize)
- artifacts: acoustic shadowing refers to the echo-free area located behind an interface that strongly reflects (e.g. tissue/air) or absorbs (e.g. tissue/bone) sound waves; enhancement refers to the increase in reflection amplitude (i.e. increased brightness) from objects that lie below a weakly attenuating structure (e.g. cyst)
- Duplex scan: grey-scale image that utilizes the Doppler effect to visualize the velocity of blood flow past the transducer
- Colour Doppler: assigns a colour based on the direction of blood flow
- advantages: relatively low cost, non-invasive, no radiation, real time imaging, may be used for guided biopsies, many different imaging planes (axial, sagittal), determines cystic versus solid
- disadvantages: highly operator-dependent, air in bowel may prevent imaging of midline structures in the abdomen, may be limited by patient habitus, poor for bone evaluation

Attenuation
Bone (= bright) > grey matter > white matter ("fatty" myelin) > CSF > air (= dark)

Magnetic Resonance Imaging

- non-invasive technique that does not use ionizing radiation
- able to produce images in virtually any plane
- patient is placed in a magnetic field; protons (H^+) align themselves along the plane of magnetization due to intrinsic polarity. A pulsed radiofrequency beam is subsequently turned on which deflects all the protons off their aligned axes due to absorption of energy from the radiofrequency beam. When the radiofrequency beam is turned off, the protons return to their pre-excitation axis, giving off the energy they absorbed. This energy is measured with a detector and interpreted by a computer to generate MR images
- the MR image reflects the signal intensity picked up by the receiver. This signal intensity is dependent on:
  1. hydrogen density: tissues with low hydrogen density (e.g. cortical bone, lung) generate little to no MR signal compared to tissues with high hydrogen density (e.g. water)
  2. magnetic relaxation times (T1 and T2): reflect quantitative alterations in MR signal strength due to intrinsic properties of the tissue and its surrounding chemical and physical environment

Remember that **w**ater is "**w**hite" on **T2** as "**W**orld **W**ar **II**"

Methods to Reduce the Risk of Contrast Induced Nephropathy
- **Optimal**: 0.9% NaCl at 1 ml/kg/hr for 12 hr pre-procedure and 12 hr post-contrast administration
- **For same day procedure**: 0.9% NaCl or $NaHCO_3$ at 3 ml/kg/hr for 1-3 hr pre-procedure and for 6 hr post-contrast administration

Table 1. Differences Between Diffusion, T1- and T2-Weighted MR Imaging

Imaging Techniques	Contrast Enhancements	Main Application	Advantages
Diffusion Weighted Imaging	Contrast dependent on the molecular motion of water Decreased diffusion is hyperintense (bright), whereas increased diffusion is hypointense (dark)	Neuroradiology	Sensitive for detection of acute ischemic stroke and differentiating an acute stroke from other neurologic pathologies Acute infarction appears hyperintense Abscess collections also show restricted diffusion
T1-Weighted	Fluid is hypointense (dark) and fat is hyperintense (bright)	Body soft tissues	Often considered an anatomic scan since they provide a reference for functional imaging
T2-Weighted	Fluid is hyperintense (bright) and fat is hypointense (dark)	Body soft tissues	Often considered a pathologic scan since they will highlight edematous areas associated with certain pathologies

Positron Emission Tomography Scans

- non-invasive technique that involves exposure to ionizing radiation (~7 mSv)
- nuclear medicine imaging technique that produces images of functional processes in the body
- current generation models integrate PET and CT technologies into a single imaging device (PET-CT) that collects both anatomic and functional information during a single acquisition
- positron-producing radioisotope, such as ^{18}FDG is chemically incorporated into a metabolically active molecule (e.g. glucose), injected into patient, which travels to target organ, accumulates in tissues of interest, and as radioactive substance begins to decay, gamma rays are produced which are detected by PET scanner
- contraindications: pregnancy
- advantages: shows metabolism and physiology of tissues (not only anatomic), in oncology allows diagnosis, staging, restaging, has predictive and prognostic value, can evaluate cardiac viability
- disadvantages: cost, ionizing radiation

Contraindications to IV Contrast

MADD Failure
Multiple myeloma
Adverse reaction previously
DM
Dehydration
Failure (renal, severe heart)

Contrast Enhancement

Table 2. Contrast Agents

Imaging Modality	Types	Advantages	Disadvantages	Contraindications
X-Ray/CT	1. Barium (oral or rectal)	Radioopaque substance which helps to delineate intraluminal anatomy, may demonstrate patency, lumen integrity, or large filling defects		Previous adverse reaction to contrast; barium enema is contraindicated in toxic megacolon, acute colitis, and suspected perforation
	2. Iodine (IV injection)	Delineates intraluminal anatomy, may demonstrate patency, lumen integrity, or large filling defects; under fluoroscopy, may also give information on function of an organ	Risk of nephrogenic systemic fibrosis in patients with end-stage renal disease	Previous adverse reaction to contrast, renal failure, DM, pregnancy, multiple myeloma, severe heart failure and dehydration eGFR <60 may require preventative measures and follow up
MRI	Gadolinium-Chelates (IV injection)	Shortens T1 relaxation time, thereby increasing signal intensity in T1-weighted sequences; gadolinium has some effect on T2-relaxation time; highlights highly vascular structures (e.g. tumours)	Risk of nephrogenic systemic fibrosis in patients with end-stage renal disease	Previous adverse reaction to contrast or if end-stage renal disease (relative contraindication)
U/S	Microbubbles (IV injection)	Since gas is highly echogenic, the microbubbles allow for echo-enhancement of a tissue		Contraindicated in individuals with right-to-left cardiac shunts or people with known hypersensitivity reactions

Chest Imaging

Chest X-Ray

Standard Views

- PA: anterior chest against film plate to minimize magnification of the heart size
- lateral: better visualization of retrocardiac space and thoracic spine (more sensitive at picking up pleural effusions)
  - helps localize lesions when combined with PA view
- AP: for bedridden patients (generally a lower quality film than PA because of enlarged cardiac silhouette)
- lateral decubitus: to assess for pleural effusion and pneumothorax in bedridden patients; however, POCUS can also be utilized for both these purposes
- lordotic: angled beam allowing better visualization of apices normally obscured by the clavicles and anterior ribs

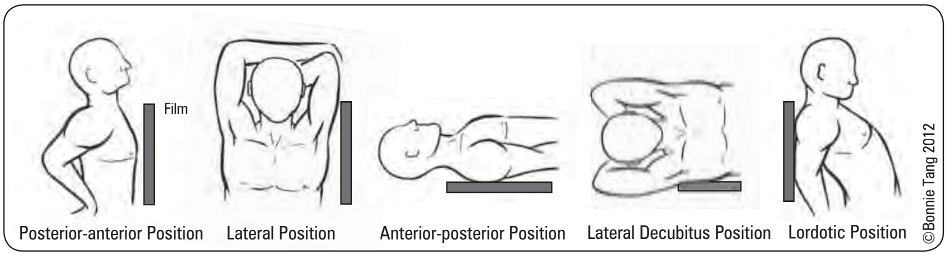


Figure 1. CXR views

Approach to CXR

Basics

- ID: patient name, MRN, sex, age
- date of exam
- markers: right and/or left
- technique: view (e.g. PA, AP, lateral), supine or erect
- indications for the study
- comparison: date of previous study for comparison (if available)
- quality of film: inspiration (6th anterior and 10th posterior ribs should be visible), penetration (thoracic spine should be visible) and rotation (clavicles vs. spinous process)

Analysis

- tubes and lines: check position and be alert for pneumothorax or pneumomediastinum
- soft tissues: neck, axillae, pectoral muscles, breasts/nipples, chest wall
  - nipple markers can help identify nipples (may mimic lung nodules)
  - amount of soft tissue, presence of masses and air (subcutaneous emphysema)
- abdomen (see *Abdominal Imaging*, MI10)
  - free air under the diaphragm, air-fluid levels, distention in small and large bowels
  - herniation of abdominal contents (i.e. diaphragmatic hernia)
- bones: C-spine, thoracic spine, shoulders, ribs, sternum, clavicles
  - lytic and blastic lesions and fractures
- mediastinum: trachea, heart, great vessels
  - cardiomegaly (cardiothoracic ratio >0.5), tracheal shift, tortuous aorta, widened mediastinum
- hila: pulmonary vessels, mainstem and segmental bronchi, lymph nodes
- lungs: lung parenchyma, pleura, diaphragm
  - comment on abnormal lung opacity, pleural effusions or thickening
  - right hemidiaphragm usually higher than left due to liver
  - right vs. left hemidiaphragm can be discerned on lateral CXR due to heart resting directly on left hemidiaphragm

Chest X-Ray Interpretation

Basics ABCDEF
AP, **P**A or other view
Body position/rotation
Confirm name
Date
Exposure/quality
Films for comparison

Analysis ABCDEF
Airways and hilar **A**denopathy
Bones and **B**reast shadows
Cardiac silhouette and **C**ostophrenic angle
Diaphragm and **D**igestive tract
Edges of pleura
Fields (lung fields)

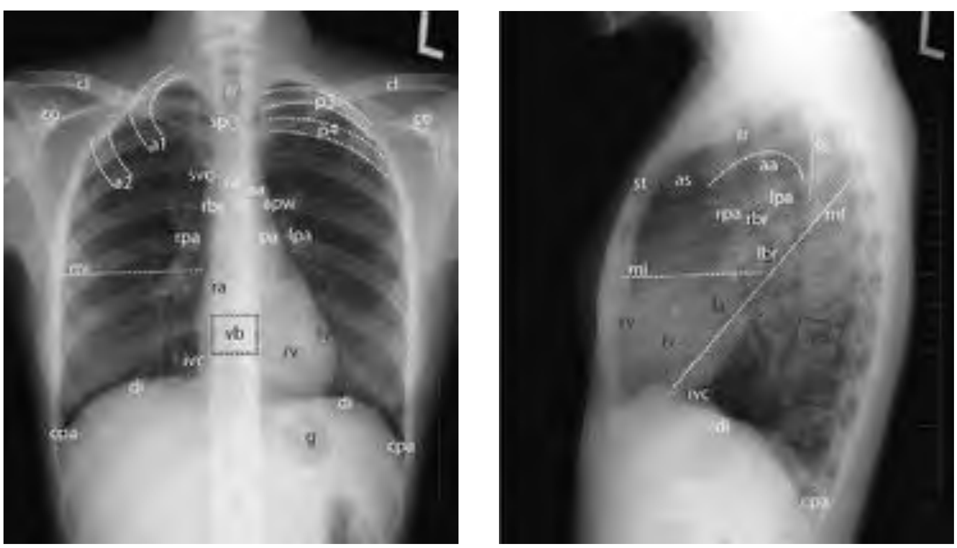
Anatomy

Localizing Lesions for Parenchymal Lung Disease

- **silhouette sign**: loss of normal interfaces due to lung pathology (consolidation, atelectasis, mass), which can be used to localize disease in specific lung segments; note that pleural or mediastinal disease can also produce the silhouette sign)
- **spine sign**: on lateral films, vertebral bodies should appear progressively radiolucent as one moves down the thoracic vertebral column; if they appear more radioopaque, it is an indication of pathology (e.g. consolidation in overlying left lower lobe)
- **air bronchogram**: branching pattern of air filled bronchi on a background of fluid filled airspaces

Table 3. Localization Using the Silhouette Sign

Interface Lost	Location of Lung Pathology
SVC/right superior mediastinum	RUL
Right heart border	RML
Right hemidiaphragm	RLL
Aortic knob/left superior mediastinum	LUL
Left heart border	Lingula
Left hemidiaphragm	LLL



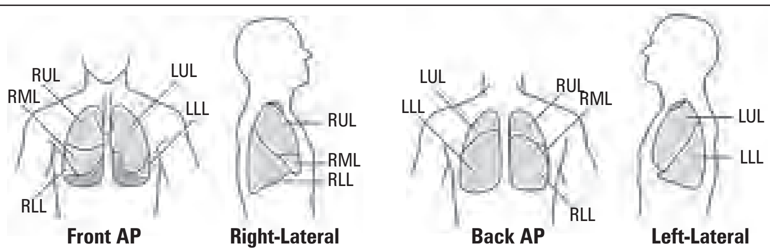
PA view

Lateral view

Legend

a1	anterior 1st rib
a2	anterior 2nd rib
aa	aortic arch
apw	aorto-pulmonary window
as	anterior airspace
ca	carina
cl	clavicle
co	coracoid process
cpa	costophrenic angle
di	diaphragm
g	gastric bubble
ivc	inferior vena cava
la	left atrium
lbr	left mainstem bronchus
lpa	left pulmonary artery
lv	left ventricle
mf	major fissure
mi	minor fissure
p3	posterior 3rd rib
p4	posterior 4th rib
pa	main pulmonary artery
ra	right atrium
rbr	right mainstem bronchus
rpa	right pulmonary artery
rv	right ventricle
sc	scapula
sp	spinous process
st	sternum
svc	superior vena cava
tr	trachea
vb	vertebral body

Figure 2. Location of fissures, mediastinal structures, and bony landmarks on CXR



RUL: Right Upper Lobe; RML: Right Middle Lobe; RLL: Right Lower Lobe; LUL: Left Upper Lobe; LLL: Left Lower Lobe

Figure 3. Location of lobes of the lung

Computed Tomography Chest

Approach to CT Chest

- soft tissue window
  - thyroid, chest wall, pleura
  - heart: chambers, coronary artery calcifications, pericardium
  - vessels: aorta, pulmonary artery, smaller vasculature
  - lymph nodes: mediastinal, axillary
- bone window
  - vertebrae, sternum, manubrium, ribs: fractures, lytic lesions, sclerosis
- lung window
  - trachea: patency, secretions
  - bronchial trees: anatomic variants, mucus plugs, airway collapse
  - lung parenchyma: fissures, nodules, fibrosis/interstitial changes
  - pleural space: effusions

Table 4. Types of CT Chest

	Advantage	Disadvantage	Contrast	Indication
Standard	Scans full lung very quickly (<1 min)	Poor at evaluating diffuse disease	±	CXR abnormality Pleural and mediastinal abnormality Lung cancer staging Follow up metastases Empyema vs. abscess
High Resolution	Thinner slices provide high definition of lung parenchyma	Only 5-10% lung is sampled	No	Hemoptysis Diffuse lung disease (e.g. sarcoidosis, hypersensitivity pneumonitis, pneumoconiosis) Pulmonary fibrosis Normal CXR but abnormal PFTs Characterize solitary pulmonary nodule
Low Dose	1/5th the radiation	Decreased detail	No	Screening Follow up infections, lung transplant, metastases
CTA	Iodinated contrast highlights vasculature	Contrast can cause severe allergic reaction and is nephrotoxic	Yes	PE Aortic aneurysms Aortic dissection

Lung Abnormalities

Atelectasis

- pathogenesis: collapse of alveoli due to restricted breathing, blockage of bronchi, external compression, or poor surfactant
- findings
  - increased opacity of involved segment/lobe, vascular crowding, silhouette sign, air bronchograms
  - volume loss: fissure deviation, hilar/mediastinal displacement, diaphragm elevation
  - compensatory hyperinflation of remaining normal lung
- differential diagnosis
  - obstructive (most common): air distal to obstruction is reabsorbed causing alveolar collapse
    - post-surgical, endobronchial lesion, foreign body, inflammation (granulomatous infections, pneumoconiosis, sarcoidosis, radiation injury), or mucous plug (cystic fibrosis)
  - compressive
    - tumour, bulla, effusion, enlarged heart, lymphadenopathy
  - traction (cicatrization): due to scarring, which distorts alveoli and contracts the lung
  - adhesive: due to lack of surfactant
    - hyaline membrane disease, prematurity
  - passive (relaxation): a result of air or fluid in the pleural space
    - pleural effusion, pneumothorax
- management: in the absence of a known etiology, persisting atelectasis must be investigated (i.e. CT thorax) to rule out a bronchogenic carcinoma

Consolidation

- pathogenesis: fluid (water, blood), inflammatory exudates, protein, or tumour in alveoli
- findings
  - air bronchograms: lucent branching bronchi visible through opacification
  - airspace nodules: fluffy, patchy, poorly defined margins with later tendency to coalesce, may take on lobar or segmental distribution
  - silhouette sign

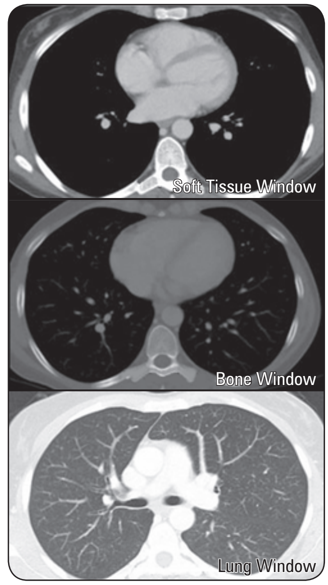


Figure 4. CT thorax windows

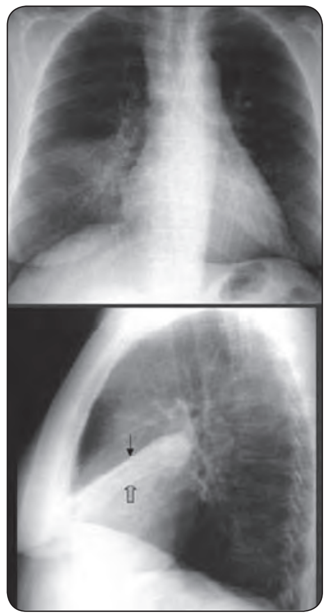


Figure 5. Atelectasis: RML collapse

DDx of Airspace Disease
- Pus (e.g. infections such as pneumonia, non-infectious inflammatory process)
- Fluid (e.g. pulmonary edema)
- Blood (e.g. pulmonary hemorrhage)
- Cells (e.g. bronchioalveolar carcinoma, lymphoma)
- Protein (e.g. alveolar proteinosis)

Figure 6. Air bronchograms in right lung

- differential diagnosis
  - fluid: pulmonary edema, blood (trauma, vasculitis, bleeding disorder, pulmonary infarct)
  - inflammatory exudates: bacterial infections, TB, allergic hypersensitivity alveolitis, BOOP, allergic bronchopulmonary aspergillosis, aspiration, sarcoidosis
  - protein: pulmonary alveolar proteinosis
  - tumour: bronchoalveolar carcinoma, lymphoma
- management: varies depending on the pattern of consolidation, which can suggest different etiologies; should also be done in the context of clinical picture

Interstitial Disease

- pathogenesis: pathological process involving the interlobular connective tissue (i.e. "scaffolding of the lung")
- findings
  - linear: fine lines caused by thickened connective tissue septae
    - Kerley A: long thin lines in upper lobes
    - Kerley B: short horizontal lines extending from lateral lung margin
    - Kerley C: diffuse linear pattern throughout lung
    - seen in pulmonary edema, lymphangietic carcinomatosis, and atypical interstitial pneumonias
  - nodular: 1-5 mm well-defined nodules distributed evenly throughout lung
    - seen in malignancy, pneumoconiosis and granulomatous disease (e.g. sarcoidosis, miliary TB)
  - reticular (honeycomb): parenchyma replaced by thin-walled cysts suggesting extensive destruction of pulmonary tissue and fibrosis
    - seen in IPF, asbestosis, and CVD
    - watch for pneumothorax as a complication
  - reticulonodular: combination of reticular and nodular patterns
  - may also see signs of airspace disease (atelectasis, consolidation)
- differential diagnosis
  - occupational/environmental exposure
    - inorganic: asbestosis, coal miner's pneumoconiosis, silicosis, berylliosis, talc pneumoconiosis
    - organic: hypersensitivity pneumonitis, bird fancier's lung, farmer's lung (moldy hay), and other organic dust
  - autoimmune: CVD (e.g. rheumatoid arthritis, scleroderma, SLE, polymyositis, mixed connective tissue disease), IBD, celiac diseae, vasculitis
  - drug-related: antibiotics (cephalosporins, nitrofurantoin), NSAIDs, phenytoin, carbamazepine, fluoxetine, amiodarone, chemotherapy (e.g. methotrexate), heroin, cocaine, methadone
  - infections: non-tuberculous mycobacteria, certain fungal infections
  - idiopathic: hypersensitivity pneumonitis, IPF, BOOP
  - for *Causes of Interstitial Lung Disease Classified by Distribution*, see Respirology, R13
- management: high resolution CT thorax and biopsy

Pulmonary Nodule

- findings: round opacity ± silhouette sign
  - note: do not mistake nipple shadows for nodules; if in doubt, repeat CXR with nipple markers
- differential diagnosis
  - extrapulmonary density: nipple, skin lesion, electrode, pleural mass, bony lesion
  - solitary nodule
    - tumour: carcinoma, hamartoma, metastasis, bronchial adenoma
    - inflammation: histoplasmoma, tuberculoma, coccidioidomycosis
    - vascular: AV fistula, pulmonary varix (dilated pulmonary vein), infarct, embolism
  - multiple nodules: metastases, abscess, granulomatous lung disease (TB, fungal, sarcoid, rheumatoid nodules, silicosis, GPA)
- management: clinical information and CT appearance determine level of suspicion of malignancy
  - if high probability of malignancy, invasive testing (fine needle aspiration, transbronchial/transthoracic biopsy) is indicated
  - if low probability of malignancy, repeat CXR or CT in 1-3 mo and then every 6 mo for 2 yr; if no change, then >99% chance benign

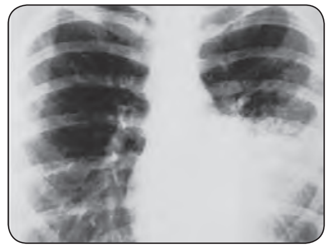


Figure 7. Consolidation: bacterial pneumonia

Figure 8. Interstitial disease: fine reticular pattern

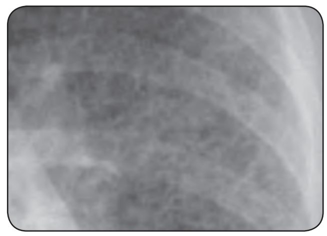


Figure 9. Interstitial disease: medium reticular pattern

DDx of Interstitial Lung Disease
FASSTEN (upper lung disease)
Farmer's lung (hypersensitivity pneumonitis)
Ankylosing spondylitis
Sarcoidosis
Silicosis
TB
Eosinophilic granuloma (Langerhans cell histiocytosis)
Neurofibromatosis
BAD RASH (lower lung disease)
BOOP
Asbestos
Drugs (nitrofurantoin, hydralazine, isoniazid, amiodarone, many chemotherapy drugs)
Rheumatological disease
Aspiration
Scleroderma
Hamman Rich (IPF) and idiopathic pulmonary fibrosis

DDx for Cavitating Lung Nodule
WEIRD HOLES
GPA (**W**egener's)
Embolic (pulmonary, septic)
Infection (anaerobes, pneumocystis, TB)
Rheumatoid (necrobiotic nodules)
Developmental cysts (sequestration)
Histiocytosis
Oncological
Lymphangioleiomyomatosis
Environmental, occupational
Sarcoidosis

Table 5. Characteristics of Benign and Malignant Pulmonary Nodules

	Malignant	Benign
Margin	Ill-defined/spiculated ("corona radiata")	Well-defined
Contour	Lobulated	Smooth
Calcification	Eccentric or stippled	Diffuse, central, popcorn, concentric
Doubling Time	20-460 d	<20 d or >460 d
Other Features	Cavitation, collapse, adenopathy, pleural effusion, lytic bone lesions, smoking history	
Size	>3 cm	<3 cm
Cavitation	Yes, especially with wall thickness >15 mm, eccentric cavity and shaggy internal margins	No
Satellite Lesions	No	Yes

Figure 10. Pulmonary nodule: bronchogenic carcinoma

Pulmonary Vascular Abnormalities

Pulmonary Edema

- pathogenesis: fluid accumulation in the airspaces of the lungs
- findings
  - vascular redistribution/enlargement, cephalization, pleural effusion, cardiomegaly (may be present in cardiogenic edema and fluid overloaded states)
  - fluid initially collects in interstitium
    - loss of definition of pulmonary vasculature
    - peribronchial cuffing
    - Kerley B lines
    - reticulonodular pattern
    - thickening of interlobar fissures
  - as pulmonary edema progresses, fluid begins to collect in alveoli causing diffuse air space disease often in a "bat wing" or "butterfly" pattern in perihilar regions with tendency to spare the outermost lung fields
- differential diagnosis: cardiogenic (e.g. CHF), renal failure, volume overload, non-cardiogenic (e.g. ARDS)

Figure 11. Peribronchial cuffing

Pulmonary Embolism

- pathogenesis: arterial blockage in the lungs due to emboli from pelvic or leg veins, rarely from PICC lines, ports, or air, fat, or amniotic fluid (difficult to diagnose on imaging except by combination of clinical history and CXR and CT findings of ARDS)
- findings
  - CXR: Westermark sign (localized pulmonary oligemia), Hampton's hump (triangular peripheral infarct), enlarged right ventricle and right atrium, atelectasis, pleural effusion, and rarely pulmonary edema
  - definitive imaging study: CT pulmonary angiography to look for filling defect in contrast-filled pulmonary arteries (emboli can be seen up to 4th order arterial branching)
  - V/Q scan: not a diagnostic study

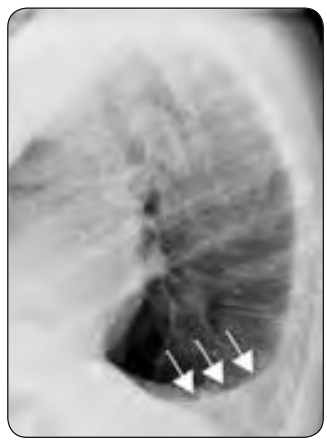


Figure 12. Pleural effusion in lateral view

Pleural Abnormalities

Pleural Effusion

Table 6. Sensitivity of Plain Film Views for Pleural Effusion

X-Ray Projection	Minimum Volume to Visualize
Lateral decubitus	25 mL: most sensitive
Upright lateral	50 mL: meniscus seen in the posterior costophrenic sulcus
PA	200 mL
Supine	Diffuse haziness

- a horizontal fluid level is seen only in a hydropneumothorax (i.e. both fluid and air within pleural cavity)
- effusion may exert mass effect, shift trachea and mediastinum to opposite side, or cause atelectasis of adjacent lung
- U/S is superior to plain film for detection of small effusions and may also aid in thoracentesis, and POCUS is now standard of care in acute situations
- fluid level >1 cm on lateral decubitus film is indication to perform thoracentesis

Figure 13. Pneumothorax

Pneumothorax

- pathogenesis: gas/air accumulation within the pleural space resulting in separation of the lung from the chest wall

- findings
  - upright chest film allows visualization of visceral pleura as curvilinear line paralleling chest wall, separating partially collapsed lung from pleural air
  - more obvious on expiratory (increased contrast between lung and air) or lateral decubitus films (air collects superiorly)
  - more difficult to detect on supine film; look for the "deep (costophrenic) sulcus" sign, "double diaphragm" sign (dome and anterior portions of diaphragm outlined by lung and pleural air, respectively), hyperlucent hemithorax, sharpening of adjacent mediastinal structures
  - mediastinal shift may occur if tension pneumothorax
- differential diagnosis: spontaneous (tall and thin males, smokers), iatrogenic (lung biopsy, ventilation, CVP line insertion), trauma (associated with rib fractures), emphysema, malignancy, honeycomb lung
- management: needle decompression or chest tube insertion, repeat CXR to ensure resolution

Asbestos

- asbestos exposure may cause various pleural abnormalities including benign plaques (most common) that may calcify, diffuse pleural fibrosis, effusion, and malignant mesothelioma

Elevated Hemidiaphragm Suggests

PAL DIP
Pregnancy
Atelectasis
Lung resection
Diaphragmatic paralysis
Intra-abdominal process
Pneumonectomy

Pleural effusion also may result in apparent elevation

Depressed Hemidiaphragm Suggests

TALC
Tumour
Asthma
Large pleural effusion
COPD

Mediastinal Abnormalities

Mediastinal Mass

- the mediastinum is divided into four compartments; this provides an approach to the differential diagnosis of a mediastinal mass
- anterior border formed by the sternum and posterior border by the heart and great vessels
  - 4 Ts: see sidebar
  - cardiophrenic angle mass differential: thymic cyst, epicardial fat pad, foramen of Morgagni hernia
- middle (extending behind anterior mediastinum to a line 1 cm posterior to the anterior border of the thoracic vertebral bodies)
  - esophageal carcinoma, esophageal duplication cyst, metastatic disease, lymphadenopathy (all causes), hiatus hernia, bronchogenic cyst
- posterior (posterior to the middle line described above)
  - neurogenic tumour (e.g. neurofibroma, schwannoma), multiple myeloma, pheochromocytoma, neurenteric cyst, thoracic duct cyst, lateral meningocele, Bochdalek hernia, extramedullary hematopoiesis
- superior boundaries (superiorly by thoracic inlet, inferiorly by plane of the sternal angle, anteriorly by manubrium, posteriorly by T1-T4, laterally by pleura)
- in addition, any compartment may give rise to lymphoma, lung cancer, aortic aneurysm or other vascular abnormalities, abscess, and hematoma

DDx Anterior Mediastinal Mass

4 Ts
Thyroid
Thymic neoplasm
Teratoma
Terrible lymphoma

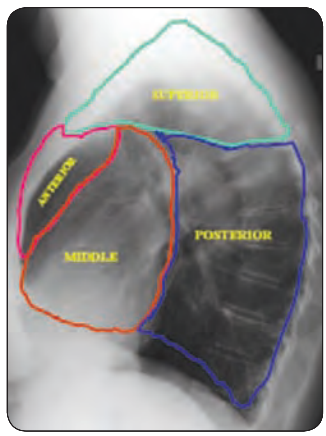


Figure 14. Lateral CXR showing 4 mediastinal compartments

Enlarged Cardiac Silhouette

- heart borders
  - on PA view, right heart border is formed by right atrium; left heart border is formed by left atrium and left ventricle
  - on lateral view, anterior heart border is formed by right ventricle; posterior border is formed by left atrium (superior to left ventricle) and left ventricle
- cardiothoracic ratio = greatest transverse dimension of the central shadow relative to the greatest transverse dimension of the thoracic cavity
  - using a good quality erect PA chest film in adults, cardiothoracic ratio of >0.5 is abnormal
  - differential of ratio >0.5
    - cardiomegaly (myocardial dilatation or hypertrophy)
    - pericardial effusion
    - poor inspiratory effort/low lung volumes
    - pectus excavatum
  - ratio <0.5 does not exclude enlargement (e.g. cardiomegaly + concomitant hyperinflation)
- pericardial effusion: globular heart with loss of indentations on left mediastinal border
- RA enlargement: increase in curvature of right heart border and enlargement of SVC
- LA enlargement: straightening of left heart border; increased opacity of lower right side of cardiovascular shadow (double heart border); elevation of left main bronchus (specifically, the upper lobe bronchus on the lateral film), distance between left main bronchus and "double" heart border >7 cm, splayed carina (late sign)
- RV enlargement: elevation of cardiac apex from diaphragm; anterior enlargement leading to loss of retrosternal air space on lateral; increased contact of right ventricle against sternum
- LV enlargement: displacement of cardiac apex inferiorly and posteriorly – "boot-shaped" heart

Tubes, Lines, and Catheters

- ensure appropriate placement and assess potential complications of lines and tubes
- avoid mistaking a line/tube for pathology (e.g. oxygen rebreather mask for pneumothoraces)

Central Venous Catheter

- used for fluid and medication administration, vascular access for hemodialysis, and CVP monitoring
- tip must be located proximal to right atrium to prevent inducing arrhythmias or perforating wall of atrium
  - if monitoring CVP, catheter tip must be proximal to venous valves
- tip of well positioned central venous catheter projects over silhouette of SVC in a zone demarcated superiorly by the anterior first rib end and clavicle, and inferiorly by top of RA
- course should parallel course of SVC – if appears to bend as it approaches wall of SVC or appears perpendicular, catheter may damage and ultimately perforate wall of SVC
- complications: pneumothorax, bleeding (mediastinal, pleural), air embolism

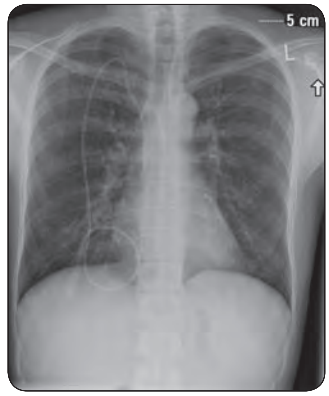


Figure 15. Well-positioned central venous catheter (CXR)

Endotracheal Tube

- frontal chest film: tube projects over trachea and shallow oblique or lateral chest radiograph will help determine position in 3 dimensions
- progressive gaseous distention of stomach on repeat imaging is concerning for esophageal intubation
- tip should be located 4 cm above tracheal carina – avoids bronchus intubation and vocal cord irritation
- maximum inflation diameter <3 cm to avoid necrosis of tracheal mucosa and rupture – ensure diameter of balloon is less than tracheal diameter above and below balloon
- complications: aspiration (parenchymal opacities), pharyngeal perforation (subcutaneous emphysema, pneumomediastinum, mediastinitis)

Nasogastric Tube

- tip and sideport should be positioned distal to esophagogastric junction and proximal to gastric pylorus
- radiographic confirmation of tube is mandatory because clinical techniques for assessing tip position may be unreliable
- complications: aspiration (parenchymal opacities), intracranial perforation (trauma patients), pneumothorax

Swan-Ganz Catheter

- to monitor pulmonary capillary wedge pressure and to measure cardiac output for suspected LV dysfunction
- tip should be positioned within right or left main pulmonary arteries or in one of their large, lobar branches
- if tip is located more distally, increased risk of prolonged pulmonary artery occlusion resulting in pulmonary infarction or, rarely, pulmonary artery rupture
- complications: pneumothorax, bleeding (mediastinal, pleural), air embolism

Chest Tube

- in dorsal and caudal portion of pleural space to evacuate fluid
- in ventral and cephalad portions of pleural space to evacuate pneumothoraces
- tube may lie in fissure as long as functioning
- complications: lung perforation (mediastinal opacities)

Abdominal Imaging

Abdominal X-Ray

- AXR 3 most common views: left lateral decubitus, supine, erect upright (see Figure 16)
- indications
  - acute abdomen: bowel perforation, toxic megacolon, bowel ischemia, small bowel obstruction, large bowel obstruction
  - chronic symptoms: constipation, calcifications (gallstones, renal stones, urinary bladder stones, etc.)
  - not useful in: GI bleeds, chronic anemia, vague GI symptoms

3 Views of AXR
- Left lateral decubitus
- Supine
- Erect/Upright

Anatomy

- abdomen divided into 2 cavities
  - peritoneal cavity: lined by peritoneum that wraps around most of the bowel, the spleen, and most of the liver; forms a recess lateral to both the ascending and descending colon (paracolic gutters)
  - retroperitoneal cavity: contains several organs situated posterior to the peritoneal cavity; the contour of these can often be seen on radiographs

Table 7. Differentiating Small and Large Bowel

Property	Small Bowel	Large Bowel
Mucosal Folds	Uninterrupted valvulae conniventes (or plicae circularis)	Interrupted haustra extend only partway across lumen
Location	Central	Peripheral (picture frame)
Maximum Diameter	3 cm	6 cm (9 cm at cecum)
Maximum Fold Thickness	3 mm	5 mm
Other	Rarely contains solid fecal material	Commonly contains solid fecal material

Approach to Abdominal X-Ray

- mnemonic: "Free ABDO"
- "Free": free air and fluid
  - free fluid
    - small amounts of fluid: increased distance between lateral fat stripes and adjacent colon may indicate free peritoneal fluid in the paracolic gutters
    - large amounts of fluid: diffuse increased opacification on supine film; bowel floats to centre of anterior abdominal wall
    - ascites and blood (hemoperitoneum) are the same density on the radiograph and therefore cannot be differentiated
    - free intraperitoneal air suggests rupture of a hollow viscus (anterior duodenum, transverse colon), penetrating trauma, or recent (<7 d) surgery
- "A": air in the bowel (can be normal, ileus, or obstruction)
  - volvulus – twisting of the bowel upon itself; from most to least common:
    - sigmoid: "coffee bean" sign (massively dilated sigmoid projects to right or mid-upper abdomen) with proximal dilation
    - cecal: massively dilated bowel loop projecting to left or mid-upper abdomen with small bowel dilation
    - gastric: rare
    - transverse colon: rare (usually young individuals)
    - small bowel: "corkscrew sign" (rarely diagnosed on plain films, seen best on CT)
  - toxic megacolon
    - manifestation of fulminant colitis
    - extreme dilatation of colon (>6.5 cm) with mucosal changes (e.g. foci of edema, ulceration, pseudopolyps), loss of normal haustral pattern
- "B": bowel wall thickening
  - increased soft tissue density in bowel wall, thumb-like indentations in bowel wall ("thumb-printing"), or a picket-fence appearance of the valvulae conniventes ("stacked coin" appearance)
  - may be seen in IBD, infection, ischemia, hypoproteinemic states, and submucosal hemorrhage
- "D": densities
  - bones: look for gross abnormalities of lower ribs, vertebral column, and bony pelvis
  - abnormal calcifications: approach by location
    - RUQ: renal stone, adrenal calcification, gallstone, porcelain gallbladder
    - RLQ: ureteral stone, appendicolith, gallstone ileus
    - LUQ: renal stone, adrenal calcification, tail of pancreas
    - LLQ: ureteral stone
    - central: aorta/aortic aneurysm, pancreas, lymph nodes
    - pelvis: phleboliths (i.e. calcified veins), uterine fibroids, bladder stones
- "O": organs
  - kidney, liver, gallbladder, spleen, pancreas, urinary bladder, psoas shadow
  - outlines can occasionally be identified because they are surrounded by more lucent fat, but all are best visualized with other imaging modalities (CT, MRI)

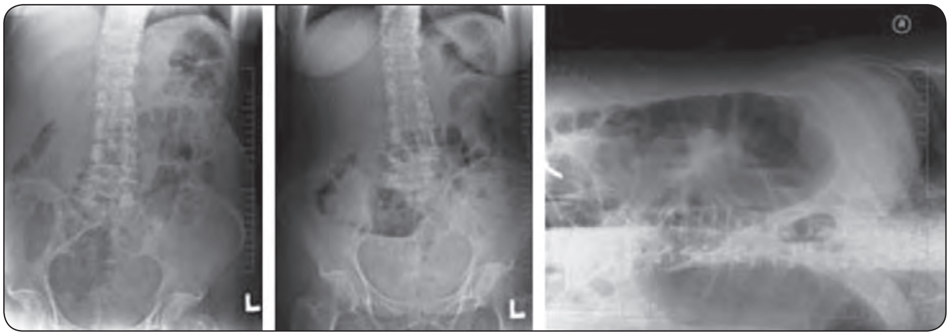


Figure 16. Normal AXRs: (left) supine anteroposterior AXR, (middle) upright anteroposterior AXR, and (right) left lateral decubitus AXR

Table 8. Abnormal Air on Abdominal X-Ray

Air	Appearance	Common Etiologies
Extraluminal Intraperitoneal (pneumoperitoneum)	Upright film: air under diaphragm Left lateral decubitus film: air between liver and abdominal wall Supine film: gas outlines of structures not normally seen: • Inner and outer bowel wall (Rigler's sign) • Falciform ligament • Peritoneal cavity ("football" sign)	Perforated viscus Post-operative (up to 10 d to be resorbed)
Retroperitoneal	Gas outlining retroperitoneal structures allowing increased visualization: • Psoas shadows • Renal shadows	Perforation of retroperitoneal segments of bowel: duodenal ulcer, post-colonoscopy
Intramural (pneumatosis intestinalis)	Lucent air streaks in bowel wall, 2 types: 1. Linear 2. Rounded (cystoides type)	1. Linear: ischemia, necrotizing enterocolitis 2. Rounded/cystoides (generally benign): primary (idiopathic), secondary to COPD
Intraluminal	Dilated loops of bowel, air-fluid levels	Adynamic (paralytic) ileus, mechanical bowel obstruction
Loculated	Mottled, localized in abnormal position without normal bowel features	Abscess (evaluate with CT)
Biliary	Air centrally over liver	Sphincterotomy, gallstone ileus, erosive peptic ulcer, cholangitis, emphysematous cholecystitis
Portal Venous	Air peripherally over liver in branching pattern	Bowel ischemia/infarction

Biliary vs. Portal Venous Air
"Go with the flow": air follows the flow of bile or portal venous blood
Biliary air is most prominent centrally over the liver
Portal venous air is most prominent peripherally

Table 9. Adynamic Ileus vs. Mechanical Obstruction

Feature	Adynamic Ileus	Mechanical Obstruction
Calibre of Bowel Loops	Normal or dilated	Usually dilated
Air-Fluid Levels (erect and left lateral decubitus films only)	Same level in the same single loop	Multiple air fluid levels giving "step ladder" appearance, dynamic (indicating peristalsis present), "string of pearls" (row of small gas accumulations in the dilated valvulae conniventes)
Distribution of Bowel Gas	Air throughout GI tract is generalized or localized • In a localized ileus (e.g. pancreatitis, appendicitis), dilated "sentinel loop" remains in the same location on serial films, usually adjacent to the area of inflammation	Dilated bowel up to the point of obstruction (i.e. transition point) No air distal to obstructed segment "Hairpin" (180°) turns in bowel

Abdominal CT

- indications for plain CT: renal colic, hemorrhage
- indications for CT with contrast
  - IV contrast given immediately before or during CT to allow identification of arteries and veins
    - portal venous phase: indicated for majority of cases
    - biphasic (arterial and portal venous phases): liver, pancreas, bile duct tumours
    - caution: contrast allergy (may premedicate with steroids and antihistamine)
    - contraindication: impaired renal function, based on eGFR
  - oral contrast: barium or water soluble (water soluble if suspected perforation) given in most cases to demarcate GI tract
  - rectal contrast: given for investigation of colonic lesions

Approach to Abdominal Computed Tomography

- look through all images in gestalt fashion to identify any obvious abnormalities
- look at each organ/structure individually, from top to bottom evaluating size and shape of each area of increased or decreased density
- evaluate the following
  - soft tissue window
    - liver, gallbladder, spleen, and pancreas
    - adrenals, kidneys, ureters, and bladder
    - stomach, duodenum, small bowel mesentery, and colon/appendix
    - retroperitoneum: aorta, vena cava, and mesenteric vessels; look for adenopathy in vicinity of vessels
    - peritoneal cavity for fluid or masses
    - abdominal wall and adjacent soft tissue
  - lung window
    - visible lung (bases)
  - bone window
    - vertebrae, spinal cord, and bony pelvis

Colorectal Cancer: CT Colonography and Colonoscopy for Detection-Systematic Review and Meta-Analysis
Radiology 2011;259:393-405
Study: Systematic review and meta-analysis.
Population: 49 studies on 11,151 patients undergoing diagnostic study for detection of colorectal cancer (CRC).
Intervention: CT colonography (CTC) and optical colonoscopy (OC).
Main Outcome Measure: Sensitivity of CTC and OC for CRC.
Results: CTC has a sensitivity of 96.1% (95% CI 93.8%, 97.7%) and OC has a sensitivity of 94.7% (95% CI 90.4%, 97.2%) for the detection of CRC.
Conclusion: CTC is highly sensitive for the detection of CRC and may be a better modality for the initial investigation of suspected CRC, assuming reasonable specificity.

CT and Bowel Obstruction

- cause of bowel obstruction rarely found on plain films – CT is best choice for imaging
- the "3,6,9" rule is a very useful guide to determining when the bowel is dilated; the maximum diameter of the bowel is 3 cm for small bowel, 6 cm for large bowel, and 9 cm for cecum; this can also be useful to distinguish small and large bowel, and to assess for 'impending' cecal perforation (e.g. post-untreated Ogilvie's syndrome)
- closed-loop obstruction: an obstruction in two locations (usually small bowel) creating a loop of bowel segment obstructed both proximally and distally; complications (e.g. ischemia, perforation, necrosis) may occur quickly

CT Colonography (virtual colonoscopy)

- emerging imaging technique for evaluation of intraluminal colonic masses (i.e. polyps, tumours)
- two CT scans of the abdomen (prone and supine) after the instillation of carbon dioxide into a prepped colon
- computer reconstruction of 2D CT images into a 3D intraluminal view of the colon
- lesions seen on 3D images correlated with 2D axial images
- indications: surveillance in low-risk patients, incomplete colonoscopy, staging of obstructing colonic lesions

Figure 17. Barium enema

Contrast Studies

Table 10. Types of Contrast Studies

Study	Organ	Procedure Description	Assessment	Findings
Cine Esophagogram	Cervical esophagus	Contrast agent swallowed Recorded for later playback and analysis	Dysphagia, swallowing incoordination, recurrent aspiration, post-operative cleft palate repair	Aspiration, webs (partial occlusion), Zenker's diverticulum, cricopharyngeal bar, laryngeal tumour
Barium Swallow	Thoracic esophagus	Contrast agent swallowed under fluoroscopy, selective images captured	Dysphagia, rule out GERD, post esophageal surgery	Achalasia, hiatus hernia, esophagitis, cancer, esophageal tear
Upper GI Series	Thoracic esophagus, stomach, or duodenum	Double contrast study: 1. Barium to coat mucosa, then 2. Gas pills for distention Patient NPO after midnight	Dyspepsia, investigate possible upper GI bleed, weight loss/anemia, post gastric surgery	Ulcers, neoplasms, filling defects
Barium Enema	Large bowel Rectum may be obscured by tube – therefore must do sigmoidoscopy to exclude rectal lesions	Colon filled retrograde with barium and air or CO_2 Bowel prep the night before procedure	Altered bowel habits, suspected lower GI bleed, weight loss/anemia, rule out large bowel obstruction, suspected perforation, check surgical anastamosis, history of polyps	Diverticulosis, neoplasms, IBD, intussusception (can be reduced with barium or air enema), volvulus
Small Bowel Follow Through	Entire small bowel	Single contrast images following upper GI series	GI bleed with non-diagnostic upper GI series/barium enema, weight	Neoplasms, IBD, malabsorption, infection
Enterography & Enteroclysis (MRI or CT)	Entire small bowel	Enterography: patient drinks 1-2 L of sorbitol, psyllium, or barium solution to distend small bowel Enteroclysis: NJ tube used to pump barium, psyllium, or sorbitol contrast media directly into small bowel	IBD, malabsorption, weight loss/ anemia, Meckel's diverticulum	Neoplasms, IBD, malabsorption, infection

Specific Visceral Organ Imaging

Liver

- U/S: assessment of cysts, abscesses, tumours, biliary tree
- CT ± IV: most popular procedure for imaging the liver parenchyma (primary liver tumours, metastases, cysts, abscesses, trauma, cirrhosis)
- MR: also excellent in evaluation of primary liver tumours, liver metastases, and other parenchymal conditions, and is particularly helpful in differentiating common benign hepatic hemangiomas from primary liver tumours and metastases
- Elastography: measures shear wave velocity by U/S (Fibroscan) or MRI (MR elastography) to non-invasively quantify liver fibrosis
- findings
  - advanced cirrhosis: liver small and irregular (fibrous scarring, segmental atrophy, regenerating nodules)
  - portal HTN: increased portal vein diameter, collateral veins, splenomegaly (≥12 cm), portal vein thrombosis, recanalization of the umbilical vein
  - porto-systemic shunts: caput medusa, esophageal varices, spontaneous spleno-renal shunt
  - U/S: cirrhosis appears nodular and hyperechoic with irregular areas of atrophy of the right lobe and hypertrophy of the caudate or left lobes
  - CT: fatty infiltration appears hypodense
- in order to be visualized, some masses require contrast

Table 11. Triphasic/Quadriphasic Liver Protocol

Phase	Time Frame	Uses
Non-Contrast CT	0	• For all initial investigations of liver lesions • Post radiofrequency ablation of liver tumours • Not usually indicated for surveillance imaging
Arterial Phase	20-30 s	• Early and late arterial phase on multidetector CT • Late arterial phase best for discriminating hypervascular HCC
Portal Venous Phase	60-70 s	• Provides maximum enhancement of hepatic tissue • Most tumours supplied by hepatic artery are relatively hypovascular, therefore appear as low-attenuation masses in portal venous phase • Hypervascular tumours wash out (HCC)
Equilibrium (Delayed) Phase	120-180 s	• Hemangioma: persistent enhancement suggests blood • Enhancement of fibrous/scar tissue (HCC capsule, focal nodular hyperplasia, cholangiocarcinoma)

Table 12. Imaging of Liver Masses

Mass	U/S	CT
Metastases	Multiple masses of variable echotexture	Usually low attenuation on contrast enhanced scan
HCC	Single/multiple masses, or diffuse infiltration	Hypervascular enhances in arterial and washes out in venous phase with portal venous tumour thrombus
Abscess	Poorly defined, irregular margin, hypoechoic contents	Low-attenuation lesion with an irregular enhancing wall
Hydatid Cyst	Simple/multiloculated cyst	Low-attenuation simple or multiloculated cyst; calcification
Hemangioma	Homogeneous hyperechoic mass	Peripheral globular enhancement in arterial phase scans; central-filling and persistent enhancement on delayed scans
Focal Nodular Hyperplasia	Well-defined mass, central scar seen in 50%	Hypervascular mass in arterial phase and isoattenuation to liver in portal venous phase
Hepatic Adenoma	Most common in young women taking oral contraceptives. Well-defined mass with hyperechoic areas due to hemorrhage	Well-defined hypervascular lesion with enlarged central vessel becoming slightly isoattenuating in venous phase

Spleen

- U/S, CT, nuclear medicine scan (nuclear medicine only to distinguish ectopic splenic tissue from enhancing tumours)
- CT for splenic trauma (hemorrhage)

Pancreas

- tumours
  - U/S: mass is more echogenic than normal pancreatic tissue
  - CT: preferred modality for diagnosis/staging
- ductal dilation secondary to stone/tumour
  - MRCP: imaging of ductal system using MRI cholangiography; no therapeutic potential

Normal liver appears denser than spleen on CT. If less dense, suspect fatty infiltration

Liver Mass DDx

5 Hs
HCC
Hydatid cyst
Hemangioma
Hepatic adenoma
Hyperplasia (focal nodular)

Revised Estimates of Diagnostic Test Sensitivity and Specificity in Suspected Biliary Tract Disease
Arch Intern Med 1998;154:2573-2581
Purpose: To assess the sensitivity and specificity of tests used to diagnose cholelithiasis and acute cholecystitis, including ultrasonography, oral cholecystography, radionucleotide scanning with Technetium, MRI, CT.
Study Characteristics: Meta-analysis of 30 studies evaluating the use of different imaging modalities in the diagnosis of biliary tract disease.
Participants: No limits.
Main Outcomes: Sensitivity and specificity of the different imaging modalities, using the gold standard of surgery, autopsy, or 3 mo clinical follow-up for cholelithiasis. For acute cholecystitis, pathologic findings, confirmation of an alternate disease, or clinical resolution during hospitalization for cholecystitis were used as the standard.
Results: For evaluating cholelithiasis, U/S had the best unadjusted sensitivity (0.97; 95% CI 0.95-0.99) and specificity (0.95, 95% CI 0.88-1.00) and adjusted (for verification bias) sensitivity (0.84; 95% CI 0.76-0.92) and specificity (0.99; 95% CI 0.97-1.00). For evaluating acute cholecystitis, radionucleotide scanning has the best sensitivity (0.97; 95% CI 0.96-0.98) and specificity (0.90; 95% CI 0.86-0.95).
Conclusions: U/S is the test of choice for diagnosing cholelithiasis and radionucleotide scanning is the superior test for diagnosing acute cholecystitis.

  - ERCP: endoscope to inject dye into the biliary tree and x-ray imaging to assess pancreatic and biliary ducts; therapeutic potential (stent placement, stone retrieval); acute pancreatitis is a complication in 5% of diagnostic procedures and 10% of therapeutic procedures

Biliary Tree

- U/S: bile ducts usually visualized only if dilated, secondary to obstruction (e.g. choledocholithiasis, benign stricture, mass)
- CT: dilated intrahepatic ductules seen as branching, tubular structures following pathway of portal venous system
- MRCP, ERCP, PTC: further evaluation of obstruction and possible intervention

Figure 18. ERCP: biliary tree

"itis" Imaging

Acute Cholecystitis

- pathogenesis: inflammation of gallbladder resulting from sustained gallstone impaction in cystic duct or, in the case of acalculous cholechystitis, due to gallbladder ischemia or cholestasis (see General Surgery, GS46)
- best imaging modality: U/S (best sensitivity and specificity); nuclear medicine (HIDA scan) can help diagnose cases of acalculous or chronic cholecystitis
- findings: thick wall, pericholecystic fluid, gallstones, dilated gallbladder, positive sonographic Murphy's sign
- management: cholecystectomy

Figure 19. Ultrasound: inflamed gallbladder

Acute Appendicitis

- pathogenesis: luminal obstruction → bacterial overgrowth → inflammation/swelling → increased pressure → localized ischemia → gangrene/perforation → localized abscess or peritonitis (see General Surgery, GS28)
- best imaging modality: U/S or CT
- findings
  - U/S: thick-walled appendix, appendicolith, dilated fluid-filled appendix, non-compressible; may also demonstrate other causes of RLQ pain (e.g. ovarian abscess, IBD, ectopic pregnancy)
  - CT: enlargement of appendix (>6 mm in outer diameter), enhancement of appendiceal wall, adjacent inflammatory stranding, appendicolith; also facilitates percutaneous abscess drainage
- management: appendectomy

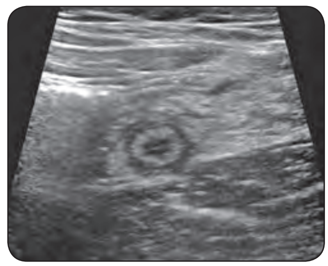


Figure 20. Ultrasound: inflamed appendix

Acute Diverticulitis

- pathogenesis: erosion of the intestinal wall (most commonly rectosigmoid) by increased intraluminal pressure or inspissated food particles → inflammation and focal necrosis → micro- or macroscopic perforation (see General Surgery, GS31)
- best imaging modality: CT is modality of choice, although U/S is sometimes used
- contrast: oral and rectal contrast given before CT to opacify bowel
- findings
  - cardinal signs: thickened wall, mesenteric infiltration, gas-filled diverticula, abscess
  - CT can be used for percutaneous abscess drainage before or in lieu of surgical intervention
  - sometimes difficult to distinguish from perforated cancer (therefore send abscess fluid for cytology and follow up with colonoscopy)
  - if chronic, may see fistula (most common to bladder) or sinus tract (linear or branching structures)
- management: ranges from antibiotic treatment to surgical intervention; can use imaging to follow progression

Computed Tomography and Ultrasonography to Detect Acute Appendicitis in Adults and Adolescents
Ann Intern Med 2004;141:537-546
Purpose: To review the diagnostic accuracy of CT and ultrasonography in the diagnosis of acute appendicitis.
Study Characteristics: Meta-analysis of 22 prospective studies evaluating the use of CT or ultrasonography, followed by surgical or clinical follow-up in patients with suspected appendicitis.
Participants: Age ≥14 with a clinical suspicion of appendicitis.
Main Outcomes: Sensitivity and specificity using surgery or clinical follow-up as the gold standard.
Results: CT (12 studies) had an overall sensitivity of 0.94 (95% CI 0.91-0.95) and a specificity of 0.95 (95% CI 0.93-0.96). Ultrasonography (14 studies) had an overall sensitivity of 0.86 (95% CI 0.83-0.88) and a specificity of 0.81 (95% CI 0.78-0.84).
Conclusions: CT is more accurate for diagnosing appendicitis in adults and adolescents, although verification bias and inappropriate blinding of reference standards were noted in the included studies.

Acute Pancreatitis

- pathogenesis: activation of proteolytic enzymes within pancreatic cells leading to local and systemic inflammatory response (see Gastroenterology, G45); a clinical/biochemical diagnosis
- best imaging modality: imaging used to support diagnosis and evaluate for complications (diagnosis cannot be excluded by imaging alone)
  - U/S good for screening and follow-up
  - CT is useful in advanced stages and in assessing for complications (1st line imaging test)
- findings
  - U/S: hypoechoic enlarged pancreas (if ileus present, gas obscures pancreas)
  - CT: enlarged pancreas, edema, stranding changes in surrounding fat with indistinct fat planes, mesenteric and Gerota's fascia thickening, pseudocyst in lesser sac, abscess (gas or thick-walled fluid collection), pancreatic necrosis (low attenuation gas-containing non-enhancing pancreatic tissue), hemorrhage
- management: supportive therapy
  - CT-guided needle aspiration and/or drainage done for abscess when clinically indicated
  - pseudocyst may be followed by CT and drained if symptomatic

Chronic Pancreatitis

- pathogenesis: (see Gastroenterology, G45)
- best imaging modality: MRCP (can show calcification and duct obstruction)
- findings: U/S, CT scan, and MRI may show calcifications, ductal dilatation, enlargement of the pancreas and fluid collections (e.g. pseudocysts) adjacent to the gland

Angiography of Gastrointestinal Tract

- anatomy of the GI tract arterial blood supply branches
  - celiac artery: hepatic, splenic, gastroduodenal, left/right gastric
  - superior mesenteric artery: jejunal, ileal, ileo-colic, right colic, middle colic
  - inferior mesenteric artery: left colic, superior rectal
- imaging modalities
  - conventional angiogram: invasive (usual approach via femoral puncture), catheter used
    - flush aortography: catheter injection into abdominal aorta, followed by selective arteriography of individual vessels
  - CT angiogram: modality of choice, non-invasive using IV contrast (no catheterization required)

Angiography requires active blood loss 1-1.5 mL/min under optimal conditions for a bleeding site to be visualized in cases of lower GI bleeding

Genitourinary System and Adrenal

Urological Imaging

KUB (Kidney, Ureter, and Bladder X-ray)

- a frontal supine radiograph of the abdomen
- **indication:** useful in evaluation of radio-opaque renal stones (all stones but uric acid and indinavir), indwelling ureteric stents /catheters, and foreign bodies in abdomen
- **findings:** addition of IV contrast excreted by the kidney (intravenous urogram) allows greater visualization of the urinary tract, but has been largely replaced by CT urography

Imaging Modality Based on Presentation
- Acute testicular pain = Doppler, U/S
- Amenorrhea = U/S, MRI (brain)
- Bloating = U/S, CT
- Flank pain = U/S, CT
- Hematuria = U/S, Cystoscopy, CT
- Infertility = HSG, MRI
- Lower abdominal mass = U/S, CT
- Lower abdominal pain = U/S, CT
- Renal colic = U/S, KUB, CT
- Testicular mass = U/S
- Urethral stricture = Urethrogram

Abdominal CT

Renal Masses

- Bozniak classification for cystic renal masses
- class I-II: benign and can be disregarded
- class IIF: should be followed
- class III-IV: suspicious for malignancy, requiring additional workup

Table 13. Bozniak Classification for Cystic Renal Masses

Classes	Definition
Simple Renal Cysts	
Class I	Fluid-attenuating well-defined lesion, no septation, no calcification, no solid components, hair thin wall
Class II	Same as class I + fine calcification or moderately thickened calcification in septae or walls; also includes hyperdense cysts (<3 cm) that do not enhance with contrast
Complex Renal Cysts	
Class III	Thick irregular walls ± calcifications ± septated, enhancing walls or septa with contrast
Renal Cell Carcinoma	
Class IV	Same as class III + soft tissue enhancement with contrast (defined as >10 Hounsfield unit increase, characterizing vascularity) with de-enhancement in venous phase ± areas of necrosis

- **plain CT KUB indications**: general imaging of renal anatomy, renal colic symptoms, assessment of renal calculi (size and location), and hydronephrosis prior to urological treatment
- **CT urography indications**: investigation of cause of microscopic/gross hematuria, detailed assessment of urinary tracts (excretory phase), high sensitivity (95%) for uroepithelial malignancies of the upper urinary tracts, assessment of renal calculi
  - **phases:** unenhanced, excretory
- **renal triphasic CT indications**: standard imaging for renal masses, allows accurate assessment of renal arteries and veins, better characterization of suspicious renal masses, especially in differentiating renal cell carcinoma from more benign masses, and pre-operative staging
  - **phases:** unenhanced, arterial and venous (nephrographic), excretory

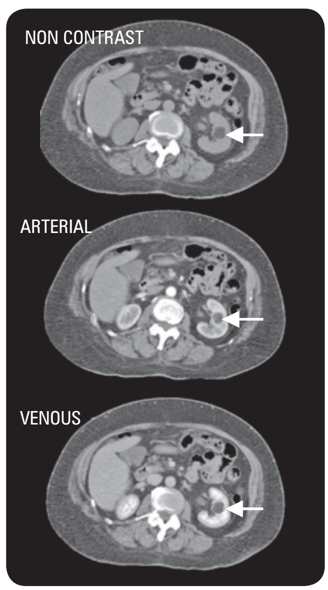


Figure 21. Triphasic CT of an angiomyolipoma: showing fat density with non-contrast scan, mildly enhancing with contrast

Ultrasound

- **indications**: initial study for evaluation of kidney size and nature of renal masses (solid vs. cystic renal masses vs. complicated cysts); technique of choice for screening patients with suspected hydronephrosis (no IV contrast injection, no radiation to patient, and can be used in patients with renal failure); TRUS useful to evaluate prostate gland and guide biopsies; Doppler U/S to assess renal vasculature
- **findings**: solid renal masses are echogenic (bright on U/S), cystic renal masses have smooth well-defined walls with anechoic interior (dark on U/S), and complicated cysts have internal echoes within a thickened, irregular wall

Retrograde Pyelography

- **indications**: visualize the urinary collecting system via a cystoscope, ureteral catheterization, and retrograde injection of contrast medium, visualized by radiograph or fluoroscopy; ordered when the intrarenal collecting system and ureters cannot be opacified using intravenous techniques (patient with impaired renal function, high grade obstruction)
- **findings**: only yields information about the collecting systems (renal pelvis and associated structures), no information regarding the parenchyma of the kidney

Voiding Cystourethrogram

- bladder filled with contrast to the point where voiding is triggered
- fluoroscopy (continuous, real-time) to visualize bladder
- **indications**: children with recurrent UTIs, hydronephrosis, hydroureter, suspected lower urinary tract obstruction or vesicoureteral reflux
- **findings**: contractility and evidence of vesicoureteric reflux

Retrograde Urethrogram

- a small Foley catheter placed into penile urethral opening
- **indications**: used mainly to study strictures or trauma to the male urethra; first-line study if trauma with blood present at urethral meatus

MRI

- **advantages**: high spatial and tissue resolution, lack of exposure to ionizing radiation and nephrotoxic contrast agents
- **indications**: indicated over CT for depiction of renal masses in patients with previous nephron sparing surgery, patients requiring serial follow-up (less radiation dosage), patients with reduced renal function, patients with solitary kidneys, clinical staging of prostate cancer (endorectal coil MRI)

Renal Nuclear Scan

Table 14. Renal Scan Tests

Type of Test	Uses	Radionuclide
Renogram	assess renal function and collecting system: evaluation of renal failure, workup of urinary tract obstruction and renovascular HTN, investigation of renal transplant	IV ^{99m}Tc-pentetate (DTPA) or mertiatide (MAG3), and imaged at 1-3 s intervals with a gamma camera over the first 60 s to assess perfusion
Morphological	Assess renal anatomy: investigation of pyelonephritis and cortical scars	^{99m}Tc-DMSA ^{99m}Tc-glucoheptonate

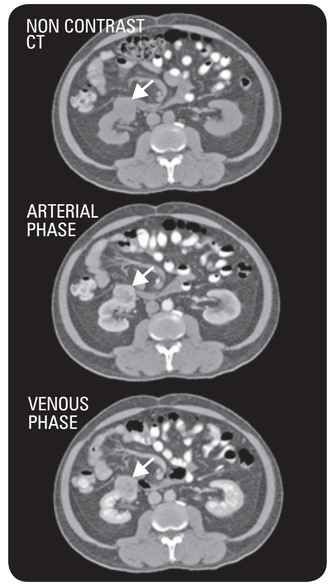


Figure 22. Triphasic CT of a renal cell carcinoma: showing arterial enhancing right renal lesion with venous washout (shunting)

Figure 23. Retrograde urethrogram: demonstrating stricture in the membranous urethra

Gynecological Imaging

Ultrasound

- transabdominal and transvaginal are the primary modalities, and are indicated for different scenarios
- transabdominal requires a full bladder to push out air containing loops of bowel
  - **indications**: good initial investigation for suspected pelvic pathology
- TVUS provides enhanced detail of deeper/smaller structures by allowing use of higher frequency sound waves at reduced distances
  - **indication**: improved assessment of ovaries, first trimester development, and ectopic pregnancies

Figure 24. Transabdominal U/S: pregnancy, 18 wk fetus

Pregnancy should always be ruled out by β-hCG before CT of a female pelvis (or any organ system) is performed

Hysterosalpingogram

- performed by x-ray images of the pelvis after cannulation of the cervix and subsequent injection of opacifying agent
- **indications**: useful for assessing pathology of the uterine cavity and fallopian tubes, evaluating uterine abnormalities (e.g. bicornuate uterus), or evaluation of fertility (absence of flow from tubes to peritoneal cavity indicates obstruction)

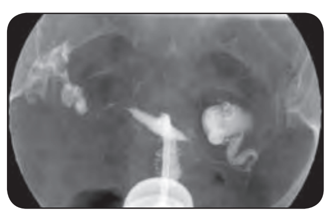


Figure 25. Hysterosalpingogram: left hydrosalpinx

CT/MRI

- **indications**: evaluating pelvic structures, especially those adjacent to the adnexa and uterus
- invaluable for staging gynecological malignancies and detecting recurrence

Sonohysterogram

- saline infusion sonohysterogram involves instilling fluid into the uterine cavity transcervically to provide enhanced endometrial visualization during TVUS examination
- **indications**: abnormal uterine bleeding, uterine cavity abnormalities that are suspected or noted on TVUS (e.g. leiomyomas, polyps, synechiae), congenital abnormalities of the uterine cavity, infertility, recurrent pregnancy loss
- **contraindications**: pregnancy, pelvic infection

Table 15. Typical and Atypical Findings on a Sonohysterogram

Finding	Typical	Atypical
Polyps	A well-defined, homogeneous, polypoid lesion isoechoic to the endometrium with preservation of the endometrial-myometrial interface	Atypical features include cystic components, multiple polyps, broad base, hypoechogenicity or heterogeneity
Leiomyoma	Well-defined, broad-based, hypoechoic, solid masses with shadowing. Overlying layer of endometrium is echogenic and distorts the endometrial-myometrial interface	Pedunculation or multilobulated surface
Hyperplasia and Cancer	Diffuse echogenic endometrial thickening without focal abnormality, although focal lesions can occur. Endometrial cancer is typically a diffuse process, but early cases can be focal and appear as a polypoid mass	
Adhesions	Mobile, thin, echogenic bands that cut across the endometrial cavity	Thick, broad-based bands that can completely obliterate the endometrial cavity, as in Asherman's syndrome

Adrenal Mass

- imaging modality: most often identified on CT scan as 'incidentaloma', can also use CT/MRI to distinguish benign from malignant masses

Table 16. Adrenal Mass Findings on CT and MRI

Factors	Adrenocortical Adenoma	Adrenocortical Carcinoma	Pheochromocytoma	Metastasis
Diameter (CT)	Usually ≤3 cm	Usually ≥4 cm	Usually >3 cm	Variable around <3 cm
Shape (CT)	Smooth margins and round/oval	Irregular with unclear margins	Round/oval with clear margins	Oval/irregular with unclear margins
Texture (CT)	Homogeneous	Heterogeneous with mixed densities	Heterogeneous with cystic areas	Heterogeneous with mixed densities
Vascularity (CT)	Not highly vascular	Usually vascular	Usually vascular	Usually vascular
Washout of Contrast Medium on CT	≥50% at 10 min	<50% at 10 min	<50% at 10 min	<50% at 10 min
Growth	Stable or very slow (<1 cm/yr)	Usually rapid (>2 cm/yr)	Slow (0.5-1 cm/yr)	Variable
Other Findings	Usually low density due to intracellular fat	Necrosis, calcifications, and hemorrhage	Hemorrhage	Occasionally hemorrhage
MRI on T2 Weighted Imaging	Isointense in relation to liver	Hyperintense in relation to liver	Markedly hyperintense in relation to liver	Hyperintense in relation to liver

Modality Based on Neuropathology Presentation
- Cognitive decline = CT
- Cord compression = MRI
- Decreased level of consciousness = CT
- Fish bone/other swallowed foreign body = CT
- Low back pain, radiculopathy = MRI
- Multiple sclerosis = MRI
- Neck infection = CT
- Orbital infection = CT
- Rule out bleed = CT
- Rule out aneurysm = CTA, MRA
- Seizure = CT
- Sinusitis = CT
- Stroke = CT, MRI
- Trauma = CT
- Weakness, systemically unwell = CT

Neuroradiology

Modalities

- CT is the modality of choice for most neuropathology; even under circumstances when MRI is preferred, CT is frequently the initial study performed because of its speed, availability, and lower cost
  - acute head trauma: CT is best for visualizing "bone and blood"; MRI is used only when CT fails to detect an abnormality despite strong clinical suspicion
  - acute stroke: MRI ideal, CT most frequently used
  - suspected subarachnoid or intracranial hemorrhage
  - meningitis: rule out mass effect (e.g. cerebral herniation, shift) prior to lumbar puncture
  - tinnitus and vertigo: CT and MRI are used in combination to detect bony abnormalities and CN VIII tumours, respectively

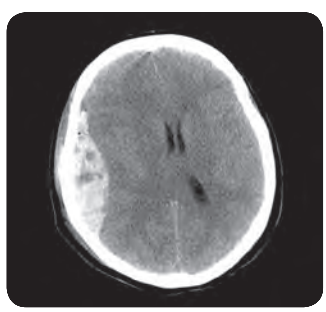


Figure 26. Epidural hematoma

Skull Films

- rarely performed, generally not indicated for non-penetrating head trauma
- **indications**: screening for destructive bony lesions (e.g. metastases), metabolic disease, skull anomalies, post-operative changes and confirmation of hardware placement, skeletal surveys

CT

- **indications**: excellent study for evaluation of bony and intracranial abnormalities
- often done first without and then with IV contrast to show vascular structures or anomalies
- vascular structures and areas of blood-brain barrier impairment are opaque (e.g. hyperattenuating or white/show enhancement) with contrast injection
  - when in doubt, look for circle of Willis or confluence of sinuses to determine presence of contrast enhancement
- posterior fossa can be obscured by extensive bony-related streak artifact
- rule out skull fracture, epidural hematoma (lenticular shape), subdural hematoma (crescentic shape), subarachnoid hemorrhage, space occupying lesion, hydrocephalus, and cerebral edema
- multiplanar imaging can be performed with newer generation of multidetector CT scanners

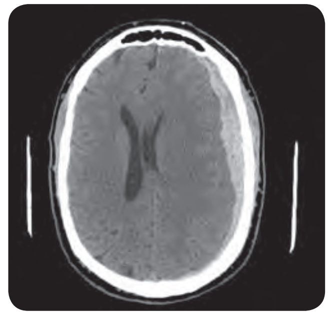


Figure 28. Subdural hematoma

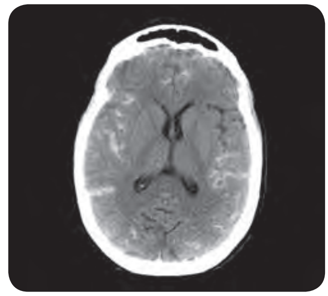


Figure 29. Subarachnoid hemorrhage

Myelography

- introduction of water-soluble, low-osmotic contrast media into subarachnoid space using lumbar puncture followed by x-ray or CT scan
- **indications**: excellent study for disc herniations, traumatic nerve root avulsions, patients with contraindication to MRI

MRI

- **indications**: shows brain and spinal soft tissue anatomy in fine detail, clearly distinguishes white from grey matter (especially T1-weighted series), multiplanar reconstruction helpful in pre-operative assessment

Cerebral Angiography/CT Angiography/MR Angiography

- **indications**: evaluation of vascular lesions such as atherosclerotic disease, aneurysms, vascular malformations, arterial dissection
- conventional DSA remains the gold standard for the assessment of neck and intracranial vessels; however, it is an invasive procedure requiring arterial (femoral) puncture; catheter manipulation has risk of vessel injury (e.g. dissection, occlusion, vasospasm, emboli)
- MRA methods (phase contrast, time of flight, gadolinium-enhanced) and CTA are much less invasive without actual risk to intracranial or neck vessels
- MRA and CTA are often used first as 'screening tests' for the assessment of subarachnoid hemorrhage, vasospasm, aneurysms

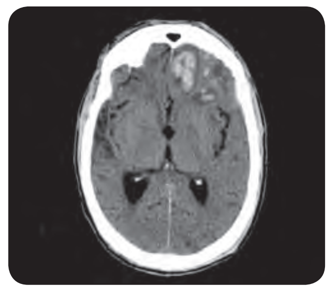


Figure 30. Intraparenchymal hemorrhage

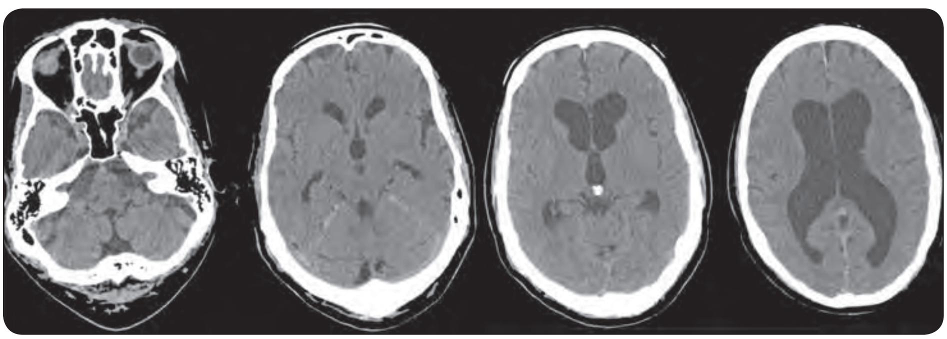


Figure 27. Hydrocephalus: ventricular dilatation (may see periventricular low attenuation due to transependymal CSF flow)

Table 17. Two Types of Hydrocephalus

Type	Cause
Communicating/Extra-Ventricular	Obstruction distal to the ventricles (e.g. at the level of the arachnoid granulations); imaging shows all ventricles dilated
Non-Communicating	Obstruction within the ventricular system (e.g. mass obstructing the aqueduct or foramen of Monro); imaging shows dilatation of ventricles proximal to the obstruction

Nuclear Medicine

- SPECT using ^{99m}Tc-exametazime (HMPAO) and ^{99m}Tc-bicisate (ECD) imaging assesses cerebral blood flow by diffusing rapidly across the blood brain barrier and becoming trapped within neurons proportional to cerebral blood flow
- ^{18}FDG PET imaging assesses cerebral metabolic activity
- **indications**: differentiation of residual tumour vs. radiation necrosis; localizing of epileptic seizure foci; evaluation of atypical dementia

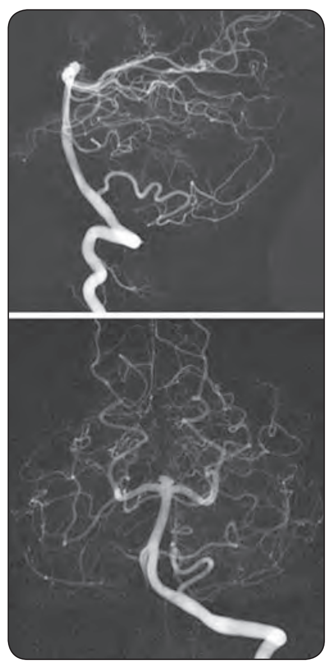


Figure 31. Vertebrobasilar circulation (note the incidental basilar tip aneurysm)

Approach to CT Head

- think anatomically, work from superficial to deep
- scan: confirm that the imaging is of the correct patient, whether contrast was used, if the patient is aligned properly, if there is artifact present
- skin/soft tissue: examine the soft tissue superficial to the skull, looking for thickening suggestive of hematoma or edema; also evaluate the ear, orbital contents (globe, fat, muscles), parotid, muscles of mastication (masseter, temporalis, pterygoids), visualized pharynx
- bone and airspace (use the bone window): check calvarium, visualize mandible, visualize C-spine (usually C1 and maybe part of C2) for fractures, absent bone, lytic/sclerotic lesions; inspect sinuses and mastoid air cells for opacity that may suggest fluid, pus, blood, tumour, or fracture; status of the orbital floor in cases of facial trauma (coronal series best)
- dura and subdural space: crescent-shaped hyperdensity in the subdural space suggests subdural hematoma; lentiform hyperdensity in the epidural space suggests epidural hematoma; check symmetry of dural thickness, where increased thickness may suggest the presence of blood
- parenchyma: asymmetry of the parenchyma suggests midline shift; poor contrast between grey and white matter suggests possible infarction, tumour, edema, infection, or contusion; hyperdensity in the parenchyma suggests enchancing lesions, intracerebral hemorrhage, or calcification; central grey matter nuclei (e.g. globus pallidus, putamen, internal capsule) should be visible, otherwise, suspect infarct, tumour, or infection
- ventricles/sulci/cisterns: examine position of ventricles for evidence of midline compression/ shift; hyperdensities in the ventricles suggest ventricular/subdural hemorrhage; enlarged ventricles suggest hydrocephalus; obliteration of sulci may suggest presence of edema causing effacement, possible blood filling in the sulci, or tumour; cistern hyperdensities may suggest blood, pus, or tumour

Approach to the CT Head
Some = **S**can
Sore = **S**kin/**S**oft Tissue
Brains = **B**one/Airspace
Demonstrate = **D**ura/Subdural space
Pushed = **P**arenchyma
Ventricles = **V**entricles/Sulci/Cisterns

Transient ischemic attacks are not associated with radiological findings

Selected Pathology

- see Neurosurgery, NS4 for intracranial mass lesions
- see Neurosurgery, NS29 and Plastic Surgery, PL28 for head trauma
- see Emergency Medicine, ER9 for vertebral trauma
- see Neurosurgery, NS27 and Orthopedics, OR23 for degenerative spinal abnormalities

Cerebrovascular Disease (see Neurology, N46 and Neurosurgery, NS17)

Symptoms of stroke → Non-contrast CT to rule out hemorrhage → Hemorrhage absent → To detect infarct, MR scan with diffusion-weighted sequence or a CTA

- pathogenesis of stroke: see Neurology, N46
- best imaging modality: infarcts best detected by MRI > CT
- findings of infarction
  - early changes
    - CT
      - usually normal within 6 h of infarction
      - edema (loss of grey-white matter differentiation – "insular ribbon" sign, effacement of sulci, mass effect)
      - within 24 h, development of low-density, wedge-shaped area of infarction extending to periphery (correlating to vascular territory distal to affected artery)
      - in case of ischemic stroke, may see hyperattenuating (bright) artery (hyperdense MCA sign) representing intravascular thrombus or embolus
      - in case of hemorrhagic stroke or transformation (common in basal ganglia and cortex), may see bright acute blood surrounded by edema
    - MRI
      - edema with high signal on T2-weighted images and FLAIR image (loss of grey-white matter differentiation, effacement of sulci, mass effect)
      - DWI shows acute high signal changes demonstrating restricted movement of water indicative of cytotoxic edema; usually indicates stroke damage before CT
      - apparent diffusion coefficient image shows low signal intensity in acute ischemia (nadir 3-5 d, returns to baseline 1-4 wk)
  - subacute changes on CT and MRI
    - edema and mass effect more prominent
    - gyral enhancement with contrast indicative of blood-brain barrier breakdown
  - chronic changes on CT and MRI
    - encephalomalacia (parenchymal volume loss) with dilatation of adjacent ventricles
- carotid artery disease
  - best imaging modality: Duplex Doppler U/S
  - other modalities: MRA or CTA if carotid angioplasty or endarterectomy is under consideration (conventional angiography reserved for inadequate MRA or CTA)

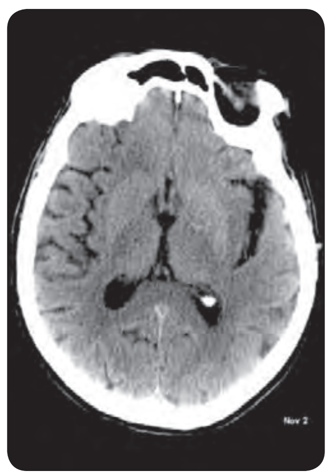


Figure 32. Insular Ribbon Sign (Left side)

Ddx for Ring Enhancing Cerebral Lesion (MAGIC DR)
Metastasis
Abscess
Glioblastoma multiforme
Infarction (subacute/chronic)
Contusion/hematoma
Demyelinating disease (e.g. MS)
Radiation necrosis

Multiple Sclerosis (refer to Neurology, N51)

- best imaging modality: MRI has high sensitivity in diagnosing MS (>90%) but low specificity (71-74%)
- findings
  - characteristic lesion on MRI is cerebral or spinal plaque
  - plaques typically found in periventricular region, corpus callosum (arranged at right angles to the corpus callosum), centrum semiovale, and to a lesser extent in deep white matter structures and basal ganglia
  - "Dawson's fingers" refers to perivenular regions of demyelination that are seen to radiate outwards into the deep periventricular region
  - plaques usually have ovoid appearance, hyperintense on T2 and hypointense on T1
  - conventional T2 may underestimate plaque size and overall plaque burden – advanced techniques (diffusion tensor imaging and MR spectroscopy) can be of use
  - perivascular and interstitial edema may be prominent
  - spinal cord lesions typical of MS
    - little or no cord swelling
    - unequivocal hyperintensity on T2-weighted sequences
    - size at least 3 mm but less than 2 vertebral segments in length
    - occupy only part of the cord in cross-section
    - focal (i.e. clearly delineated and circumscribed on T2-weighted sequences)

CNS Infections

- **leptomeningitis**
  - pathogenesis: inflammation of the pia or arachnoid mater, most often secondary to hematogenous spread from infection or via organisms gaining access across areas not protected by the blood-brain barrier (choroid plexus or circumventricular organs)
    - pathogens include: *S. pneumoniae, H. influenzae, N. meningitidis, L. monocytogenes*
  - best imaging modality: MRI (T2-weighted/FLAIR) superior to CT
  - findings
    - meningeal enhancement (following the gyri/sulci, and/or basal cisterns), hydrocephalus (communicating), cerebral swelling, subdural effusion
    - a normal MRI does not rule out leptomeningitis
- **herpes simplex encephalitis** (see Infectious Diseases, ID18)
  - pathogenesis: inflammation of the brain parenchyma secondary to infection with herpes simplex virus, asymmetrically affects the limbic regions of the brain (i.e. temporal lobes, orbitofrontal region, insula, and cingulate gyrus)
  - best imaging modality: MRI (T1- and T2-weighted)
  - findings
    - acute (within 4-5 d): asymmetric high intensity lesions on T2 MRI in temporal and inferior frontal lobes strongly suggestive
    - DDx: infarct, tumour, status epilepticus, limbic encephalitis
    - CT may show low density in temporal lobe and insula; rarely basal ganglia involvement
    - long-term may show parenchymal loss to affected areas
- **cerebritis/cerebral abscess**
  - pathogenesis: an infection of the brain parenchyma (cerebritis) which can progress to a collection of pus (abscess), most frequently due to hematogenous spread of infectious organisms, commonly located in the distribution of the MCA
    - pathogens include: *S. aureus* (often in IV drug users, nosocomial), *Streptococcus*, Gram negative bacteria, *Bacteroides*
  - best imaging modality: MRI including DWI imaging series (abscess will be DWI positive); CT still used as a viable alternative
  - findings according to one of four stages of abscess formation
    - early cerebritis (1-3 d): inflammatory infiltrate with necrotic centre, low intensity on T1, high intensity on T2
    - late cerebritis (4-9 d): ring enhancement may be present
    - early capsule (10-13 d): ring enhancement
    - late capsule (14 d or greater): well demarcated ring-enhancing lesion, low intensity core, with mass effect; considerable edema around the lesion, seen as hyperintensity on T2

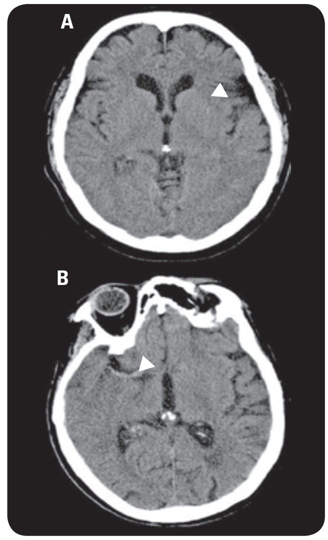


Figure 33. CT images of early infarct: (A) absence of left insular ribbon (B) hyperdense artery

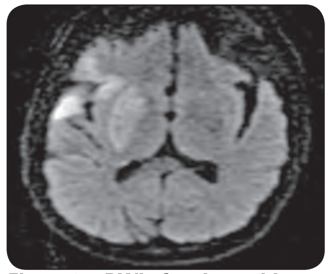


Figure 34. DWI of patient with right frontotemporal infarct

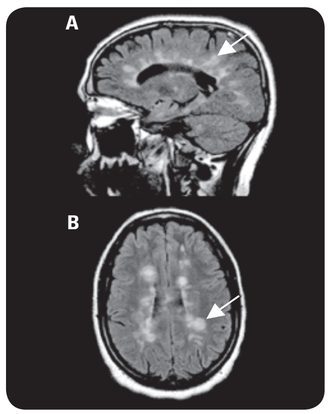


Figure 35. T2-weighted FLAIR: (A) sagittal (B) axial images of multiple sclerosis with periventricular "Dawson's Fingers"

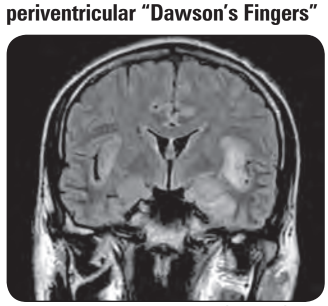


Figure 36. T2-weighted (FLAIR) coronal image of herpes simplex virus encephalitis affecting temporal lobes

Musculoskeletal System

Modalities

- refer to MI2 for advantages and disadvantages of the following imaging modalities

Plain Film/X-Ray

- usually initial study used in evaluation of bone and joint disorders
- indications: fractures and dislocations, arthritis, assessment of malalignment, orthopedic hardware, and bone tumours (initial)
- minimum of two films orthogonal to each other (usually AP and lateral) to rule out a fracture
- image proximal and distal joints (particularly important with paired bones (e.g. radius/ulna)
- minimally effective in evaluating soft tissue injury

CT

- evaluation of fine bony detail
- indications: assessment of complex, comminuted, intra-articular or occult fractures including distal radius, scaphoid, skull, spine, acetabulum, calcaneus, and sacrum
- evaluation of soft tissue calcification/ossification

MRI

- indications: evaluation of internal derangement of joints (e.g. ligaments, joint capsule, menisci, labrum, cartilage), assessment of tendons and muscle injuries, characterization and staging of soft tissue and bony masses

Ultrasound

- indications: tendon injury (e.g. rotator cuff, Achilles tendon), detection of soft tissue masses and to determine whether cystic or solid, detection of foreign bodies, U/S guided biopsy and injections
- Doppler determines vascularity of structures

Nuclear Medicine (Bone Scintigraphy)

- determine the location and extent of bony lesions
- ^{99m}Tc-methylene diphosphonate localizes to areas of increased bone turnover or calcification – growth plate in children, tumours, infections, fractures, metabolic bone disease (e.g. Paget's), sites of reactive bone formation, and periostitis
- advantages: very sensitive, capable of imaging entire body with relatively low dose radiation
- disadvantages: low specificity, not widely available due to special requirements (e.g. gamma camera, radiopharmaceuticals)

Approach to Bone X-Rays

- identification: name, MRN, age of patient, type of study, region of investigation
- soft tissues: swelling, calcification/ossification
- joints: alignment, joint space, presence of effusion, osteophytes, erosions, bone density, overall pattern, and symmetry of affected joint
- bone: periosteum, cortex, medulla, trabeculae, density, articular surfaces, bone destruction, bone production, appearance of the edges or borders of any lesions

Trauma

Fracture/Dislocation

- description of fractures
- site of fracture (bone, region of bone, intra-articular vs. extra-articular)
- pattern of fracture line (simple vs. comminuted)
- displacement (distal fragment with reference to the proximal fragment)
- soft tissue involvement (calcification, gas, foreign bodies)
- type of fracture (stress vs. pathologic)
- for specific fracture descriptions and characteristics of fractures, see Orthopedics, OR5

Arthritis

Radiographic Hallmarks of Osteoarthritis
- joint space narrowing – typically non-uniform
- subchondral sclerosis
- subchondral cyst formation
- osteophytes

Radiographic Hallmarks of Rheumatoid Arthritis
- joint space narrowing – typically uniform
- soft tissue swelling
- erosions
- periarticular osteopenia

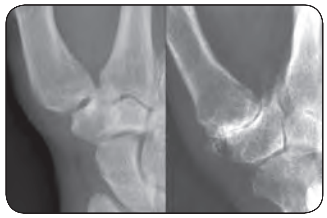


Figure 37. X-ray of first carpometacarpal joint: normal image (left) and osteoarthritis (right) with joint space narrowing and subchondral sclerosis

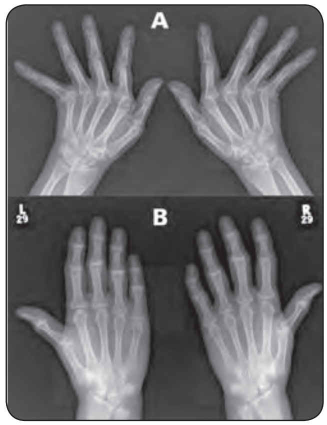


Figure 38. Rheumatoid arthritis (A) compared with osteoarthritis (B) changes on X-ray

Bone Tumour

Approach
- metastatic tumours to bone are much more common than primary bone tumours, particularly if age >40 yr
  - diagnosis usually requires a biopsy if primary not located
  - few benign tumours/lesions have potential for malignant transformation
  - MRI is good for tissue delineation and pre-operative assessment of surrounding soft tissues, neurovascular structures, and medullary/marrow involvement
  - plain film is less sensitive than other modalities but useful for assessing aggressiveness and constructing differential diagnosis

Considerations and Tumour Characteristics
- for specific bone tumours, see Orthopedics, OR46
- age – most common tumours by age group
  - <1 yr of age: metastatic neuroblastoma
  - 1-20 yr of age: Ewing's sarcoma in tubular bones
  - 10-30 yr of age: osteosarcoma and Ewing's tumour in flat bones
  - >40 yr of age: metastases, multiple myeloma, and chondrosarcoma
- multiplicity: metastases, myeloma, lymphoma, fibrous dysplasia, enchondromatosis
- location within bone
  - epiphysis: giant cell tumour, chondroblastoma, geode, eosinophilic granuloma, infection
  - metaphysis: simple bone cyst, aneurysmal bone cyst, enchondroma, chondromyxoid fibroma, nonossifying fibroma, osteosarcoma, chondrosarcoma
  - diaphysis: fibrous dysplasia, aneurysmal bone cyst, brown tumours, eosinophilic granuloma, Ewing's sarcoma
- expansile
  - aneurysmal bone cyst, giant cell tumour, enchondromas, brown tumours, metastases (especially renal and thyroid), plasmacytoma
- matrix mineralization
  - chondroid (popcorn calcification) or osseous
- margin/zone of transition: area between lesion and normal bone
- cortex: intact, disturbed
- periosteal reaction
- soft tissue mass

Benign Lesions which may have Aggressive Features
- Osteomyelitis
- Osteoblastoma
- Aneurysmal bone cyst
- Langerhans cell histiocytosis
- Myositis ossificans

Periosteal Reaction
- "Onion skinning" = Ewing's sarcoma
- "Sunburst", "hair on end" = osteosarcoma
- "Codman's triangle" = osteosarcoma, Ewing's sarcoma, subperiosteal abscess

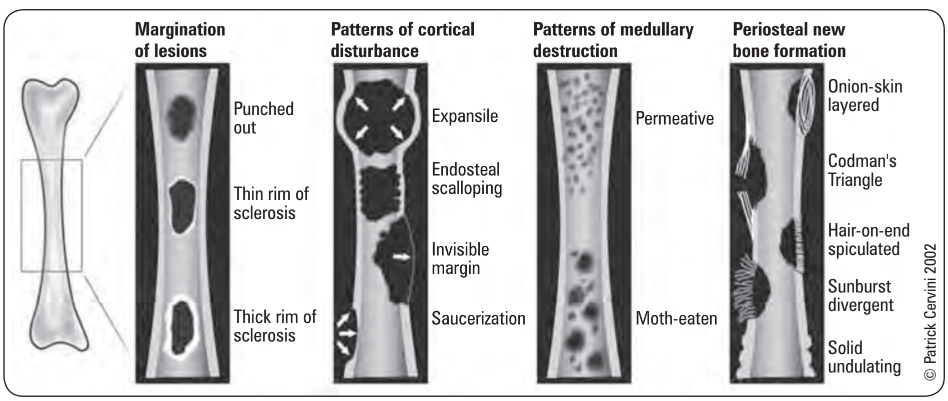


Figure 39. Radiographic appearance of bone remodelling and destruction processes

Table 18. Characteristics of Benign and Malignant Bone Lesions

Benign	Malignant
Thin sclerotic margin/sharp delineation of lesion	Poor delineation of lesion – wide zone of transition
Overlying cortex intact	Loss of overlying cortex/bony destruction
No or simple periosteal reaction	Periosteal reaction
No soft tissue mass	Soft tissue mass

Metastatic Bone Tumours

- all malignancies have potential to metastasize to bone
- metastases are 20-30x more common than primary bone tumours
- metastasis can cause a lytic or a sclerotic reaction when seeding to bone
- when a primary malignancy is first detected, a bone scan is often part of the initial workup
- may present with pathological fractures or pain
- biopsy or determination of primary is the only way to confirm the diagnosis
- most common metastatic bone tumours: breast, prostate, lung, see Orthopedics, OR46

Lytic = decreased density
Sclerotic = increased density

Table 19. Characteristic Bone Metastases of Common Cancers

Lytic	Sclerotic	Expansile	Peripheral
Breast Lung Thyroid Kidney Multiple myeloma	Prostate Breast Lymphoma Lung Bowel Medulloblastoma Treated tumours	Thyroid Renal	Kidney Lung Melanoma (KLM: flies to the periphery)

Infection

Osteomyelitis

- MRI is the imaging modality of choice for demonstrating bone, bone marrow, and soft tissue abnormalities
- ^{99m}Tc, followed by ^{111}In labeled white cell scan or gallium radioisotope scan
- plain film changes visible 8-10 d after process has begun
  - soft tissue swelling
  - local periosteal reaction
  - pockets of air (from anaerobes) may be seen in the tissues, may also suggest necrotizing fasciitis
  - mottled and nonhomogeneous with a classic “moth-eaten” appearance
  - cortical destruction

Bone Abscess

- overlying cortex has periosteal new bone formation
- sharply outlined radiolucent area with variable thickness in zone of transition
- variable thickness periosteal sclerosis
- sequestrum: a piece of dead bone within a Brodie’s abscess
- a sinus tract or cloaca may communicate between the abscess through the cortex to the surface of the bone
- best modality: MRI for bone, bone marrow, and soft tissue abnormalities; CT for sequestra and cortical erosions

Metabolic Bone Disease

Osteoporosis

- reduction in amount of normal bone mass; fewer and thinner trabeculae; diffuse process affecting all bones
- DEXA: gold standard for measuring bone mineral density
  - T-score: the number of standard deviations from the young adult mean, most clinically valuable
    - osteopenia: $-2.5 <$ T-score < -1
    - osteoporosis: T-score ≤ -2.5
  - Z-score: the number of standard deviations from the age-matched mean
  - risk of fracture: related to bone mineral density, age, history of previous fractures, steroid therapy
  - diagnostic sensitivity of DEXA highest when bone mineral density measured at lumbar spine and proximal femur
- appearance on plain film
  - osteopenia: reduced bone density on plain films
    - may also be seen with osteomalacia, hyperparathyroidism, and disuse
  - compression of vertebral bodies
  - biconcave vertebral bodies (“codfish” vertebrae)
  - long bones have appearance of thinned cortex and increased medullary cavity
    - look for complications of osteoporosis (e.g. insufficiency fractures: hip, vertebrae, sacrum, pubic rami)
- see Endocrinology, E38

Osteoporosis
Reduced amount of bone

OsteoMalacia
Normal amount of bone, but reduced Mineralization of normal osteoid

Osteomalacia/Rickets

- reduction in bone mineral density; normal amount of bone, but reduced mineralization of normal osteoid
- usually due to vitamin D deficiency, resulting in softening and bowing of long bones
- similar to osteoporosis, initial radiological appearance of osteopenia (coarse and poorly defined bone texture)
- "fuzzy", ill-defined trabeculae
- Looser's zones (pseudofracture)
  - characteristic radiologic feature
  - fissures or clefts at right angles to long bones and extending through cortex
  - DDx: chronic renal disease, fibrous dysplasia, hyperthyroidism, Paget's, osteodystrophy, X-linked hypophosphatemia

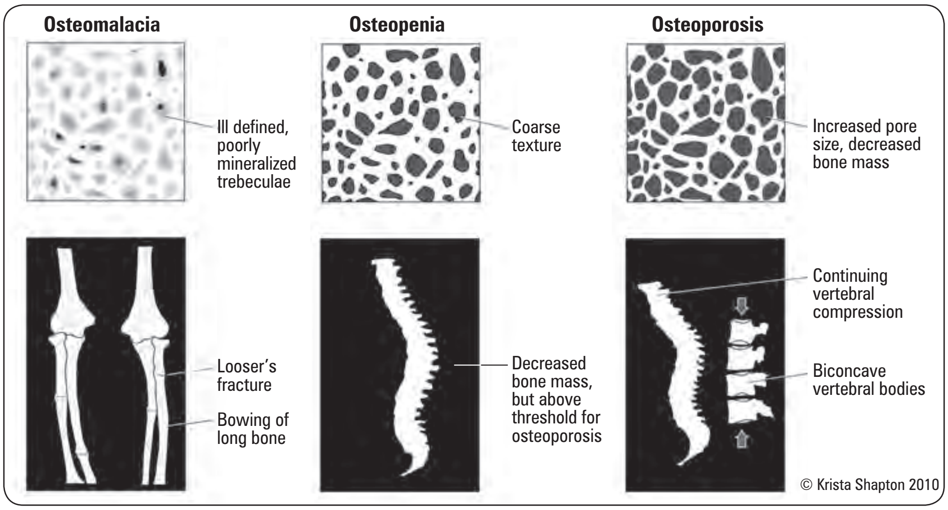


Figure 40. Osteomalacia, osteopenia, and osteoporosis

Hyperparathyroidism

- most common cause is renal failure (secondary hyperparathyroidism)
- chondrocalcinosis
  - calcium crystal deposition in hyaline cartilage or fibrocartilage (including arteries and peri-articular soft tissue)
  - resorption of bone typically in hands (subperiosteal and at tufts), sacroiliac joints (subchondral), skull ("salt and pepper" appearance), osteoclastoma (brown tumours)
  - "rugger jersey spine": band-like osteosclerosis at superior/inferior margins of vertebral bodies
- see Endocrinology, E38

Paget's Disease

- abnormal remodeling involving single or multiple bones – especially skull, spine, pelvis
- 3 phases: 1st phase = lytic, 2nd phase = mixed (lytic/sclerotic), 3rd phase = sclerotic
- features
  - coarsening of the trabeculae with bone expansion
  - bone softening/bowing
  - bone scan will reveal high activity, especially at bone ends
  - thickened cortex
- see Endocrinology, E42

Nuclear Medicine

Brain

- ^{99m}Tc-exametazime (HMPAO) and ^{99m}Tc-bicisate (ECD) imaging used in SPECT to assess cerebral blood flow and cellular metabolism, taken up predominantly in grey matter; used for dementia, traumatic brain injury and to a lesser extent vasculitis, neuropsychiatric disorders and occasionally stroke; also the most commonly used tracers to confirm brain death (i.e. absent blood flow to the brain and absent uptake on delayed planar and SPECT images in brain and brainstem, assuming study is technically adequate); either tracer can be used for seizure imaging to assess for the most likely location of epileptogenic focus but usually must be made available for 24 hr and the patient followed by a nurse who is competent to administer the activity at the time of seizure
- PET imaging assesses metabolic activity most commonly with ^{18}FDG; used for dementia imaging, grade and stage of brain tumours, occasionally for seizure disorder imaging, and vasculitis; PET imaging with amyloid tracers for diagnosis of Alzheimer's disease is becoming more common
- CSF imaging, intrathecal administration of ^{111}In DTPA to evaluate CSF leak or to differentiate normal pressure hydrocephalus from brain atrophy
- CSF shunt evaluation for obstruction (most commonly ventriculoperitoneal) with sterile or pyrogen free ^{99m}Tc (usually) or ^{111}In-DTPA; small quantity of activity is injected into the reservoir under sterile conditions and should flow freely into the peritoneal cavity by 45 min; maneuvers such as pumping the shunt, sitting the patient upright or ambulating are acceptable to encourage flow during this time
- adrenergic imaging of the heart with MIBG has been used to differentiate dementias with autonomic dysfunction (i.e. Lewy Body and Parkinson's disease) from other forms of dementia (i.e. autonomic impairment associated with decreased MIBG activity in the heart)

Thyroid

Radioactive Iodine Uptake (see Endocrinology, E20)

- index of thyroid function (trapping and organification of iodine)
- radioactive ^{131}I given PO to fasting patient (small quantity)
- measure percentage of administered iodine taken up by thyroid
- increased RAIU: toxic multinodular goitre, toxic adenoma, Graves' disease
- decreased RAIU: subacute thyroiditis, late Hashimoto's disease, exogenous thyroid hormone or iodine, falsely decreased in patient with recent radiographic contrast studies, high dietary iodine (e.g. seaweed, taking a "thyroid vitamin")
- Important – iodine uptake helps in the differential of hyperthyroidism only, not hypothyroidism (exception is pediatrics)

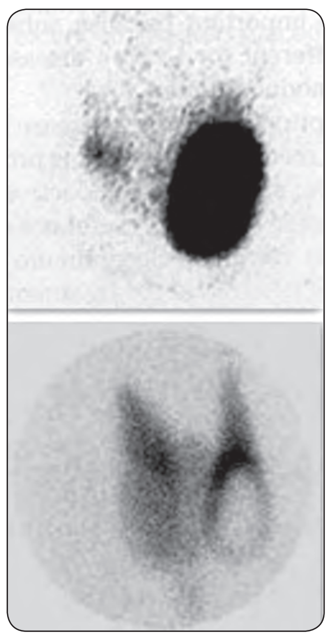


Figure 41. Multinodular goiter (top). Cold nodule (bottom)

Thyroid Imaging (Scintiscan)

- ^{99m}Tc-pertechnetate IV or radioactive iodine (^{123}I); most Canadian sites use pertechnetate to reduce cost
- provides functional anatomic detail
- hot (hyperfunctioning) lesions: usually benign (e.g. adenoma, toxic multinodular goitre), cancer very unlikely (less than 1%)
- cold (hypofunctioning) lesions: cancer must be considered until biopsy negative even though only 6-10% are cancerous; decision to biopsy should be based on clinical and sonographic features
- isointense i.e. "warm" lesions: cancer must be considered as an isointense lesion may represent cold nodules superimposed on normal tissue; if cyst suspected, correlate with U/S

Radioiodine Ablation

- ^{131}I for Graves' disease, multinodular goitre, thyroid cancer (in the case of thyroid cancer, ablation performed at higher dose and after thyroidectomy)
- serum thyroglobulin used to detect recurrent thyroid cancer in a patient that has received ablation
- advice should be given for patient-specific precautions to remain away from family members and caregivers to reduce radiation exposure after thyroid ablation, do not initiate pregnancy for 6 mo, small risk of exophthalmos, thyroid storm, secondary malignancy

Pediatric Hypothyroidism

- Pertechnetate thyroid scan can differentiate thyroid agenesis, hemiagenesis, lingular thyroid, organification defect, however should not wait for a diagnosis to start thyroid hormone replacement in a neonate; start immediately

Respiratory

V/Q Scan

examine areas of lung in which ventilation and perfusion do not match

- ventilation scan
  - patient breathes radioactive gas (nebulized ^{99m}Tc-DTPA, ^{133}Xe, or most commonly Technegas) through a closed system, filling alveoli proportionally to ventilation
  - ventilation scan defects indicate: airway obstruction (i.e. air trapping), chronic lung disease, bronchospasm, tumour mass obstruction
- perfusion scan
  - radiotracer injected IV (^{99m}Tc-MAA) → trapped in pulmonary capillaries (0.1% of arterioles occluded) according to blood flow
  - relatively contraindicated in severe pulmonary HTN, right-to-left shunt, previous history of pneumonectomy, small child. In these cases fewer particles are usually given
- to rule out PE
  - indications: some institutions favour in pregnancy (lower radiation dose to breast than CT), or where CT contrast contraindicated (e.g. contrast allergy, renal failure)
  - areas of lung are well ventilated but not perfused (unmatched defect) are suspicious for acute infarction
  - defects are wedge-shaped, extend to periphery, usually bilateral and multiple
  - often reported as high probability (> 2 large i.e. segmental mismatched perfusion defects), intermediate, low, very low, or normal according to modified PIOPED II criteria although now are increasingly reported as PE present, indeterminate or normal
  - useful in finding clinically important emboli
  - decreased detection of incidentalomas commonly found on CT
- not valid for assessment of PE when patients have consolidation and the test can be limited by ventilatory problems (e.g. COPD), much like CT
- modified V/Q scan (perfusion only, lower dose contrast) may be used for pregnant patients if CXR is normal or If there are ventilatory problems

Ventilation Scan Defects Indicate
Airway obstruction, chronic lung disease, bronchospasm, tumour mass obstruction

Perfusion Scan Defects Indicate
Reduced blood flow due to PE, COPD, asthma, bronchogenic carcinoma, inflammatory lung diseases (pneumonia, sarcoidosis), mediastinitis, mucous plug, vasculitis

V/Q Scan
For PE investigation: normal scan makes PE unlikely
Probability of PE: high 80-100%, intermediate 20-80%, low <20%, very low <10%

Cardiac

Myocardial Perfusion Scanning

- to investigate coronary artery disease (CAD), assess treatment of CAD, pre op risk stratification, viability testing
- ^{99m}Tc-sestamibi, or ^{99m}Tc-tetrofosmin are used most commonly, thallium 201 was used previously but largely discontinued due to high radiation doses to patients and unfavourable imaging characteristics; today thallium still used for viability studies
- injected at peak exercise (85% max predicted heart rate by the Bruce protocol, chest pain, ECG changes) or after persantine challenge (vasodilator), or dobutamine infusion (chronotropic, again to 85% predicted heart rate); can be done as stress only protocol with optional rest or as stress and rest combined protocol (i.e. as 1 day or 2 day protocol).
- patients with left bundle usually given pharmacologic stress because EKG is difficult to interpret for ST changes and avoids a characteristic artifact
- pharmacologic stress contraindicated if BP is < 90 systolic; persantine exacerbates asthma, so patients with asthma and wheeze who cannot exercise usually get dobutamine infusion; reverse persantine with aminophylline or caffeine
- persistent defect (at rest and stress) suggests infarction or myocardial scar; reversible defect (only during stress) suggests ischemia
- used to discriminate between reversible (ischemia) vs. irreversible (infarction) changes when other investigations are equivocal
- Courage trial indicates that patients with >10% ischemic myocardium benefit most from revascularization
- see Cardiology and Cardiac Surgery, C13

Radionuclide Ventriculography

- ^{99m}Tc tagged to red blood cells, tagged albumin is also acceptable
- first pass through RV → pulmonary circulation → LV; provides information about RV function, presence of shunts
- cardiac MUGA scan sums multiple cardiac cycles, usually at least 200 beats
- evaluation of LV function and regional wall motion, ejection fraction
- images are obtained by gating (synchronizing) the count acquisitions to the ECG signal
- can assess diastolic dysfunction
- provides information on ejection fraction (normal = 50-65%), ventricular volume, and wall motion
- indications: most commonly to monitor potential cardiac toxicity with chemotherapy or herceptin, as a gold standard of ejection fraction in defibrillator work up

Abdomen and Genitourinary System

HIDA Scan (Cholescintigraphy)

- IV injection of ^{99m}Tc-disofenin (DISIDA) or ^{99m}Tc-mebrofenin which is bound to protein, taken up, and excreted by hepatocytes into biliary system
- can be performed in non-fasting state but prefer NPO after midnight
- indicated in workup of cholecystitis when abdominal ultrasound result is equivocal:
  - acute cholecystitis: no visualization of gallbladder at 4 h or 1 hour after administration of morphine
  - chronic cholecystitis: no visualization of gallbladder at 1 h but seen at 4 h or after morphine administration
- gallbladder visualized when cystic duct is patent (rules out acute cholecystitis with >99% certainty), usually seen by 30 min to 1 h
- differential diagnosis of obstructed cystic duct: acute/chronic cholecystitis, decreased hepatobiliary function (commonly due to alcoholism), bile duct obstruction, parenteral nutrition, fasting less than 4 h or more than 24 h
- also used to assess bile leaks post-operatively or in trauma
- gallbladder ejection fraction (>38% is normal) can be measured after a fatty meal or CCK to assess for biliary dyskinesia

RBC Scan

- IV injection of radiotracer with sequential images of the abdomen (^{99m}Tc RBCs)
- GI bleed
  - if bleeding acutely at <0.5 mL/min, the focus of activity in the images generally indicates the site of the acute bleed, look for a change in shape and location on sequential image, requires active bleeding to localize
  - if bleeding acutely at >0.5 mL/min, use angiography (more specific)
- liver lesion evaluation
  - hemangioma has characteristic appearance: cold early (limited blood flow to lesion), fills in later (accumulation of tagged cells greater than surrounding liver parenchyma)

Other Important Nuclear Medicine Abdominal Tests

- Meckel's Scan: uses Tc 99m pertechnetate; give patient ranitidine premedication; Meckel's diverticulum contains gastric mucosa which will light up at the same time as the stomach and get brighter with time like stomach
- Indium 111 octreoscan: a somatostatin analog used for evaluation and staging of neuroendocrine tumours including carcinoid; gastrinoma and carcinoid tend to be more octreotide avid than insulinoma.
- Iodinated MIBG: a norepinephrine analog, used for pheochromocytoma, neuroblastoma and medullary thyroid cancer most commonly; limited cardiac applications as above
- solid and liquid gastric emptying: a standardized solid or liquid meal is labelled, usually with Tc 99m sulfur colloid and gastric emptying studied over time. There are normal ranges for solids and liquids

Urea Breath Test

- indication: diagnosis of gastric *Helicobacter pylori* infection
- patient administered ^{14}C-labelled urea orally, urea metabolized by *H. pylori* to ammonia and $^{14}CO_2$, ^{14}C-labled CO_2 is measured via plastic filament detectors or liquid scintillation

Functional Renal Imaging

- evaluation of renal function and anatomy using ^{99m}Tc DTPA or Tc 99m MAG3
- frequently used to provide index of relative function between two kidneys
- frequently used in adults to assess for UPJ obstruction (by assessing the clearance half time with lasix), and assess renal transplants or as a nuclear GFR study in patients wanting to donate kidneys
- in children, imaging with Tc 99m DMSA is used to assess for pyelonephritis
- in children, the injection of tracer into the bladder via foley catheter is often used to assess for reflux

Bone

Bone Scan

- isotopes, usually ^{99m}Tc-diphosphonate
- radioactive tracer binds to hydroxyapatite of bone matrix
- increased binding when increased blood supply to bone and/or high bone turnover (active osteoblasts)
- indications: bone pain of unknown origin, staging or restaging of cancer with boney mets (or primary bone cancer), imaging of arthroplasty complications like loosening or infection, osteomyelitis imaging

- when used to assess for osteomyelitis, usually done in combination with gallium or white blood cell scan
- differential diagnosis of positive bone scan: bone metastases (breast, prostate, lung, thyroid), primary bone tumour, arthritis, fracture, infection, anemia, Paget's disease
- lytic lesions like multiple myeloma, renal cell cancer, eosinophilic granuloma: typically normal or cold (false negative); need a skeletal survey
- "superscan": increased bone uptake and poor renal uptake due to diffuse metastases (breast, prostate) or metabolic causes (i.e. renal osteodystrophy)

Interventional Radiology

Vascular Procedures

Angiography

- injection of contrast material through a catheter placed directly into an artery or vein to delineate vascular anatomy
- catheter can be placed into a large vessel (e.g. aorta, vena cava) for a "flush" or selectively placed into a branch vessel for more detailed examination of smaller vessels and specific organs
- indications: diagnosis of primary occlusive or stenotic vascular disease, aneurysms, coronary, carotid and cerebral vascular disease, PE, trauma, bleeding (GI, hemoptysis, hematuria), vascular malformations, as part of endovascular procedures (endovascular aneurysm repair, thrombolysis, stenting, and angioplasties)
- complications (<5% of patients): puncture site hematoma, infection, pseudoaneurysm, AV fistula, dissection, thrombosis, embolic occlusion of a distal vessel
- due to improved technology, non-invasive evaluation of vascular structures is being performed more frequently (colour Doppler U/S, CTA, and MRA)
- see *Neuroradiology*, MI18

Advanced ischemia patients should receive surgery rather than thrombolysis

On U/S, veins are compressible, arteries are not

Thrombolytic Therapy for Pulmonary Embolism
Cochrane DB Syst Rev 2009;3:CD004437
Study: Systematic review of RCTs comparing thrombolytic therapy with placebo, heparin, or surgical intervention.
Patients: 679 patients with acute PE.
Intervention: Thrombolytics vs. heparin or placebo.
Outcome: Death rate, recurrence of PE, major and minor hemorrhagic events.
Results: Non-significant difference between thrombolytics and heparin or placebo in all measured outcomes. Rt-PA and heparin together reduced need for treatment for in-hospital events. Thrombolytics improved hemodynamic outcome, lung VQ scans, pulmonary angiography assessment, and echocardiograms greater than heparin. Need for further double-blinded RCTs.
Conclusion: We cannot conclude whether thrombolytic therapy is better than heparin for pulmonary embolism based on limited evidence found.

Percutaneous Transluminal Angioplasty and Stents

- introduction and inflation of a balloon into a stenosed or occluded vessel to restore distal blood supply
- common alternative to surgical bypass grafting with 5-yr patency rates similar to surgery, depending on site
- renal, iliac, femoral, mesenteric, subclavian, coronary, and carotid artery stenoses are amenable to treatment
- vascular stents may help improve long-term results by keeping the vessel wall patent after angioplasty
- stents are also used for angioplasty failure or complications
- stent grafts (metal mesh covered with durable fabric) may provide an alternative treatment option for aneurysms and AV fistulas
- complications: similar to angiography, but also includes vessel rupture

Thrombolytic Therapy

- may be systemic (IV) or catheter directed
- infusion of a fibrinolytic agent (urokinase, streptokinase, TNK, tPA – used most commonly) via a catheter inserted directly into a thrombus
- can restore blood flow in a vessel obstructed with a thrombus or embolus
- indications: treatment of ischemic limb (most common indication), early treatment of MI or stroke to reduce organ damage, treatment of venous thrombosis (DVT or PE)
- complications: bleeding, stroke, distal embolus, reperfusion injury with myoglobinuria and renal failure if advanced ischemia present

Chemoembolization delivers chemotherapy directly into the tumour through its feeding blood supply and traps the drug in place by embolization

Embolization

- injection of occluding material into vessels
- permanent agents: amplatzer plugs, coils, glue, and onyx
- temporary: gel foam, autologous blood clots
- indications: management of hemorrhage (epistaxis, trauma, GI bleed, GU bleed), treatment of arteriovenous malformation, pre-operative treatment of vascular tumours (bone metastases, renal cell carcinoma), varicocele embolization for infertility, symptomatic uterine fibroids
- complications: post-embolization syndrome (pain, fever, leukocytosis), unintentional embolization of a non-target organ with resultant ischemia

Inferior Vena Cava Filtre

- insertion of metallic "umbrellas" to mechanically trap emboli and prevent PE
- may be temporary (retrievable) or permanent
- inserted via femoral vein, jugular vein, or antecubital vein
- usually placed infrarenally to avoid renal vein thrombosis
- indications: contraindication to anticoagulation, failure of adequate anticoagulation (e.g. recurrent PE despite therapeutic anticoagulant levels), complication of anticoagulation

Figure 42. Retrievable IVC filter

Central Venous Access

- variety of devices available
- PICC, external tunneled catheter (Hickman or dialysis catheters), subcutaneous port (Portacath®)
- indications: chemotherapy, TPN, long-term antibiotics, administration of fluids and blood products, blood sampling
- complications: venous thrombosis and central venous stenosis, infection including sepsis, pneumothorax

Indications for Central Venous Access

FAT CAB
Fluids
Antibiotics
TPN
Chemotherapy
Administration of blood
Blood sampling

Nonvascular Interventions

Percutaneous Biopsy

- replaces open surgical procedure
- many sites are amenable to biopsy using U/S, fluoroscopy, CT or MR guidance
- complications: false negative (sampling error or tissue necrosis), pneumothorax in 30% of lung biopsies (chest tube required in ~5%), acute pancreatitis (pancreatic biopsies), bleeding from liver biopsies in patients with uncorrectable coagulopathies or ascites (can be minimized with transjugular approach)

Abscess Drainage

- placement of a drainage catheter into an infected fluid collection
- administer broad spectrum IV antibiotics prior to procedure
- routes: percutaneous (most common), transgluteal, transvaginal, transrectal
- complications: hemorrhage, injury to intervening structures (e.g. bowel), bacteremia, sepsis

Figure 43. Femoral arteriogram: distal occlusion of superficial femoral artery

Percutaneous Biliary Drainage/Cholecystostomy

- placement of drainage catheter ± metallic stent into obstructed biliary system (PBD) or gallbladder (cholecystostomy) for relief of jaundice or infection
- percutaneous gallbladder access can be used to crush or remove stones
- indications
  - cholecystostomy: acute cholecystitis
  - PBD: biliary obstruction secondary to stone or tumour, cholangitis
- complications
  - acute: sepsis, hemorrhage
  - long-term: tumour ingrowth and stent occlusion

Percutaneous Nephrostomy

- placement of catheter into renal collecting system
- indications: hydronephrosis, pyonephrosis, ureteric injury with or without urinary peritonitis (traumatic or iatrogenic)
- complications: bacteria and septic shock, hematuria due to pseudoaneurysm or AV fistulas, injury to adjacent organs

Gastrostomy/Gastrojejunostomy

- percutaneous placement of catheter directly into either stomach (gastrostomy) or through stomach into small bowel (transgastric jejunostomy)
- indications: inability to eat (most commonly CNS lesion e.g. stroke) or esophageal obstruction, decompression in gastric outlet obstruction
- complications: gastroesophageal reflux with aspiration, peritonitis, hemorrhage, bowel or solid organ injury

Radiofrequency Ablation

- U/S or CT guided probe is inserted into tumour, radiofrequency energy delivered through probe causes heat deposition and tissue destruction
- indications: hepatic tumours (HCC and metastases), renal tumours
- complications: destruction of neighbouring tissues and structures, bleeding

Breast Imaging

Modalities

Mammography

Description
- x-ray imaging of the breasts for screening in asymptomatic patients, or diagnosis of clinically-detected or screening-detected abnormalities (see General Surgery, GS54)
- routine evaluation involves two standard views: cranio-caudal and medial-lateral-oblique

Indications
- screening
  - begin screening from age 50 q2 yr
  - no strong data to support screening >70 yr, but may continue screening if in good general health
  - if <50, screening is only recommended for those with high risk of breast cancer
  - screening detects 2-8 cancers/1,000 women screened
- surveillance
  - follow-up of women with previous breast cancer
- diagnostic: includes mammography with special views and/or ultrasound
  - work-up of an abnormality that may be suggestive of breast cancer including a lump or thickening, localized nodularity, dimpling or contour deformity, a persistent focal area of pain, and spontaneous serous or sanguinous nipple discharge from a single duct
  - women with abnormal screening mammograms
  - suspected complications of breast implants

Table 20. Breast Imaging Reporting and Data System (BI-RADS®) Mammography Categories

Assessment Categories	Imaging Findings	Follow-Up Recommendations
BI-RADS 0	Incomplete	Additional imaging Comparison to prior films
BI-RADS 1	Negative	Routine screening
BI-RADS 2	Benign	Routine screening
BI-RADS 3	Probably benign Likelihood of malignancy is <2%	Unilateral mammogram at 6 mo
BI-RADS 4	Suspicious abnormality	Biopsy
BI-RADS 5	Highly suspicious of malignancy Likelihood of malignancy is 95%	Biopsy
BI-RADS 6	Malignancy confirmed by biopsy	Definitive therapy

Breast Ultrasound

Indications
- characterization of palpable abnormalities (ultrasound 1st line <30 yr and in lactating and pregnant women, >30 yr need mammogram 1st)
- further characterization of mammographic findings
- guidance for interventional procedures

Breast MRI

Description
- contrast enhanced MRI of the breasts
- sensitive for detecting invasive breast cancer (95-100%) but specificity variable (37-97%)
- for diagnosis, used only after mammography and U/S investigation
- use as a screening modality is limited to high risk patients, in conjunction with mammography

Indications
- "problem solving" of indeterminate findings following complete mammographic and ultrasound work up
- evaluation of patients with suspected silicone implant rupture and problems associated with breast implants
- evaluation of previously diagnosed breast cancer: positive margins, recurrence, response to chemotherapy
- High Risk Screening
  - known BRCA1 or BRCA2 mutation, or other gene predisposing to breast cancer or untested first-degree relative of a carrier of such a gene mutation
  - family history consistent with a hereditary breast cancer syndrome and/or estimated personal lifetime cancer risk >25%
  - high-risk marker on prior biopsy (atypical ductal hyperplasia, atypical lobular hyperplasia, lobular carcinoma *in situ*)
  - radiation therapy to chest (before age 30)

Breast Interventional Procedures

Description
- includes fine needle aspirate biopsy, core needle biopsy, stereotactic biopsy, MRI guided biopsy, abscess drainage, and cyst aspiration (see General Surgery, GS54)

Indications
- cystic mass: complex cyst, symptomatic, suspected abscess
- solid mass: confirm diagnosis of a lesion suspicious for malignancy (BI-RADS® Category 4 or 5)
- suspicious calcifications: confirm diagnosis of a lesion suspicious for malignancy (BI-RADS® Category 4 or 5) – stereotactic biopsy
- initial percutaneous biopsy procedure that was insufficient or discordant with imaging
- presurgical wire localization of a lesion

Breast Findings

Breast Masses
- definition: a space occupying lesion seen in two different projections; if seen in only a single projection it should be called an "asymmetry" until its three-dimensionality is confirmed

Table 21. Mammographic Features of Benign and Malignant Breast Masses

	Benign	Malignant
Shape	Oval, round, lobular	Irregular
Margin	Circumscribed, well-defined	Indistinct, microlobulated, spiculated
Density	Radiolucent (oil cyst, lipoma, fibrolipoma, galactocele, hamartoma)	Radiodense
Calcifications (± mass)	Popcorn (hyalinizing fibroadenoma), lucent centred (oil cyst/fat necrosis), layering (milk of calcium), vascular, round, scattered	Pleomorphic (vary in size and shape), amorphous (indistinct), fine linear, coarse heterogeneous, regional, segmental, clustered

Other Findings
- tubular density/dilated duct: branching tubular structures usually represent enlarged ducts (milk ducts); if they are clearly identified as such, these densities are of little concern
- intramammary lymph node: typical lymph nodes are circumscribed, reniform and often have a fatty notch and centre; usually less than 1 cm, and usually seen in the outer, often upper part of the breast; when these characteristics (particularly fatty centre or notch) are well seen, the lesion is almost always benign and insignificant
- focal asymmetry: area of breast density with similar shape on two views, but completely lacking borders and conspicuity of a true mass; must be carefully evaluated with focal compression to exclude findings of a true mass or architectural distortion
  - if focal compression shows mass-like character, or if the area can be palpated, biopsy generally recommended

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