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college of science
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health physics

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X-ray production and Diagnostic Radiology

References

THE ESSENTIAL PHYSICS OF MEDICAL IMAGING

SECOND EDITION

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X-ray production and Diagnostic Radiology

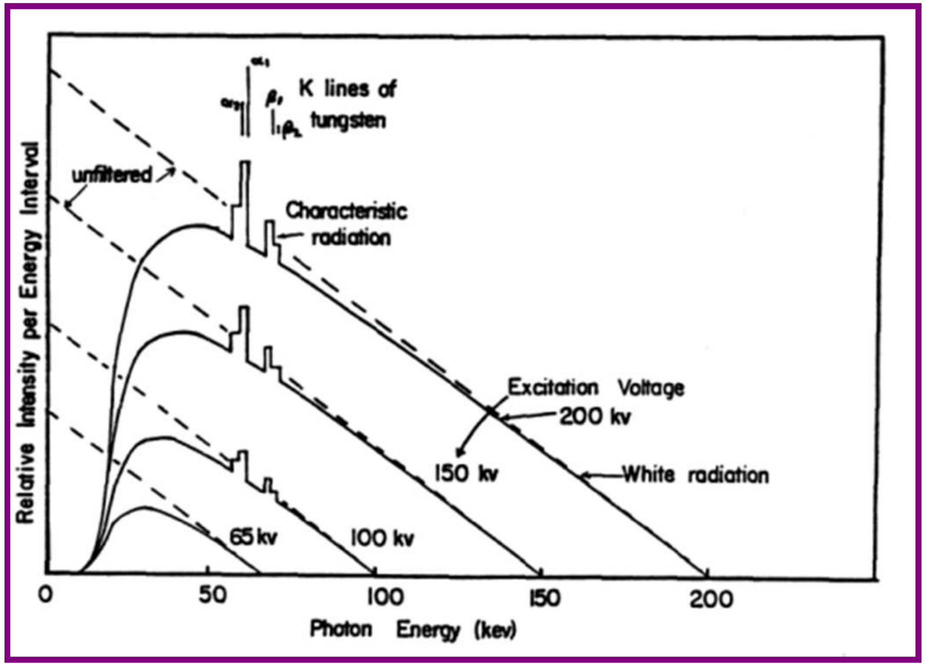
The classical X-ray tube requires:

electron source

electron acceleration potential

target for X-ray production

The intensity of the electron beam determines the intensity of the X-ray radiation. The electron energy determines the shape of the bremsstrahlungs spectrum, in particular the endpoint of the spectrum. Low energy X-rays are absorbed in the tube material.



components of the modern X-ray tube are:

- cathode (electron source)
- anode (acceleration potential)
- rotor/stator (target device)
- glass/metal envelope (vacuum tube)

X-ray Production

When a beam of monoenergetic electrons that had been accelerated across a high potential difference is abruptly decelerated by stopping the electron beam (as in the case of an X-ray tube, a cathode ray tube, or a klystron microwave generator), a small fraction of the energy in the electron beam is converted into X-rays.

$$f_e = 1 \times 10^{-3} \times ZE,$$

where

f_e = fraction of the energy in the electron beam that is converted into X-rays,
Z = atomic number of the target in the X-ray tube or whatever the electron beam strikes in any other device, and
E = voltage across the X-ray tube or other device (mega volts, MV). The numerical value of the voltage E is equal to the kinetic energy of the electron, expressed in eV, as it strikes the target. Thus, an electron that has been accelerated across a voltage of 0.1 MV has acquired a kinetic energy of 0.1 MeV (or 100 keV).

This is the operating principle of traditional diagnostic, industrial, and analytical X-ray tube (Fig. 5-8). The American physicist William D. Coolidge invented this type of X-ray tube in 1913. In 1937, Dr. Coolidge was awarded an honorary MD degree by the University of Zurich in recognition of his many contributions of physics to medical science. It is interesting to note that Coolidge lived to the age of 101 years, despite his extensive experience with X-rays.

An electron beam, usually on the order of milliamperes, is generated by heating the cathode. A voltage difference on the order of tens to hundreds of kilo volts across the tube accelerates the electrons to form a monoenergetic beam in which the kinetic energy of the electrons in electron volts is numerically equal to the voltage across the tube. The high-speed electrons are stopped by a high-atomic-numbered metal target that is embedded in the anode. Some of the kinetic energy in the electron beam is converted into X-rays (bremsstrahlung) when the electrons are suddenly stopped. In X-ray generators where the voltage is less than several hundred thousand volts, the X-rays (photons) are emitted mainly at angles around 90° to the direction of the electron beam. A hole in the protective shielding that houses the X-ray tube allows a useful X-ray beam to emerge from the shielded tube.

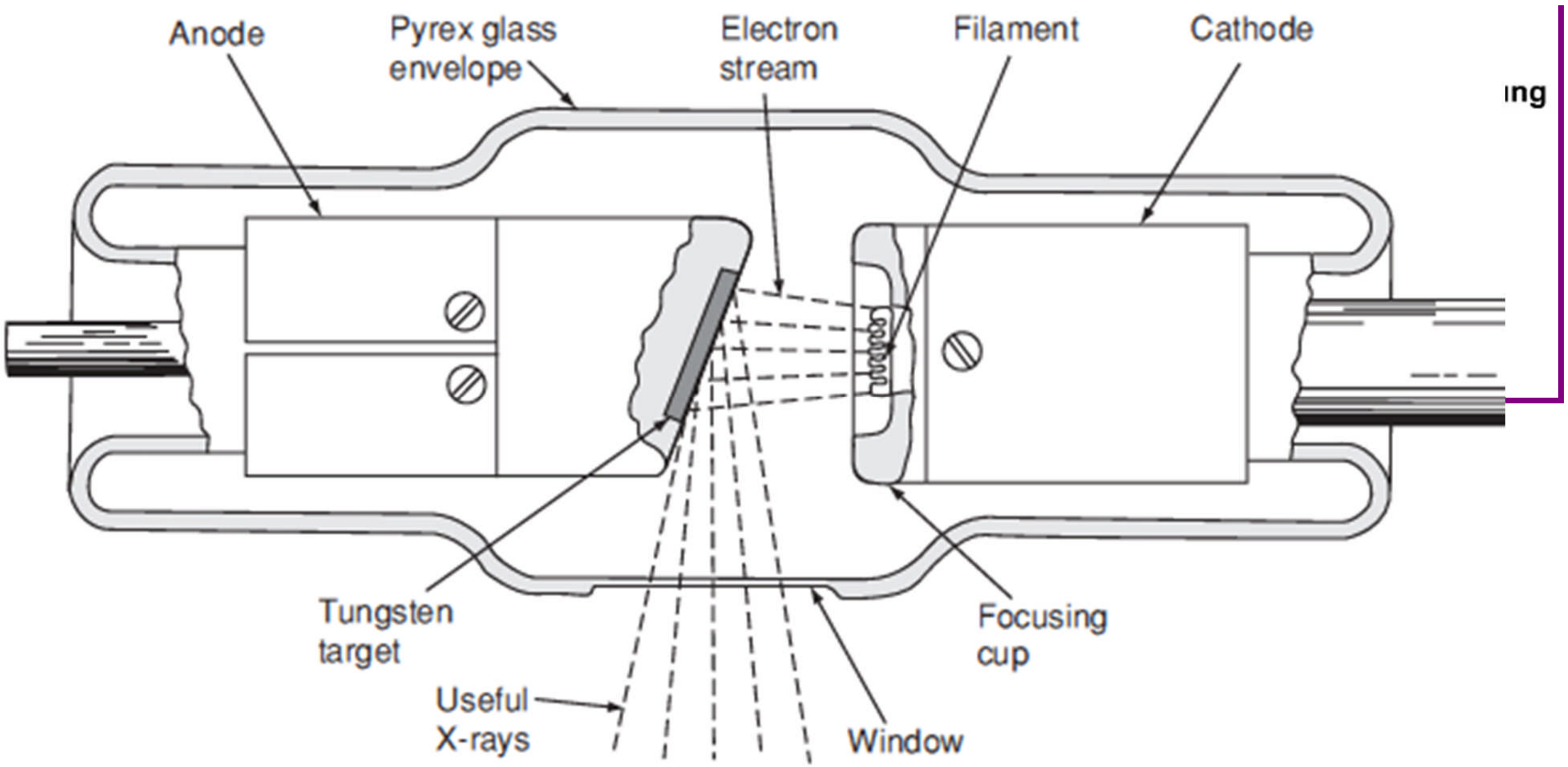
The X-rays that are produced in this manner have a continuous energy distribution that approaches a maximum energy equal to the kinetic energy of the electron that was stopped instantaneously and thus all of its kinetic energy was converted into an X-ray photon. If an electron were to be instantaneously stopped by the target, all of its kinetic energy would be converted into an X-ray photon. This would represent the maximum-energy (or shortest-wavelength) photon possible with the given voltage across the tube. However, this maximum limit can only be approached, since no electron can be stopped instantaneously. The fact that the electrons are slowed down at different rates due to different ionization and excitation collisions leads to a continuous energy distribution up to the theoretical maximum energy that is determined only by the high voltage across the X-ray tube (Fig. 5-9). If we have a full-wave rectified, but unfiltered AC voltage across the X-ray tube, then the voltage

The power, P watts, in the electron beam of an X-ray machine is given by the product of the high voltage across the tube, V volts, and the beam current i amperes.

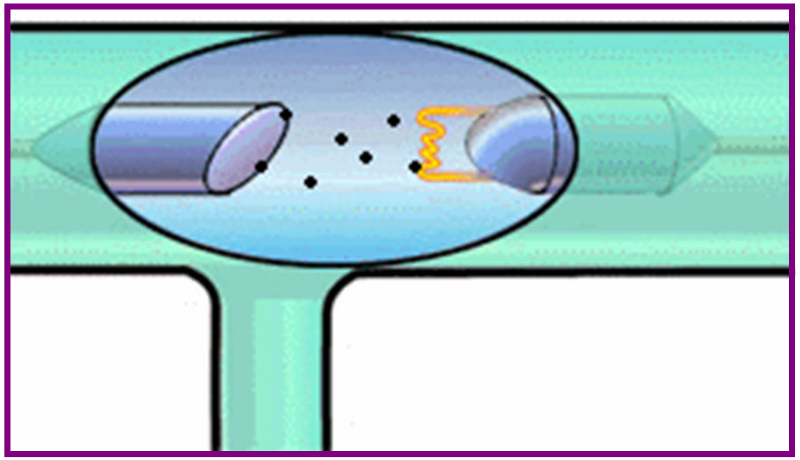
$$P\,(\text{beam}) = V \times i.$$

Since the fraction of the beam power that is converted to X-rays is proportional to ZV, the intensity of the X-ray beam, I, is proportional to the product of ZV and Vi:

$$I(\text{X-rays}) \propto (ZV \times Vi) \propto ZV^2 i.$$



Typical operation conditions are:



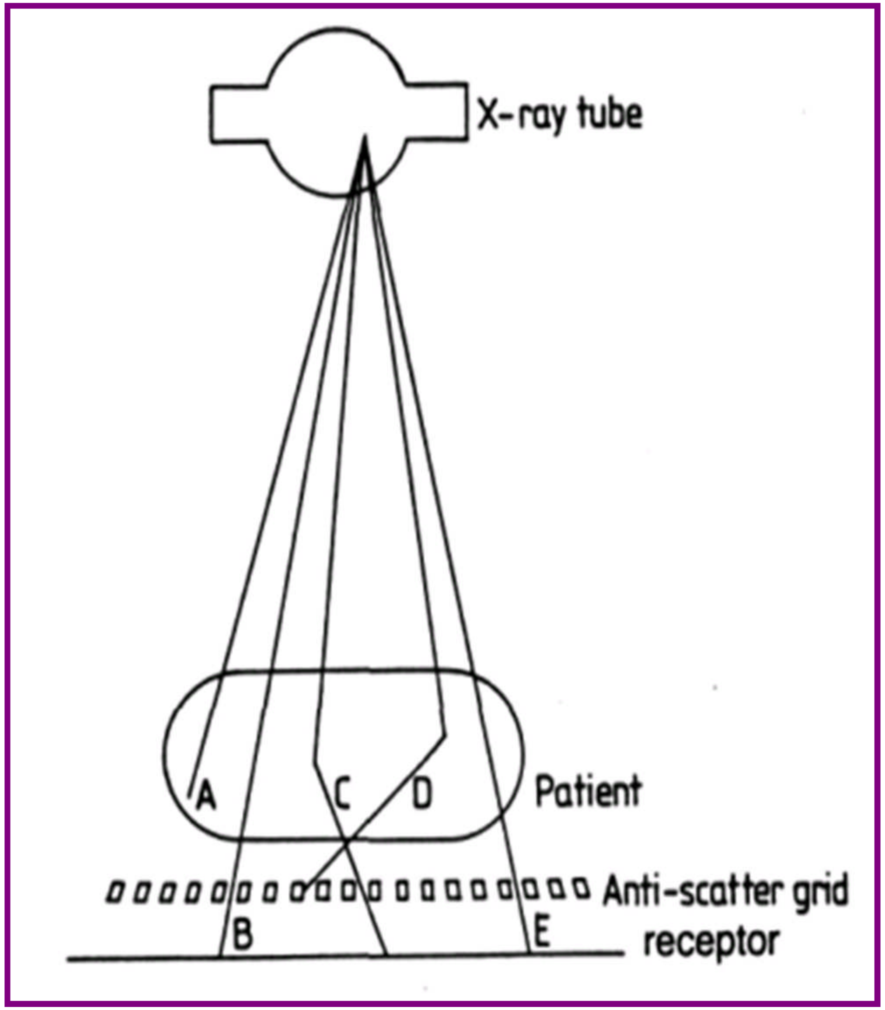
Acceleration Voltage: 20 to 150 kV

Electron Current: 1 to 5 mA (for continuous operation)

Electron Current: 0.1 to 1.0 A (for short exposures)

The radiographic image of the X-ray exposure is determined by the interaction of the X-rays which are transmitted through the patient with a photon detector (film, camera etc.)

Primary X-ray photons have passed through the patient without interaction, they carry useful information.
They give a measure for the probability that a photon pass through the patient without interaction which is a function of the body tissue attenuation coefficients.



Secondary photons result from interaction inside the patient, they are usually deflected from their original direction and carry therefore only little information. They create background noise which degrades the contrast of the image.

Scattered photons are often absorbed in grids between the patient and the image receptor.

The two dimensional image *I*(*x, y*) of the three dimensional distribution of the X-ray attenuating body tissue of the patient can be described as a function of the initial photon intensity *N* of energy *E*, the energy absorption efficiency of the image receptor *ε*(*E*) (film) and the attenuation coefficients *μ* which have to be considered along the photon path in z-direction.

$$I(x,y) = \int (N(E) \cdot \epsilon(E) \cdot E \cdot e^{(-\int \mu(x,y,z)dz)} + S(E) \cdot \epsilon(E) \cdot E)dE$$

with *S*(*E*) as distribution of the scattered secondary X-ray photons.

The expression can be simplified to:

$$I(x,y) = \int N(E) \cdot \epsilon(E) \cdot E \cdot e^{(-\int \mu(x,y,z)dz)}(1+R)dE$$

with *R* as the ratio of secondary to primary radiation.

The **contrast** C **of the target tissue volume is defined in terms of the image distribution function** I_1 and I_2:

$$C = \frac{I_1 - I_2}{I_1}$$

I_1 **gives the energy absorbed outside the target tissue**

I_2 **gives the energy absorbed inside the target volume**.

Approximating for an X-ray energy E:

$$I_1 = N \cdot \epsilon(E) \cdot E \cdot e^{(-\mu_1 t)} + S \cdot \epsilon(E)E$$

$$I_2 = N \cdot \epsilon(E) \cdot E \cdot e^{(-\mu_1(t-x)-\mu_2 x)} + S \cdot \epsilon(E)E$$

This yields for the contrast C:

$$C = N \cdot \epsilon(E) \cdot E \cdot e^{-\mu_1 t} \cdot (1 - e^{[-(\mu_2-\mu_1)x]})/I_1$$

$$C = \frac{(1 - e^{(\mu_1-\mu_2)x})}{(1+R)}$$

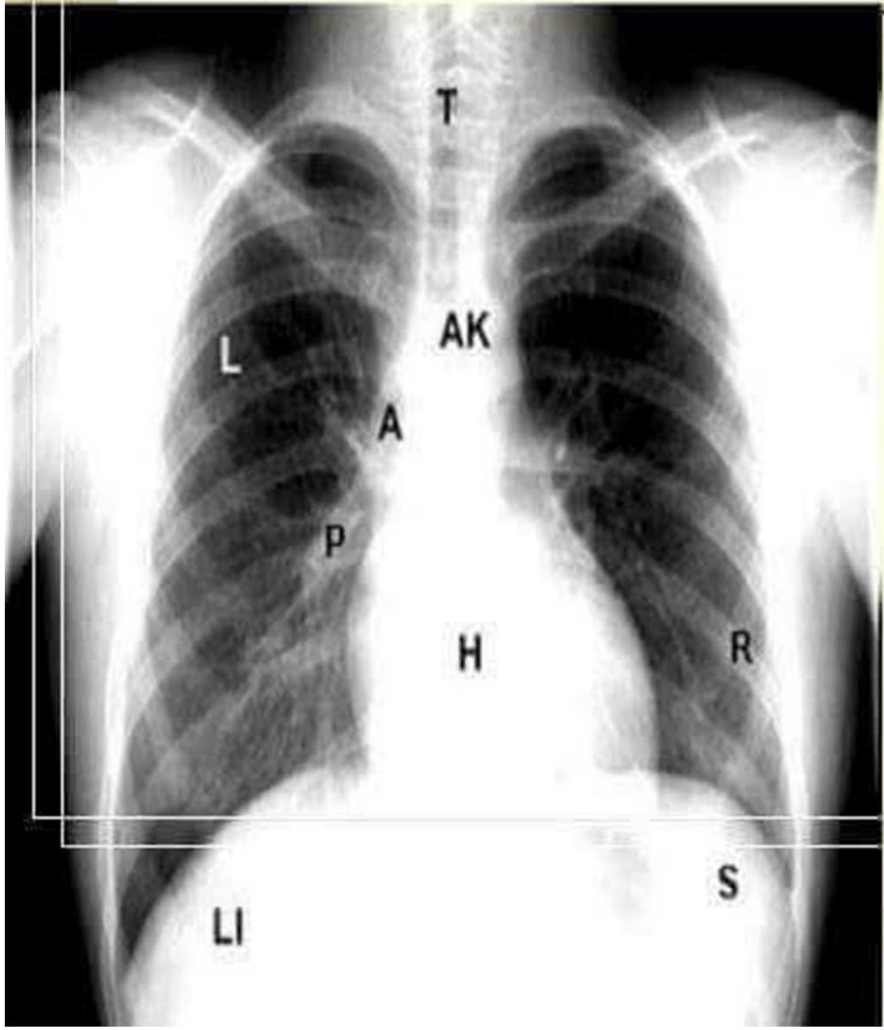
The contrast depends mainly on the difference of attenuation coefficients μ_1 **and** μ_2 **as well as on the ratio of scattered to primary X-ray photons.**


kV
mAs


kV
%.mAs
150 200 300 400 500

TEST	K.V	mAs	TEST	K.V	mAs
Skull	56	20	Hand	41	1.8
Baby skull	48	12,16	ankle	46	6
Jaw	46	8	thigh	55	12
Baby chest	44	5	shoulder		4.5
Chest	50	12	Nike	66	32
Wrist	44	4	Chest(on desk)	58	10
Elbow	45	4	Arms	48	6.3
Baby wrist	40	2			
Baby Pelvis	44	3.2			
The leg	45	6			
knee	46	6			
Baby knee	42	2			
foot	43	3.2			
Baby foot	40	1			
Baby abdomen	45	6			
nose	41	3			
Splinted Leg	48	16			

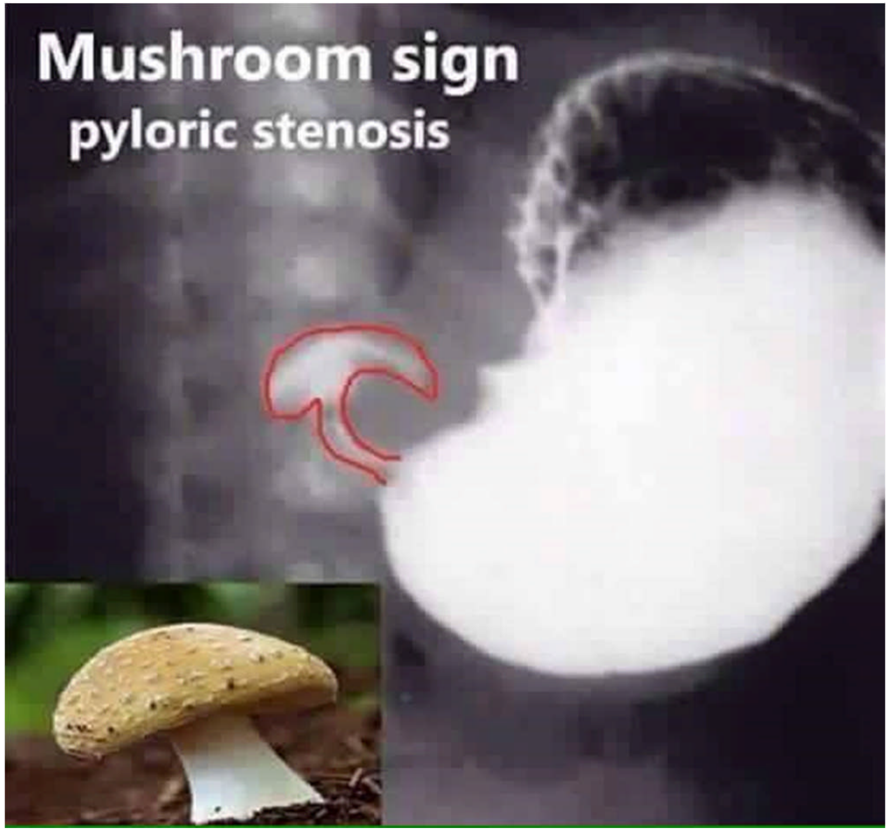
NORMAL CHEST X-RAY



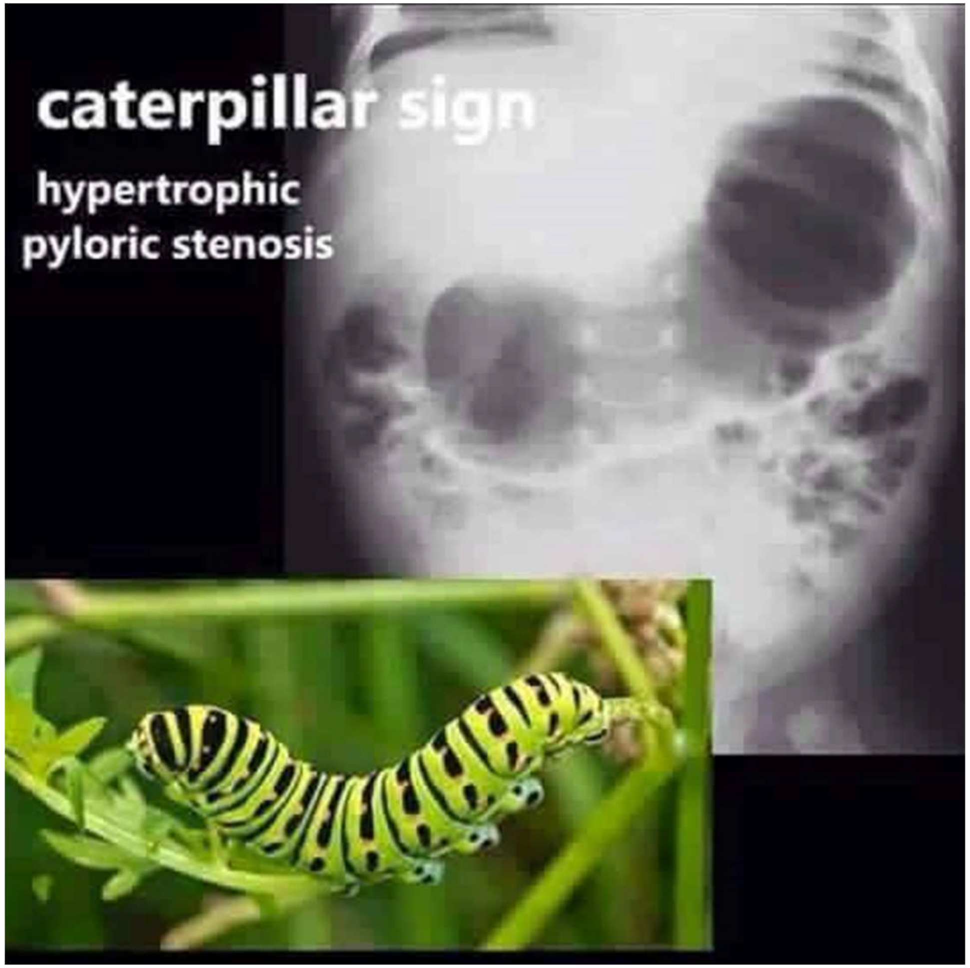
- L- Lung
- T- Trachea
- AK- Aortic Knob
- A- Ascending Aorta
- H- Heart
- R- Ribs
- P- Pulmonary Artery
- S- Spleen

Like Medical
Information & MCQs
By Dr NM Noori


football sign
pneumoperitoneum
L
Wilson


Mushroom sign
pyloric stenosis


corkscrew sign
diffuse oesophagal spasm


Claw sign
Intussusception

caterpillar sign
hypertrophic
pyloric stenosis

Goose neck sign: Endocardial cushion defects

Scimitar sign: Partial anomalous pulmonary venous return

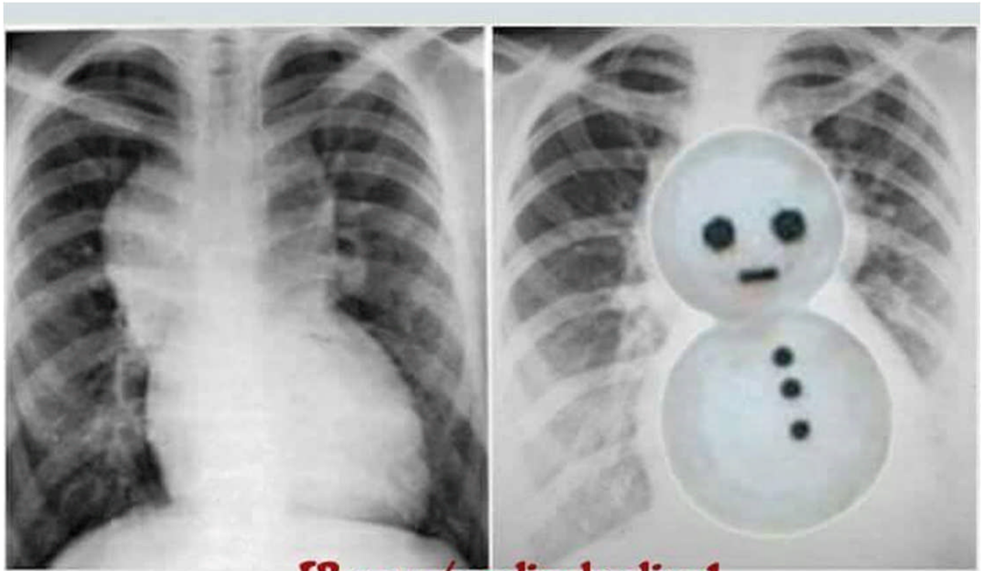
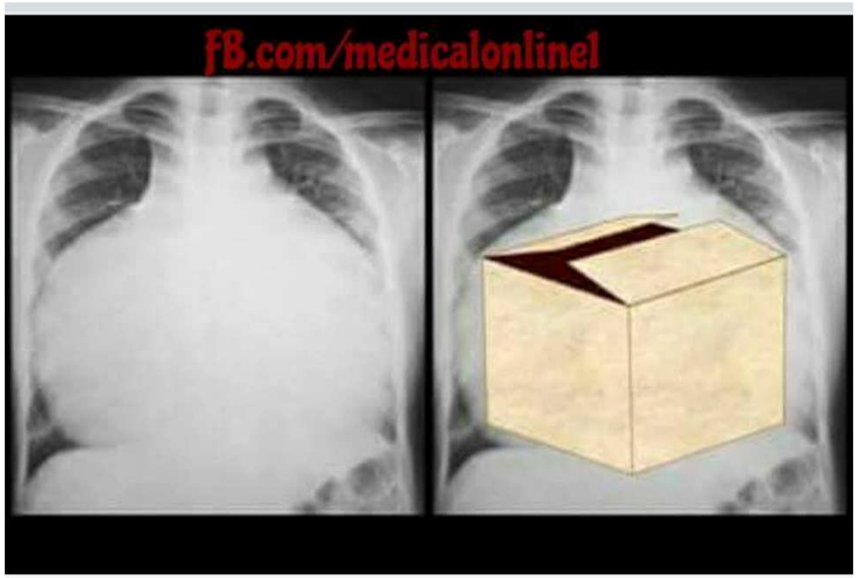
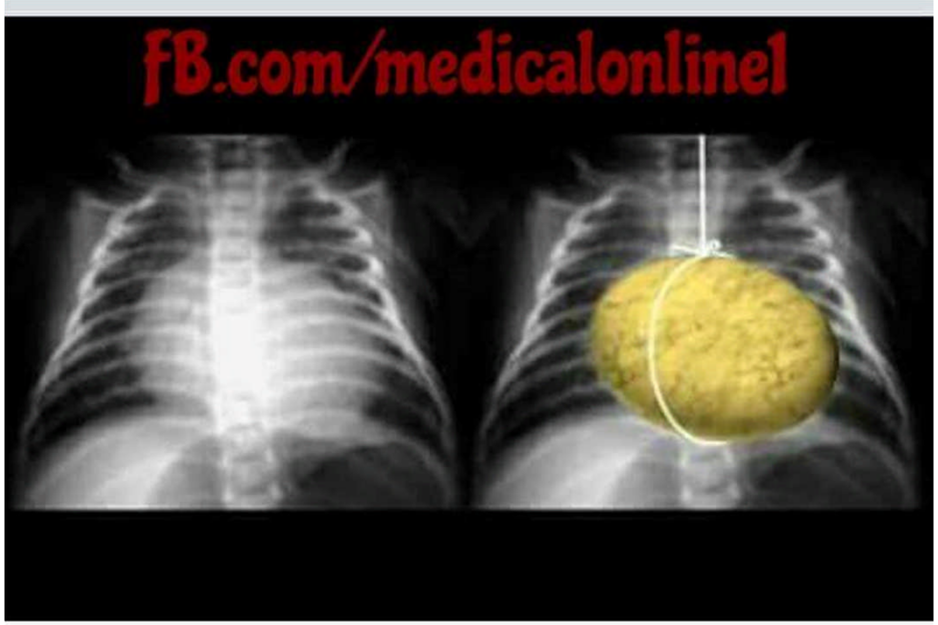


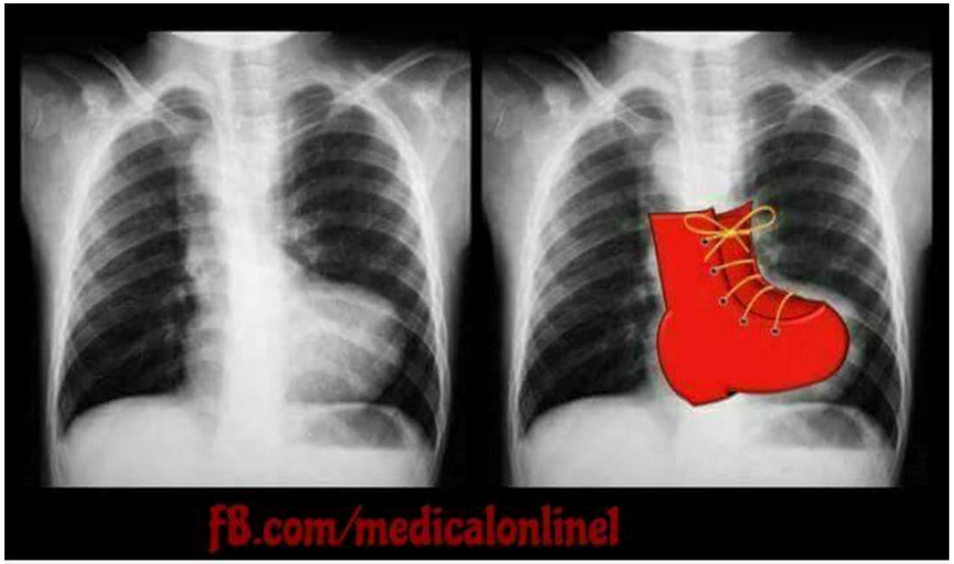
Figure of 8/ Snowman appearance: Total anomalous pulmonary venous connection (TAPVC)



Box shaped heart: Ebstein's anomaly



Egg on string/ Egg on side appearance: Transposition of great arteries (TGA)



Boot shaped heart: Tetralogy of Fallot (TOF)

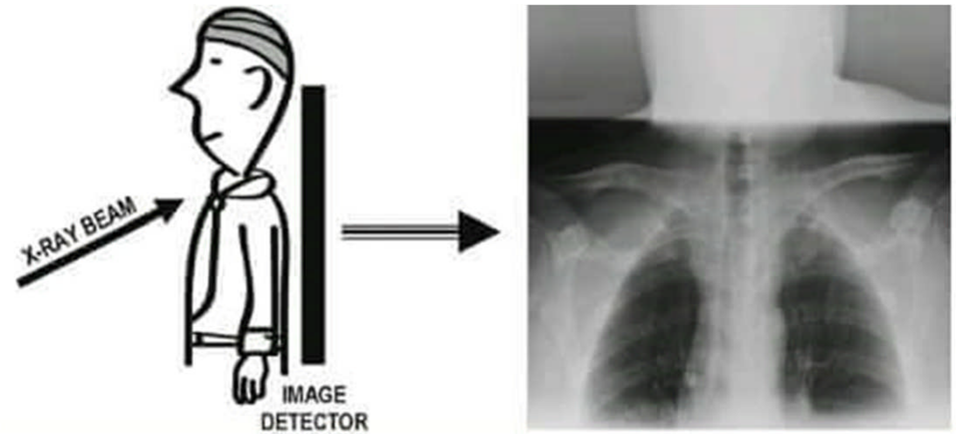


FIGURE 3.2 - THE LORDOTIC PROJECTION
The lordotic view is especially useful for visualizing the lung apices. The clavicles are projected cephalad, allowing a clear view of the lung apices

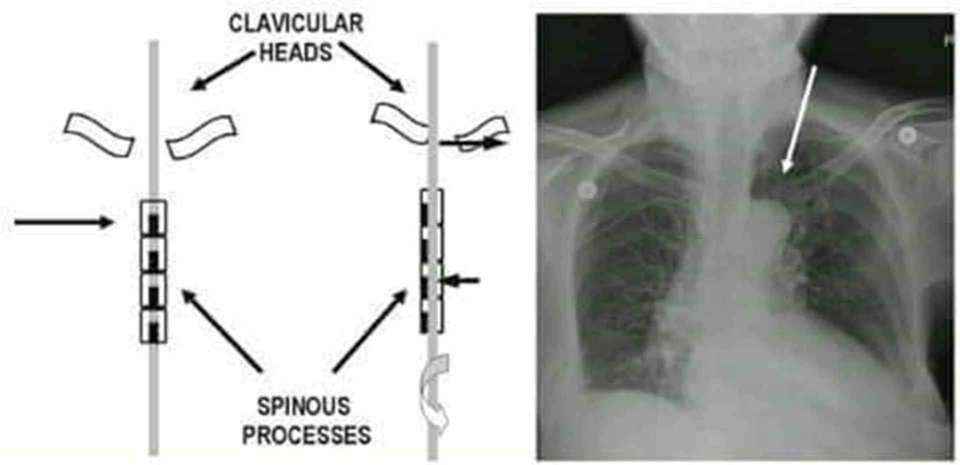


FIGURE 3.3 - ROTATION OF THE CHEST
In this illustration, note how the clavicle heads and spinous processes of the vertebral bodies appear in the AP position and with rotation of the chest to the left. On the chest X-ray, the *arrow* points to the left clavicular head, indicating that the patient is rotated to the left

FIGURE 3.5 - NORMAL KUB

FIGURE 3.6 - NORMAL BARIUM ENEMA

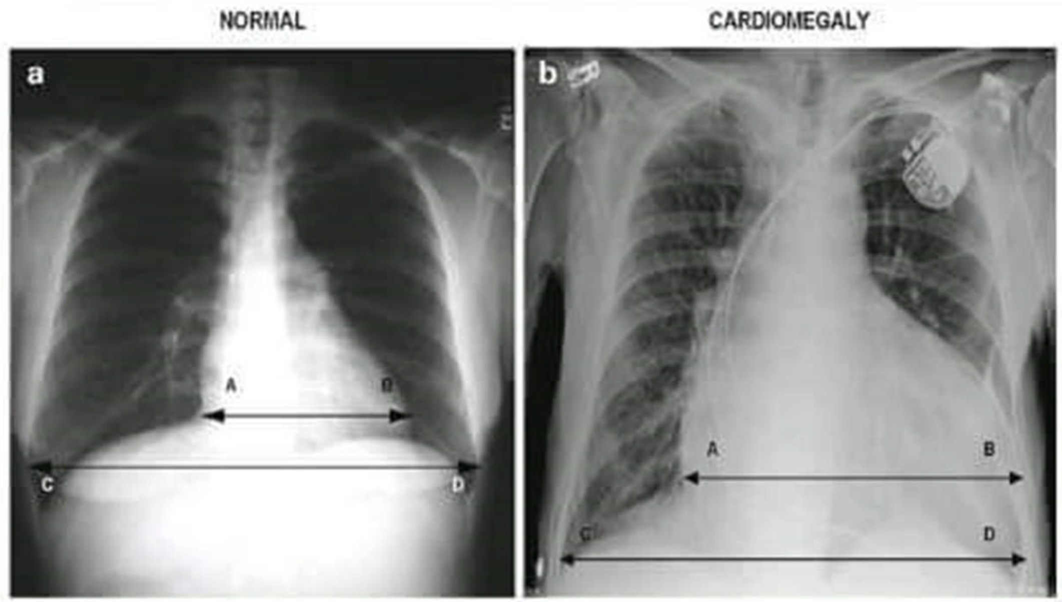
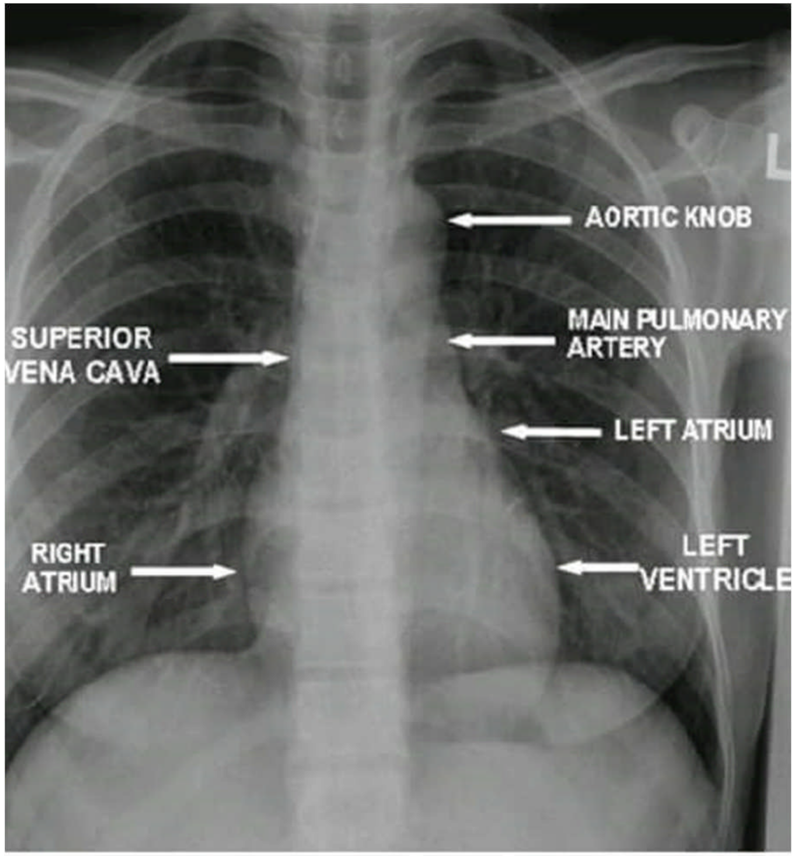


FIGURE 9.2 - MEASURING THE CARDIAC SILHOUETTE
(**a**) When evaluating the size of the heart, A–B should be 50–55% the measurement of C–D (the transverse thoracic diameter). (**b**) Shows marked enlargement of the cardiac silhouette with mild pulmonary vascular congestion. Note how the ratio of A–B to C–D is greater than 50%



RE 9.1 - CARDIAC CONTOURS

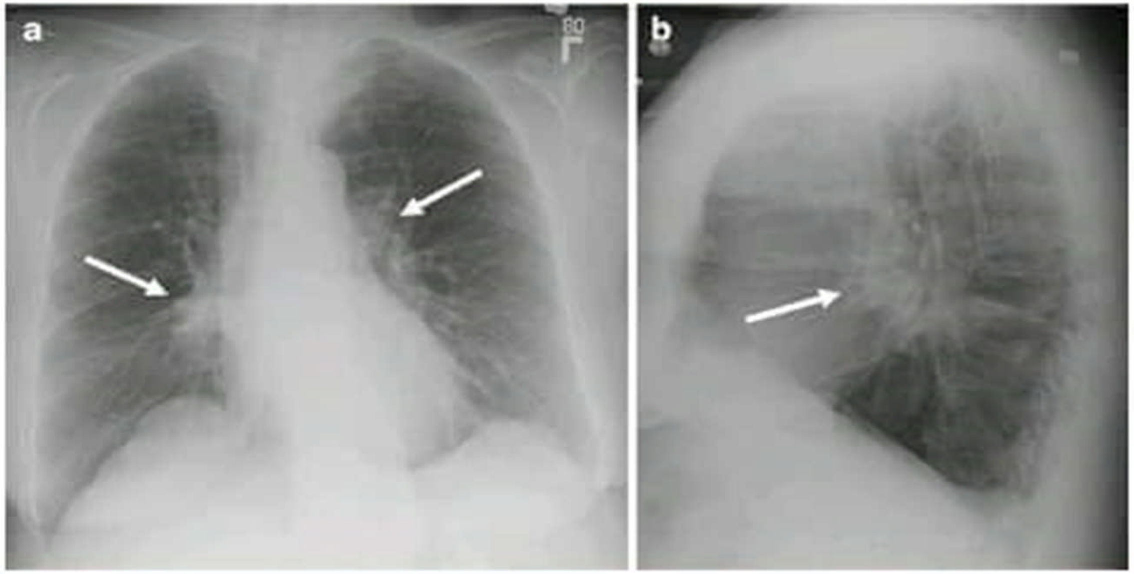


FIGURE 10.5 - HILAR ADENOPATHY
PA (**a**) and lateral (**b**) chest radiographs show a patient with hilar adenopathy (*arrows*)

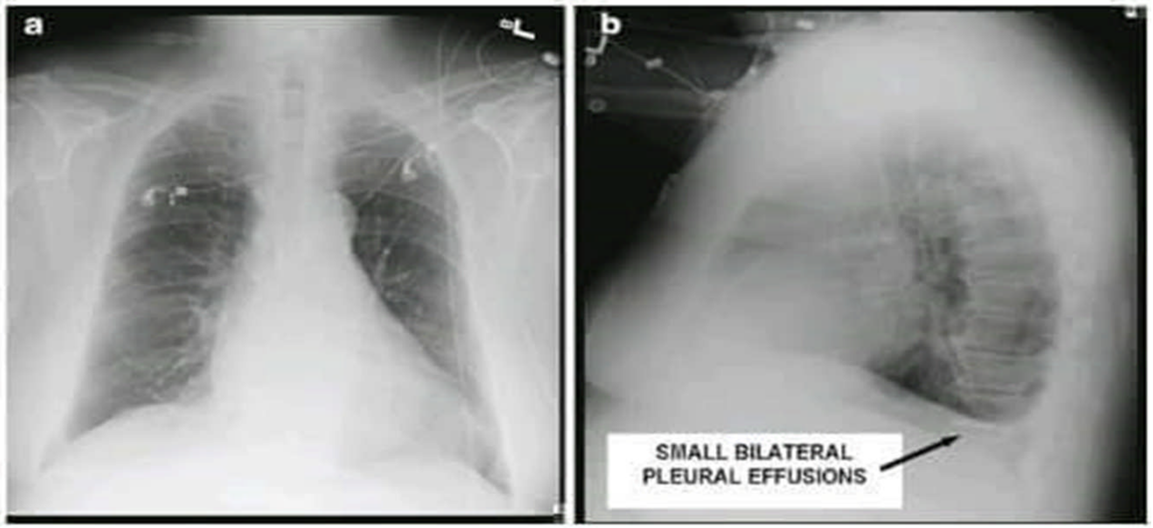


FIGURE 10.3 - BILATERAL PLEURAL EFFUSIONS FRONTAL (A) AND LATERAL (B) VIEWS OF A PATIENT WITH SUSPECTED BILATERAL PLEURAL EFFUSIONS
Note that although bilateral pleural effusions are clearly evident on the lateral projection, (b) the costophrenic angles are clear and sharp on the frontal view (a)

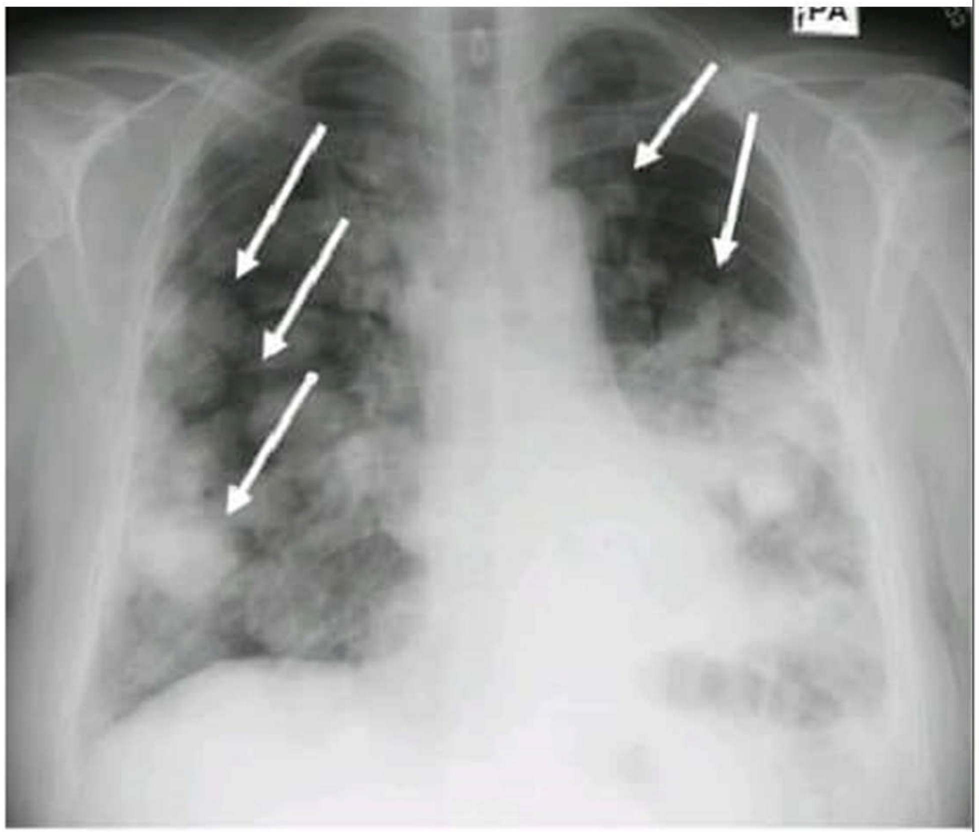


FIGURE 11.5 - PULMONARY NODULES
Frontal chest radiograph demonstrating numerous pulmonary nodules throughout both lung fields (*arrows*)

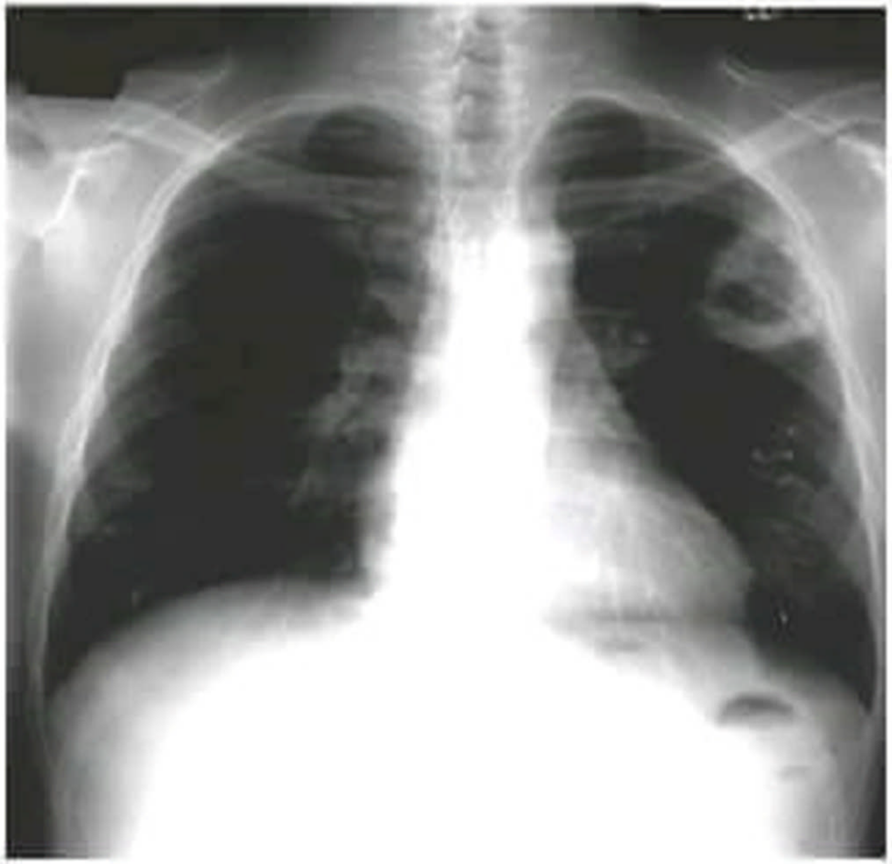


FIGURE 11.4 - CAVITARY LESION
Note the area of decreased density in the left upper lobe within the area of parenchymal disease

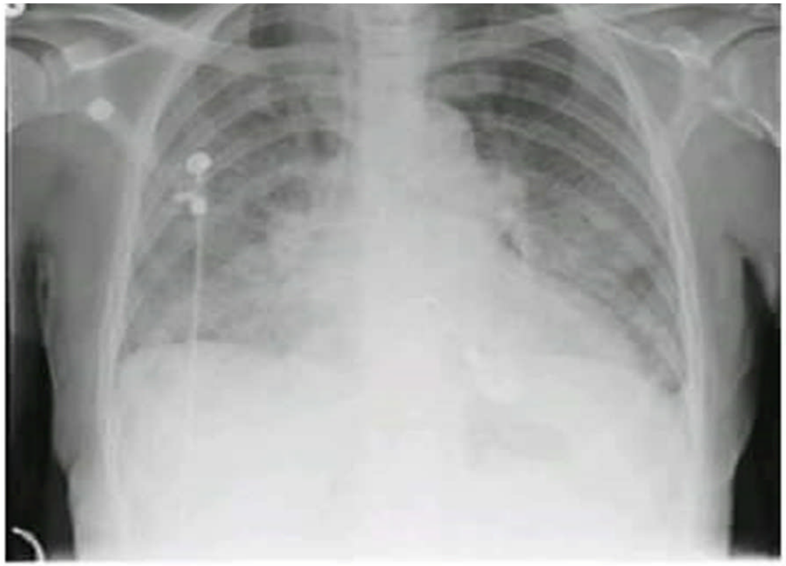
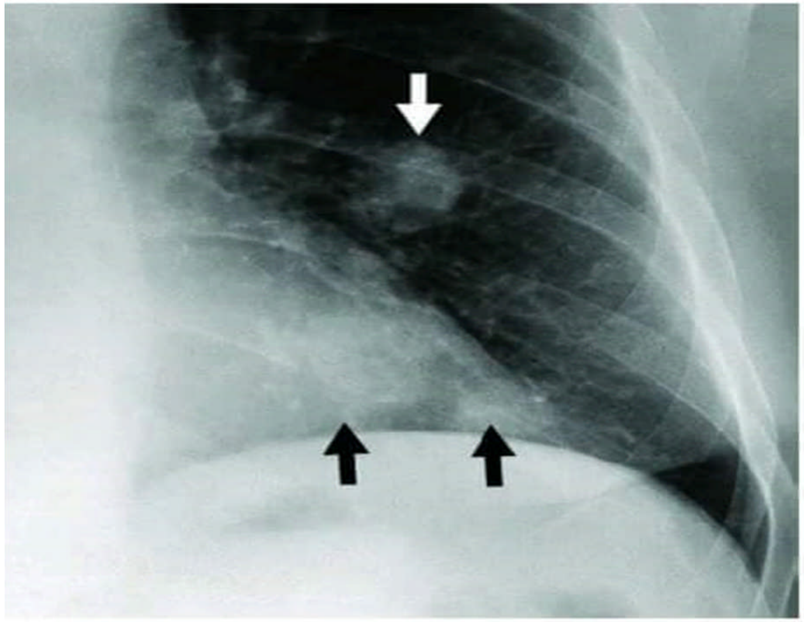


FIGURE 12.2 AIR SPACE CONSOLIDATION
Frontal chest radiograph demonstrating diffuse air space disease

Metastases



ig. 6.17 This is what typical metastases (arrows) look like: nultiple round nodules with relatively sharp margins sur-ounded by pulmonary parenchyma.

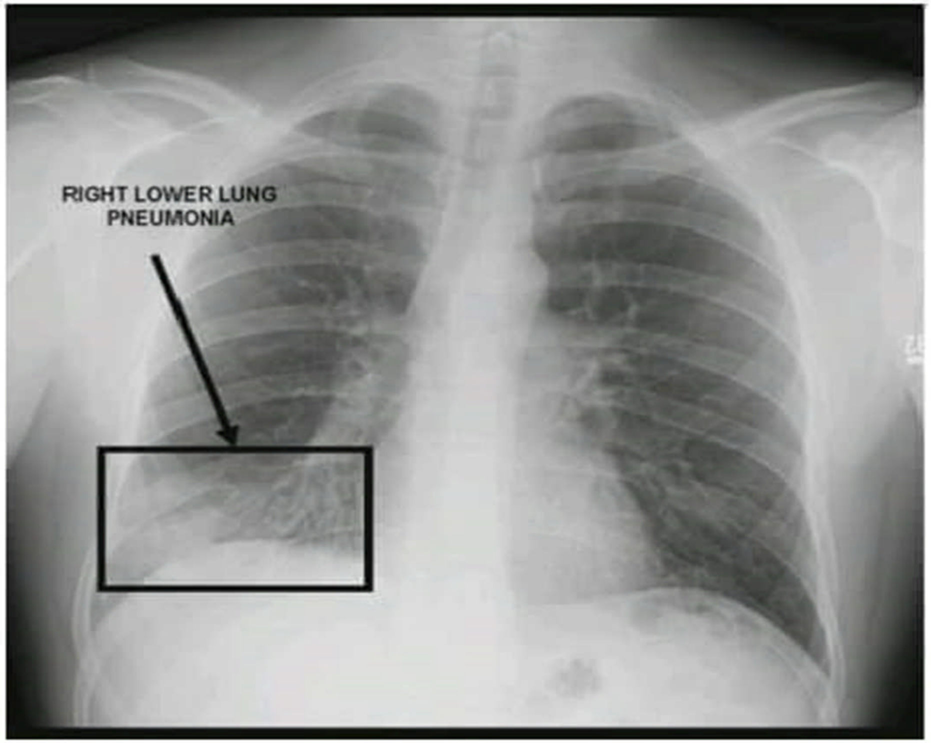


FIGURE 12.4 - PNEUMONIA Patchy airspace disease in the right lower lung consistent with pneumonia

Bronchial Carcinoma

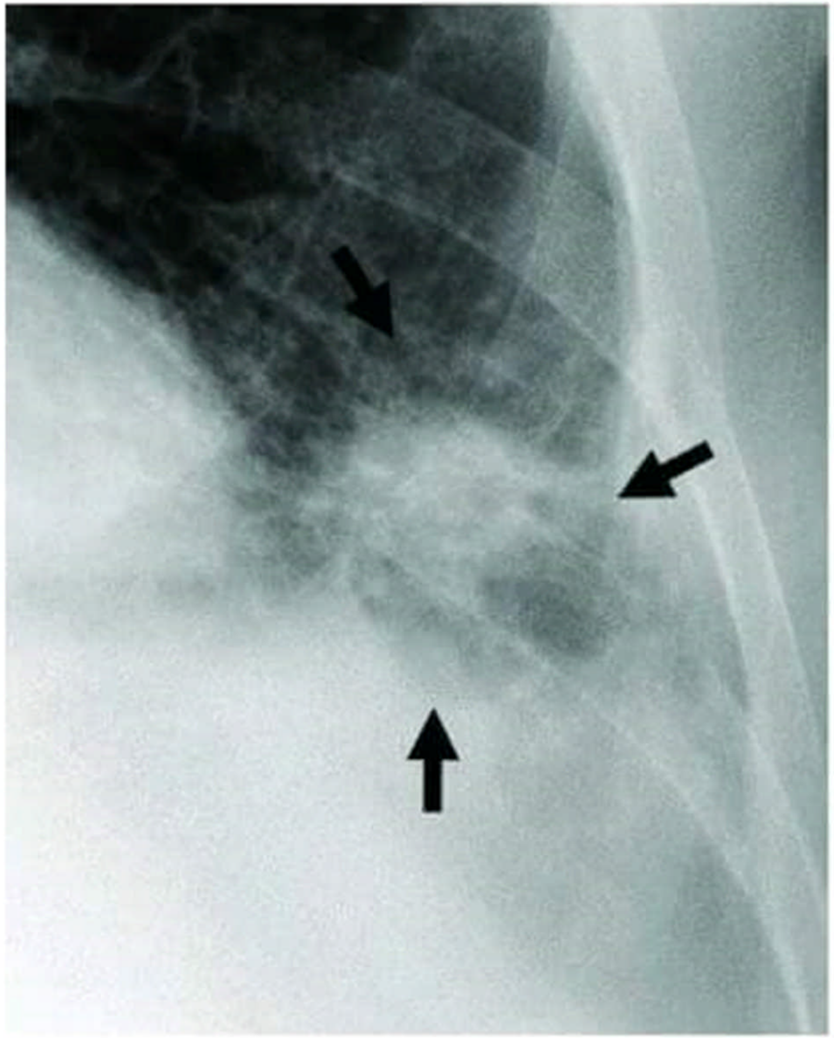


Fig. 6.**18** This bronchial carcinoma (arrows) has a spiculated border. The tumor invades and distorts the surrounding pulmonary parenchyma in the process (see also Fig. 6.**8a**).

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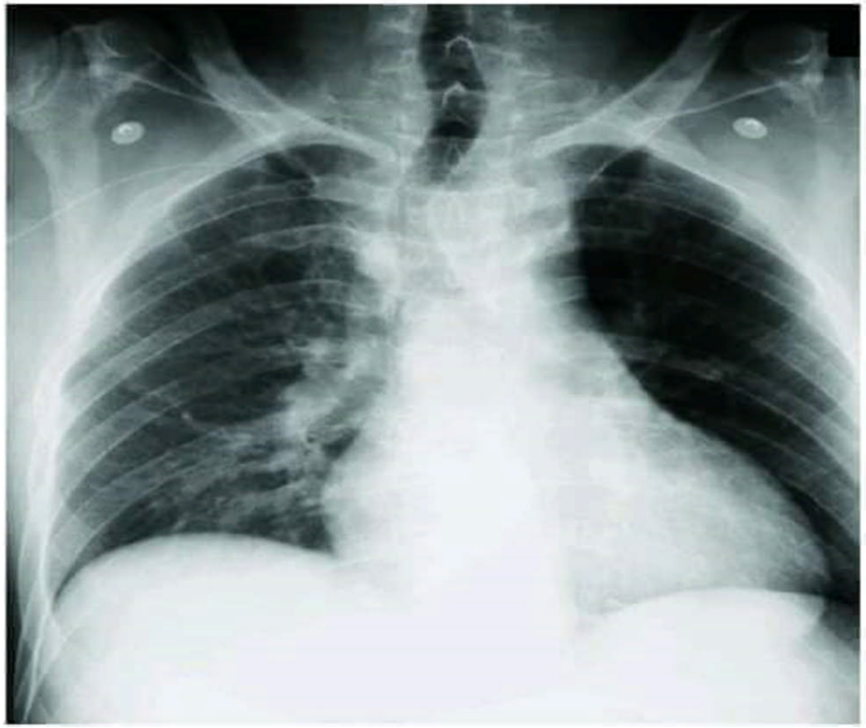
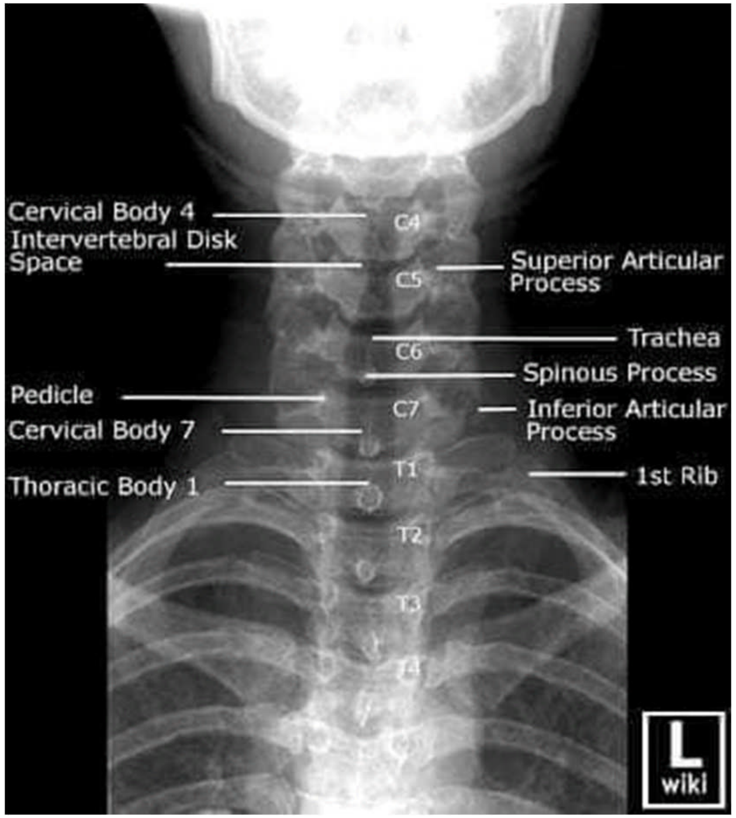
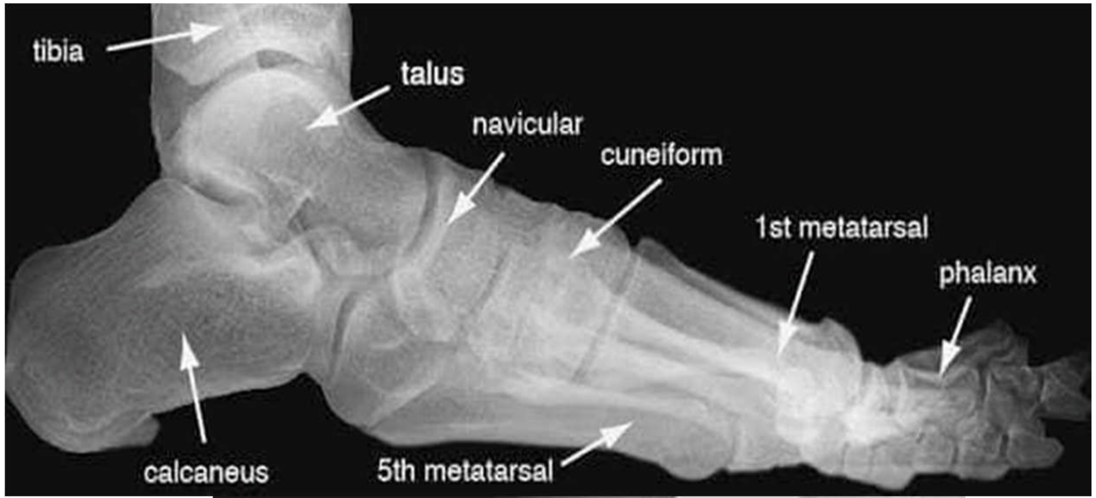
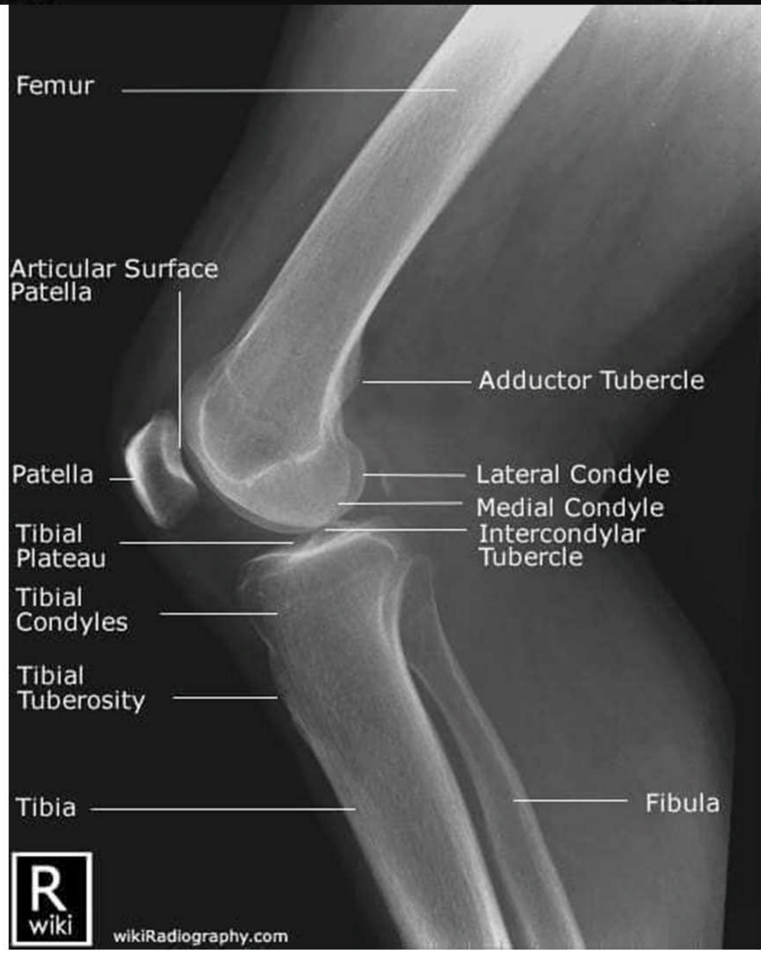
Metastases of Testicular Carcinoma

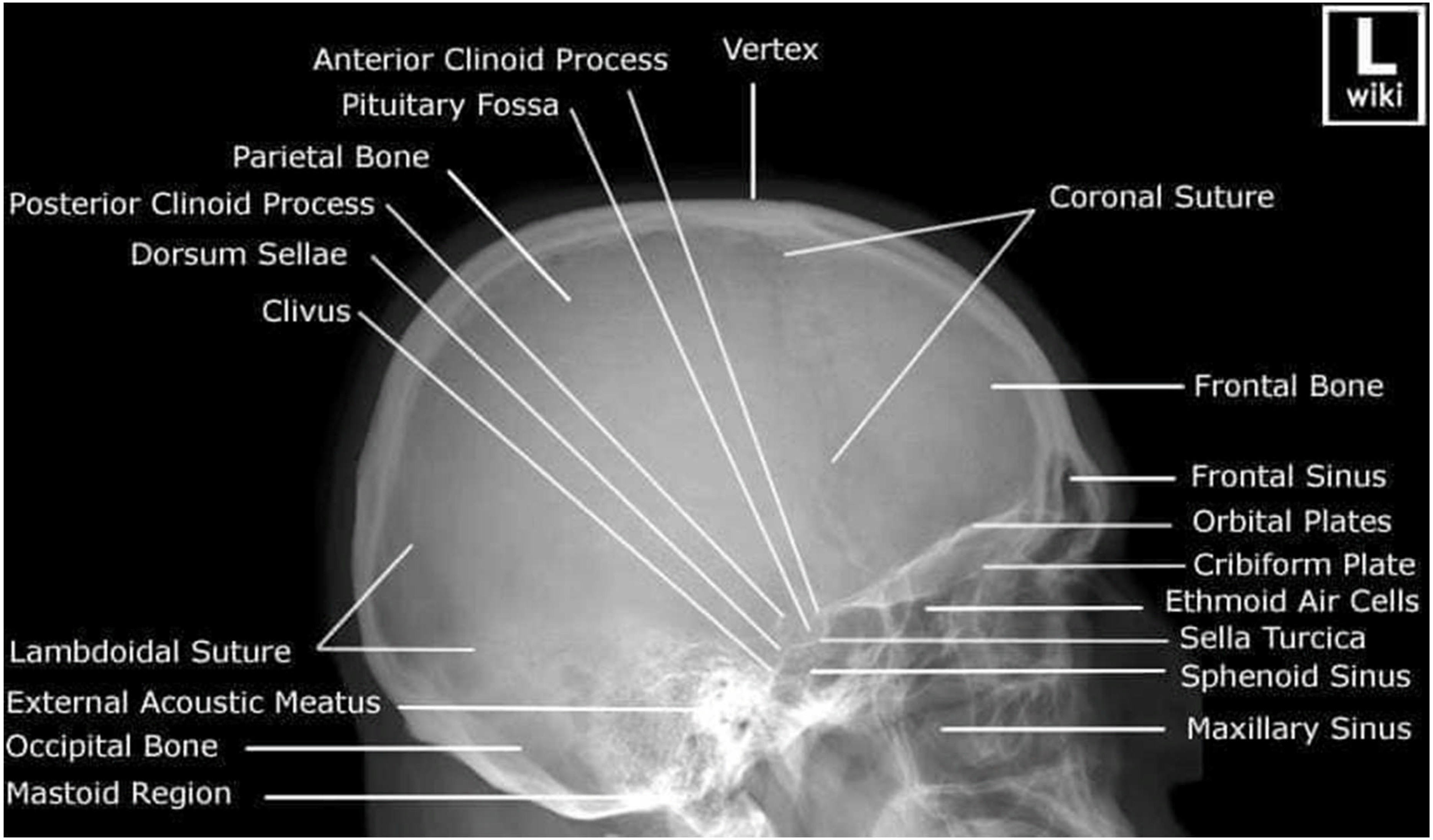
Hemothorax




Cervical Body 4
Intervertebral Disk Space
Superior Articular Process
Trachea
Spinous Process
Pedicle
Inferior Articular Process
Cervical Body 7
1st Rib
Thoracic Body 1
C4
C5
C6
C7
T1
T2
T3
T4
L wiki


tibia
talus
navicular
cuneiform
1st metatarsal
phalanx
calcaneus
5th metatarsal


Femur
Articular Surface Patella
Adductor Tubercle
Patella
Lateral Condyle
Medial Condyle
Intercondylar Tubercle
Tibial Plateau
Tibial Condyles
Tibial Tuberosity
Tibia
Fibula
R wiki
wikiRadiography.com


Anterior Clinoid Process
Vertex
L wiki
Pituitary Fossa
Parietal Bone
Posterior Clinoid Process
Coronal Suture
Dorsum Sellae
Clivus
Frontal Bone
Frontal Sinus
Orbital Plates
Cribiform Plate
Ethmoid Air Cells
Lambdoidal Suture
Sella Turcica
Sphenoid Sinus
External Acoustic Meatus
Maxillary Sinus
Occipital Bone
Mastoid Region

Endocardial cushion defect (ECD) is an abnormal heart condition. The walls separating all four chambers of the heart are poorly formed or absent. Also, the valves separating the upper and lower chambers of the heart have defects during formation. ECD is a congenital heart disease, which means it is present from birth.

Partial anomalous pulmonary venous return, sometimes called partial anomalous pulmonary venous connection, is a heart defect present at birth (congenital) in which some of the pulmonary veins carrying blood from the lungs to the heart flow into other blood vessels or into the heart's upper right chamber (right atrium), instead of correctly entering the heart's upper left chamber (left atrium). This causes some oxygen-rich blood from the lungs to mix with oxygen-poor blood before entering the right atrium.

Total anomalous pulmonary venous return (TAPVR) is a rare congenital malformation in which all four pulmonary veins do not connect normally to the left atrium. Instead the four pulmonary veins drain abnormally to the right atrium (right upper chamber) by way of an abnormal (anomalous) connection

Ebstein anomaly is a rare heart defect that's present at birth (congenital). In Ebstein anomaly, your tricuspid valve — the valve between the two right heart chambers (right atrium and right ventricle) — doesn't work properly. The tricuspid valve sits lower than normal in the right ventricle, and the tricuspid valve's leaflets are abnormally formed.

Diffuse interstitial (in-tur-STISH-ul) lung disease refers to a large group of lung disorders that affect the interstitium, which is the connective tissue that forms the support structure of the alveoli (air sacs) of the lungs. ... Treatment may depend on the underlying cause of the disease and your health status.

Air space opacification is a descriptive term that refers to filling of the pulmonary tree with material that attenuates x-rays more than the surrounding lung parenchyma. It is one of the many patterns of lung opacification and is equivalent to the pathological diagnosis of pulmonary consolidation.

Pyloric stenosis is a narrowing of the opening from the stomach to the first part of the small intestine (the pylorus). Symptoms include projectile vomiting without the presence of bile. This most often occurs after the baby is fed

Diffuse esophageal spasm (DES) is a condition characterized by uncoordinated contractions of the **esophagus**, which may cause difficulty swallowing (dysphagia) or regurgitation. In some cases, it may cause symptoms such as chest pain, similar to heart disease.