IMAGING PROCEDURES IN ONCOLOGY: RADIOLOGICAL DIAGNOSIS

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Medical imaging

- Medical imaging is the technique and process of imaging the interior of a body for clinical analysis and medical intervention, as well as visual representation of the function of some organs or tissues (physiology)
- Medical imaging seeks to reveal internal structures hidden by the skin and bones, as well as to diagnose and treat disease
- Medical imaging also establishes a database of normal anatomy and physiology to make it possible to identify abnormalities
- Although imaging of removed organs and tissues can be performed for medical reasons, such procedures are usually considered part of pathology instead of medical imaging

Medical imaging

- Medical imaging is often perceived to designate the set of techniques that noninvasively produce images of the internal aspect of the body
- In this restricted sense, medical imaging can be seen as the solution to mathematical inverse problems
- This means that cause (the properties of living tissue) is inferred from effect (the observed signal)
- In the case of medical ultrasound, the probe consists of ultrasonic pressure waves and echoes that go inside the tissue to show the internal structure
- In the case of projectional radiography, or computed tomography (CT), the tube uses X-ray radiation, which is absorbed at different rates by different tissue types such as bone, muscle, and fat

Medical imaging

- Devices that perform medical imaging
  - Radiography (projection radiography and fluoroscopy)
  - Ultrasound
  - Computed tomography
  - Magnetic resonance imaging
  - Gamma cameras
  - PET
  - SPECT

X-ray: what is this?

- X-rays are a form of electromagnetic energy formed when high-speed electrons bombard a tungsten anode target
- Like light energy, these useful rays have properties of waves and particles
- However, X-rays have a much shorter wavelength than visible light, allowing tham to penetrate matter
- Most X-rays have a wavelength ranging from 10 nanometers to 10 picometers

A historical view of x-rays

- In many languages, X-radiation is referred to as Röntgen radiation, after the German scientist Wilhelm Conrad Röntgen, who discovered it on November 8, 1895.
- He named it X-radiation to signify an unknown type of radiation
- Röntgen received the first Nobel Prize in Physics for his discovery

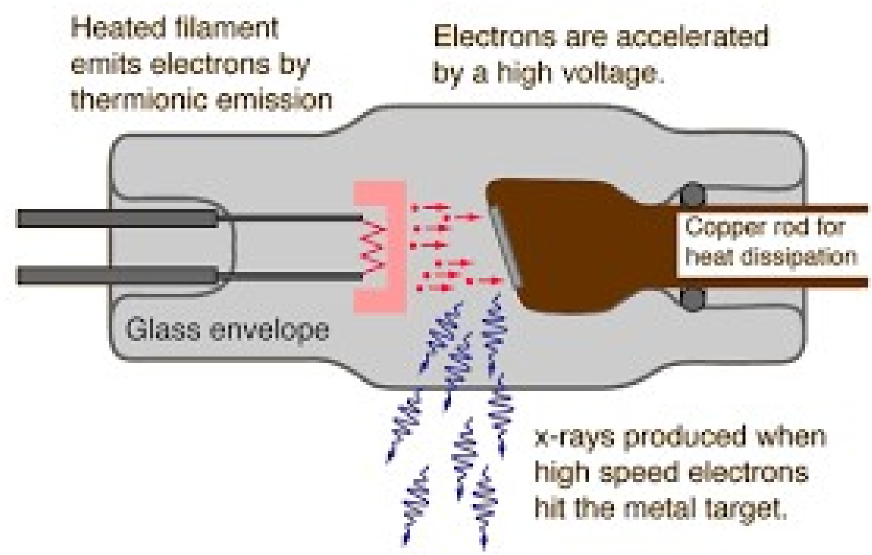
A historical view of x-rays

- The first tube with which Roentgen discovered X-rays

- Hand mit Ringen (Hand with Rings): print of Wilhelm Röntgen's first "medical" X-ray, of his wife's hand

X-ray tube

- An X-ray tube is a vacuum tube that converts electrical input power into X-rays
- The availability of this controllable source of X-rays created the field of radiography, the imaging of partly opaque objects with penetrating radiation
- In contrast to other sources of ionizing radiation, X-rays are only produced as long as the X-ray tube is energized

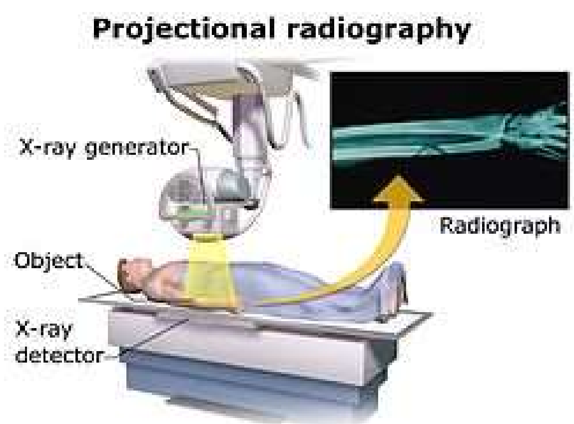


X-ray machine for radiography

- Projectional radiography, also known as conventional radiography, is a form of radiography and medical imaging that produces two-dimensional images by X-ray radiation
- The image acquisition is generally performed by radiographers, and the images are often examined by radiologists
- Both the procedure and any resultant images are often simply called 'X-ray'

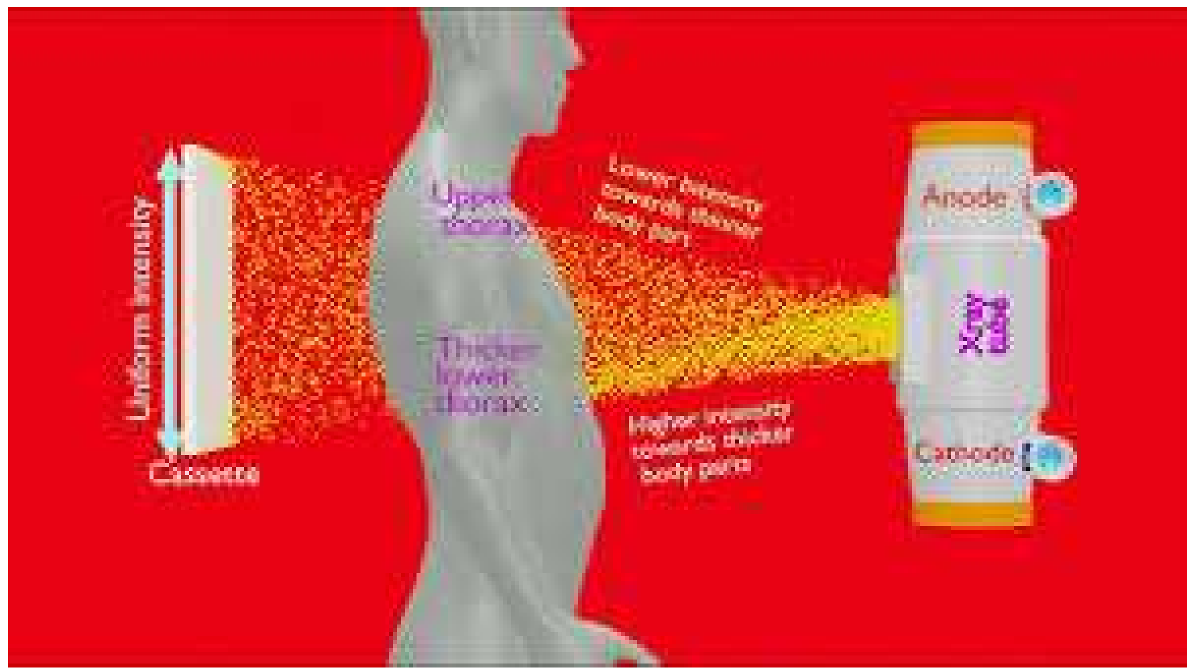
X-ray machine for radiography

- Plain radiography or roentgenography generally refers to projectional radiography (without the use of more advanced techniques such as computed tomography that can generate 3D-images)
- Plain radiography can also refer to radiography without a radiocontrast agent or radiography that generates single static images, as contrasted to fluoroscopy, which are technically also projectional



Basics of X-ray images, conical projection

- The definition of an X-ray image is:
  - X-ray image represents a conical projection of the body in one plane, whichit is created by the summation of the projection of all layers of the body through which the x-rays pass



Physiological contrasts on radiography

- The five basic radiographic densities:
  - Metal (Bright white)
  - Mineral (White)
  - Fluid/soft tissue (Gray)
  - Fat (Dark gray)
  - Air (Black)

Types of X-ray machines

- Classic X-ray machine for radiographs

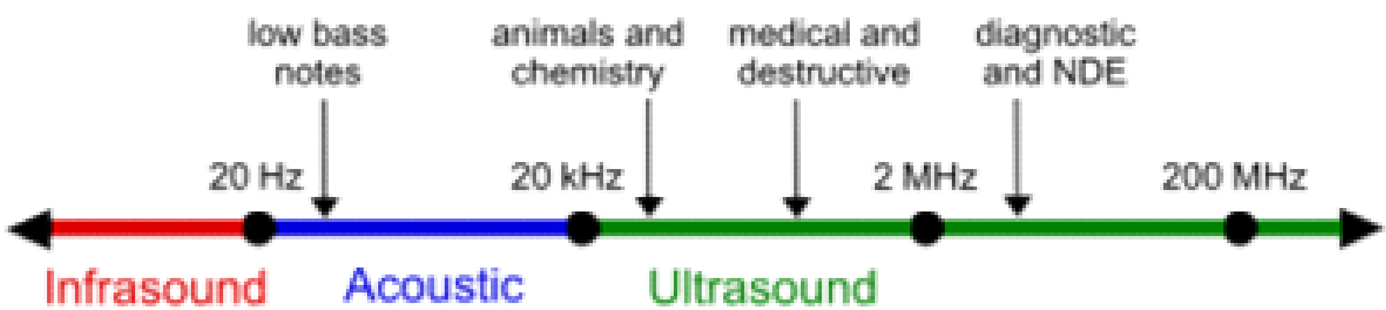
Types of X-ray machines

- Interventional X-ray machine

ULTRASONOGRAPHY (US)

Physical principles of ultrasound

- Ultrasound is sound with frequencies greater than 20 kilohertz
- This frequency is the approximate upper audible limit of human hearing in healthy young adults
- The physical principles of acoustic waves apply to any frequency range, including ultrasound
- Ultrasonic devices operate with frequencies from 2 MHz up to 30 Megahertz



Ultrasound

- Medical ultrasound is an ultrasound-based diagnostic medical imaging technique used to visualize muscles, tendons, and many internal organs to capture their size, structure and any pathological lesions with real time tomographic images
- Ultrasound has been used by radiologists and sonographers to image the human body for at least 70 years and has become a widely used diagnostic tool
- The technology is relatively inexpensive and portable, especially when compared with other techniques, such as magnetic resonance imaging (MRI) and computed tomography (CT)

Ultrasound

- Ultrasound is also used to visualize fetuses during routine and emergency prenatal care
- As currently applied in the medical field, properly performed ultrasound poses no known risks to the patient
- Sonography does not use ionizing radiation, and the power levels used for imaging are too low to cause adverse heating or pressure effects in tissue
- Although the long-term effects due to ultrasound exposure at diagnostic intensity are still unknown, currently most doctors feel that the benefits to patients outweigh the risks

Properties of ultrasonic waves

- Ultrasonic waves have two essential properties: speed and frequency
- They have smaller wavelengths
- As a result, their penetrating power is high
- The relationship between speed, frequency and wavelength is as follows:
  - speed = frequency x wavelengths
- Ultrasonic waves cannot travel through vacuum (the x-ray propagates through the vacuum)

Properties of ultrasonic waves

- Ultrasonic waves travel at the speed of sound in the medium
- The speed of ultrasonic waves depends on the density of the medium
- They have maximum velocity in a denser medium
- In a homogeneous medium, ultrasonic waves travel at a constant velocity
- In low viscosity liquids, ultrasonic waves produce vibrations

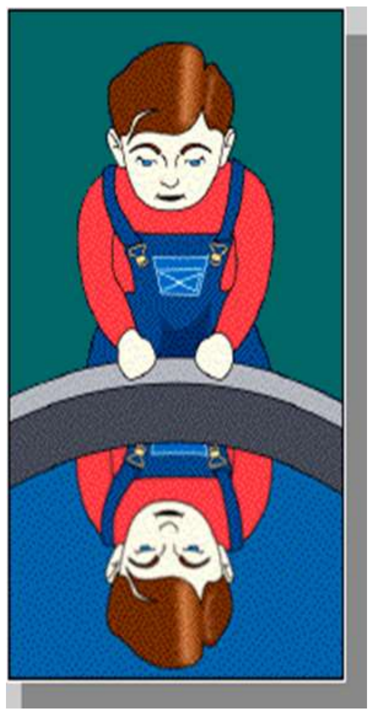
Properties of ultrasonic waves

- The higher frequency and shorter wavelength of ultrasound waves results in better spatial resolution
- Increasing the frequency affects:
  - increase in resolution - better visibility of smaller objects
  - reduction of penetration - lower penetration depth
  - better directivity (collimation) of waves
- Lower frequency → greater penetration (examination of deeper tissues)
- Higher frequency → less penetration but better differentiation of details (examination of superficial organs)

Properties of ultrasonic waves - *attenuation*

- Attenuation is the process of weakening ultrasound waves
- Ultrasound waves undergo reflection, refraction, dispersion and absorption

Reflection



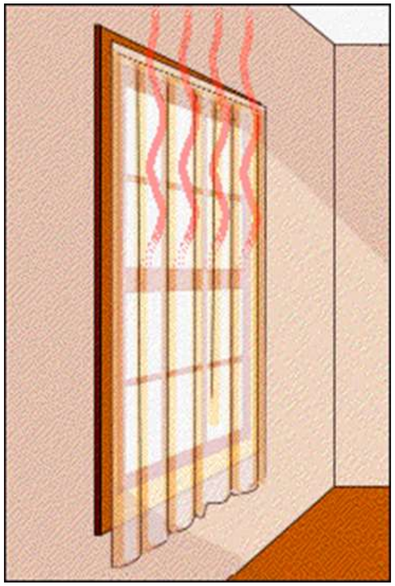
Properties of ultrasonic waves - *attenuation*

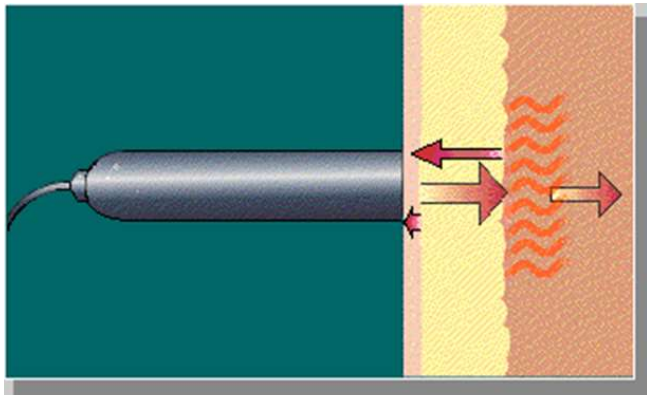
dispersion

refraction

Properties of ultrasonic waves - *attenuation*

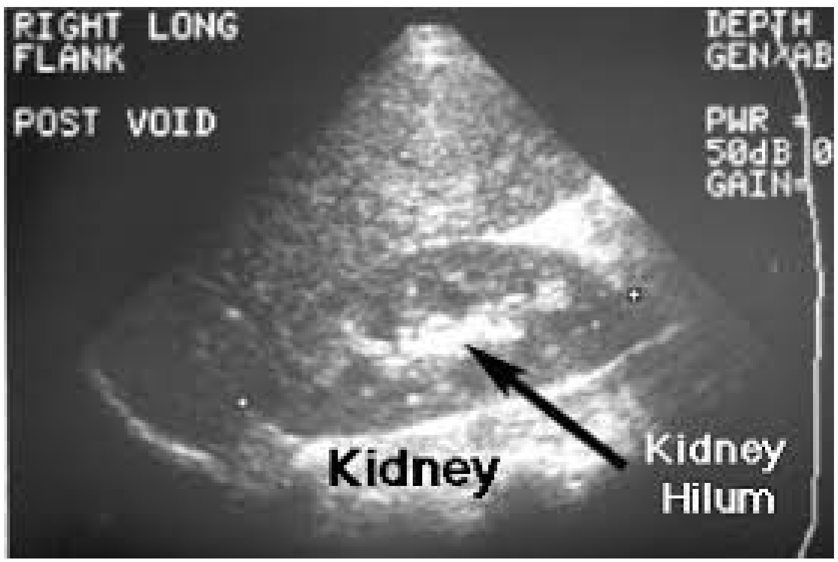
- Absorption represents the conversion of a part of the energy of ultrasound waves into heat



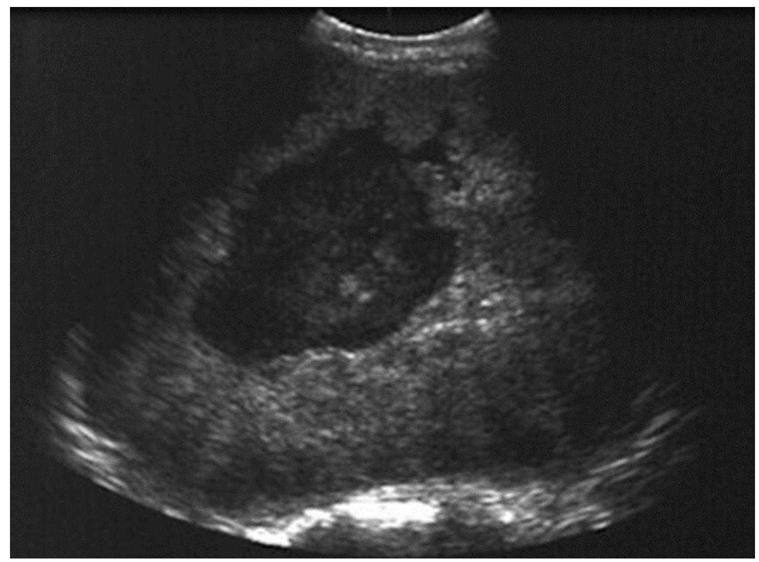


Ultrasound

right kidney

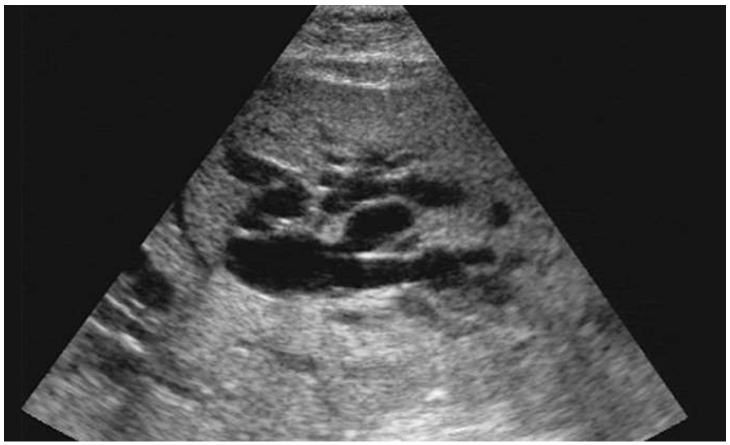


liver cancer

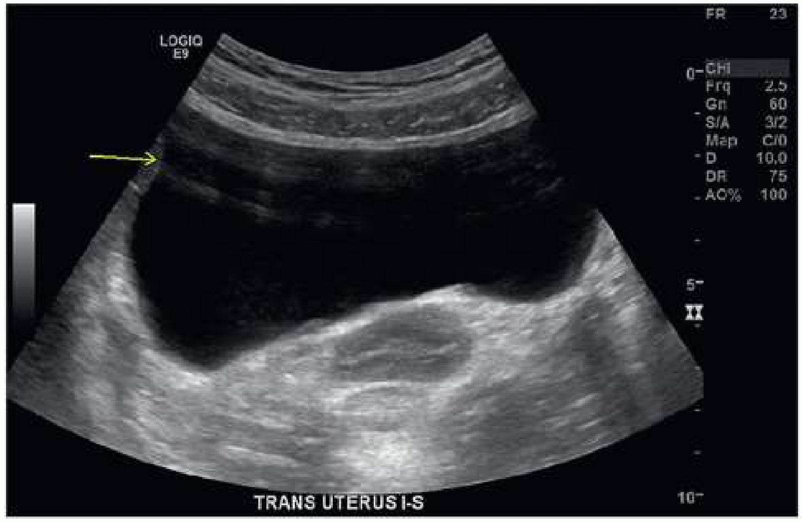


Ultrasound

pancreatic cancer

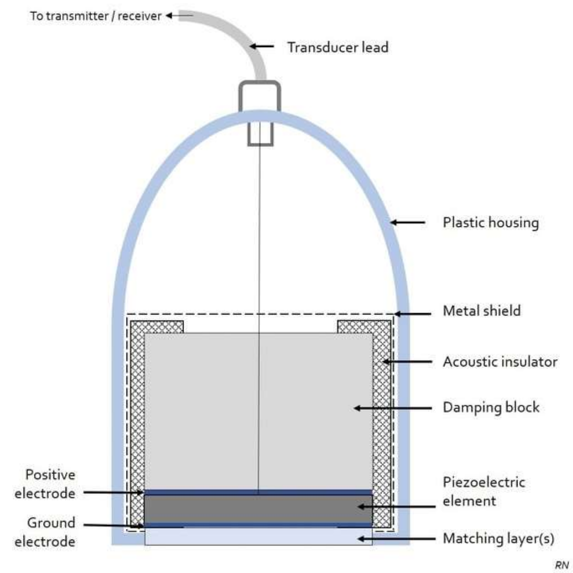


bladder



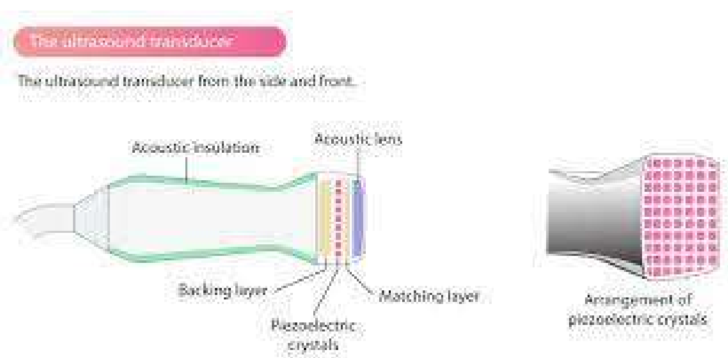
Ultrasound transducer

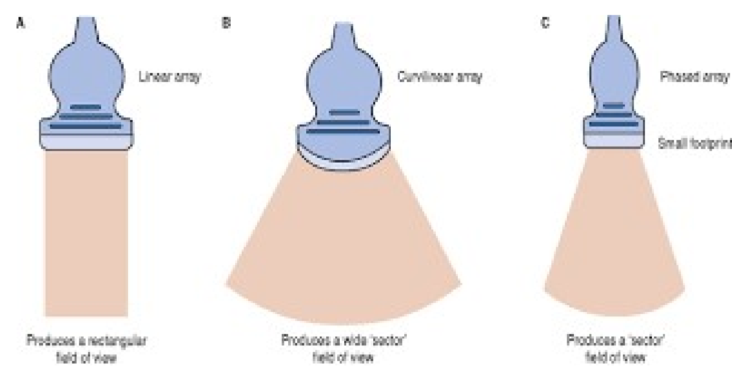
- An **ultrasound transducer** converts electrical energy into mechanical (sound) energy and back again, based on the piezoelectric effect
- It is the hand-held part of the ultrasound machine that is responsible for the production and detection of ultrasound waves



Ultrasound

- Ultrasound waves are produced by a transducer, which can both emit ultrasound waves, as well as detect the ultrasound echoes reflected back
- In most cases, the active elements in ultrasound transducers are made of special ceramic crystal materials called piezoelectrics
- These materials are able to produce sound waves when an electric field is applied to them, but can also work in reverse, producing an electric field when a sound wave hits them





COMPUTED TOMOGRAPHY (CT)

History of CT

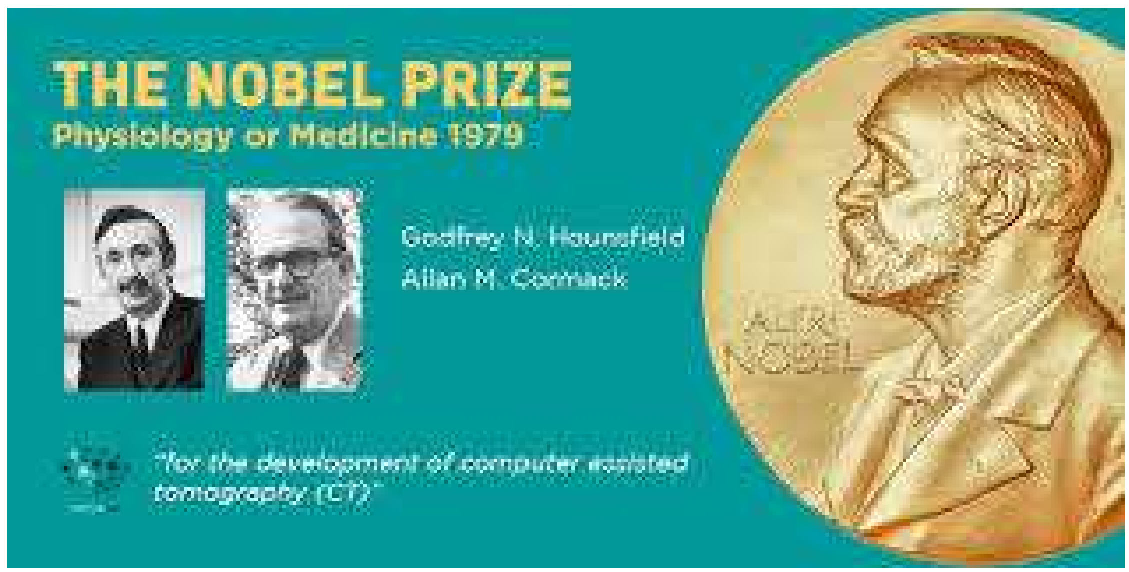
- Half a century has passed since the discovery of computerized tomography (CT-Computerized Tomography), the greatest advance in diagnostic radiology after Roentgen's discovery of X-rays at the end of the 19th century
- It is based on X-ray radiation, and is a radiological diagnostic modality that involves computer reconstruction of the cross-section of the body based on multiple measurements of the degree of attenuation (weakening) of directed X-rays
- Another essential component of CT is tomography, which requires a mathematical procedure for image processing with the help of computers and software in them

History of CT

- The cross-sections that are obtained as a result of the examination are a computer-processed projection of part of the patient's body, which can be processed in various ways with further software procedures, so reconstructions in other planes are also obtained
- Credit for the discovery of CT goes to Godfrey Hounsfield (1919-2004), an English electrical engineer, and Allan Cormack (1924-1998), a South African physicist
- In 1979 Hounsfield and Cormack were awarded the Nobel Prize in Medicine and Physiology for the discovery of computed tomography

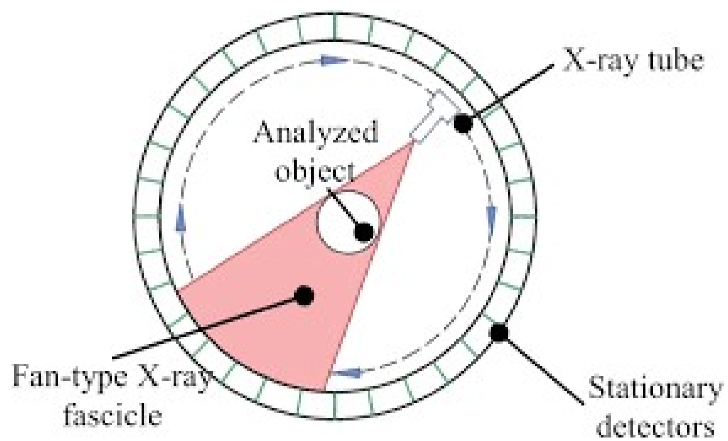
History of CT

- The research lasted in the period 1967.-1971.
- In London, the first examination was carried out in 1971.
- The first clinical research was done by neuroradiologist James Ambrose at the Mayo Clinic, USA



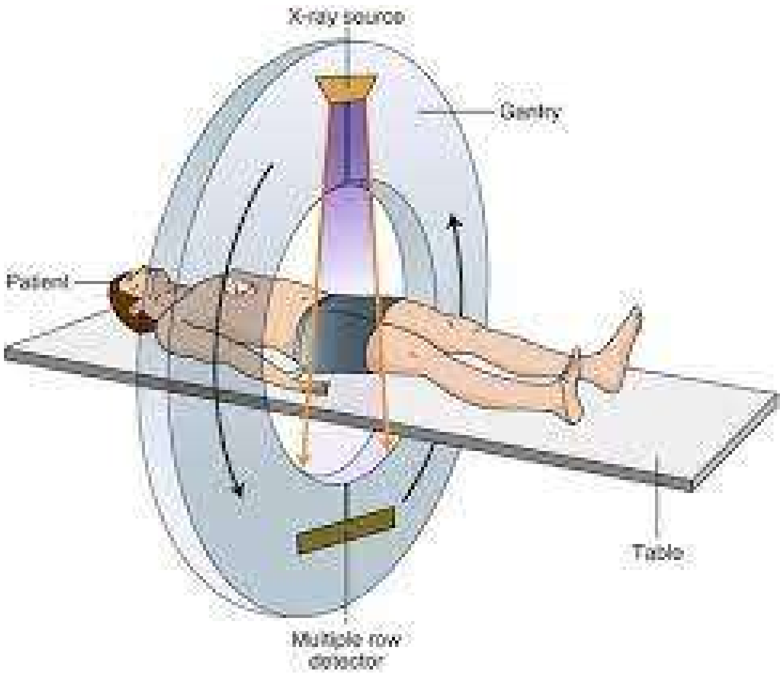
Principles of work of CT

- X-ray beam is passed at a cross section through a patients body
- This eliminates superimposition
- The beam is finely collimated this reduces scatter and gives better contrast resolution
- The collimated beam pass through the body, the body tissue absorbs the beam



Principles of work of CT

- The beam exits the body and strikes the detectors
- The detectors are quantitative and distinguish differences in tissue contrast
- Detector converts photons to an analog signal
- The ADC converts it to digital signal
- Digital data is sent to CPU for reconstruction

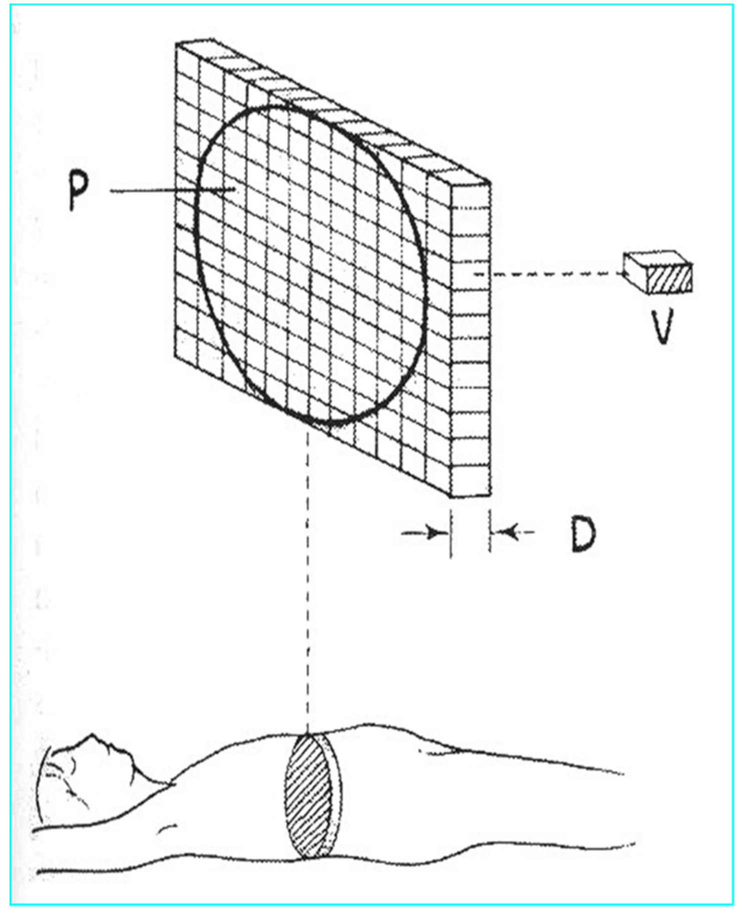


Principles of work of CT

- CT enables the creation of images of transverse sections transverse to the longitudinal axis of the body using a collimated X-ray beam, which, passing through the object, is weakened due to absorption, and the intensity of the remaining part of the signal is registered by special detectors
- The X-ray tube and detectors rotate synchronously around the object, in one plane
- The absorption of X-rays depends on the atomic composition and density of individual tissues, as well as on the energy of X-ray radiation

Image analysis

- *P - Pixel (picture element)*
  The smallest unit of a CT image.
  Cross-sectional segment of the body
- *V – Voxel*
  Three-dimensional pixel - volume element
- *D* – Layer thickness

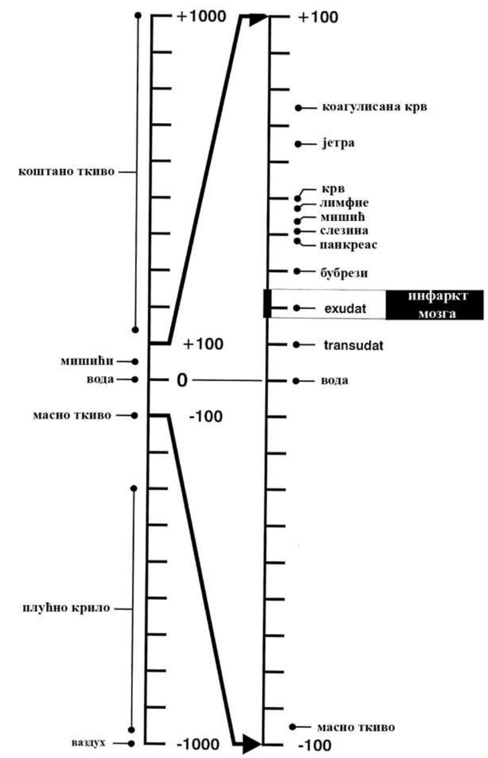


Hounsfield scale

- The Hounsfield scale, named after Sir Godfrey Hounsfield, is a quantitative scale for describing radiodensity
- It is frequently used in CT scans, where its value is also termed CT number
- The Hounsfield unit (HU) scale is a linear transformation of the original linear attenuation coefficient measurement into one in which the radiodensity of distilled water at standard pressure and temperature (STP) is defined as 0 Hounsfield units (HU), while the radiodensity of air at STP is defined as −1000 HU

Hounsfield scale

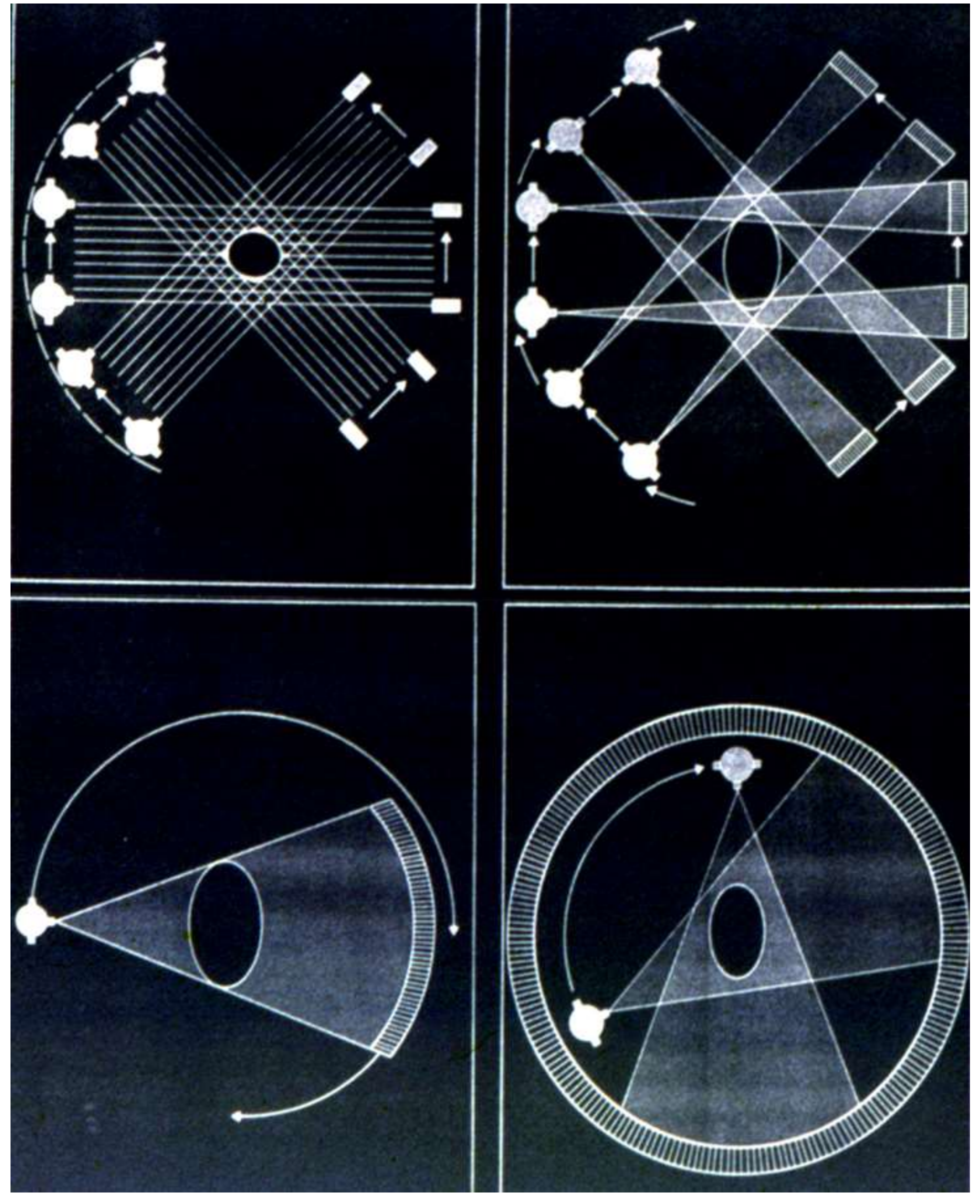
- On the tomogram (CT section of the body) shown in gray scale, the attenuation (density) values of the tissue are measured
- Density:
  - Air -1000 HU
  - Fat -120 to -90 HU
  - Distilled water 0 HU
  - Subdural hematoma +75 to +100 HU
  - Bone +300 to +1000 HU



Generations of CT machines

- **Sequential CT** also known as step-and-shoot CT, or **axial CT** is a type of scanning method in which the CT table moves stepwise
- The table increments to a particular location and then stops which is followed by the X-ray tube rotation and acquisition of a slice
- Then the table increments again and another slice is taken
- The table has to make a stop in taking slices
- This results in an increased time of scanning

Seqential CT



Generations of CT machines

- **Helical CT** (simultaneously with the rotation of the tube-detector system, the table for the patient moves as well)
- Spinning tube, commonly called spiral CT, or helical CT, is an imaging technique in which an entire X-ray tube is spun around the central axis of the area being scanned
- The main limitation of this type of CT is the bulk and inertia of the equipment (X-ray tube assembly and detector array on the opposite side of the circle) which limits the speed at which the equipment can spin

Generations of CT machines

- Multidetector row CT (**MDCT**) is the newer advancement in CT technology
- The use of multiple detector rows allows faster scanning and thinner collimation
- These improvements allow routine scans to be performed faster
- MDCT enables CT angiography or virtual endoscopy

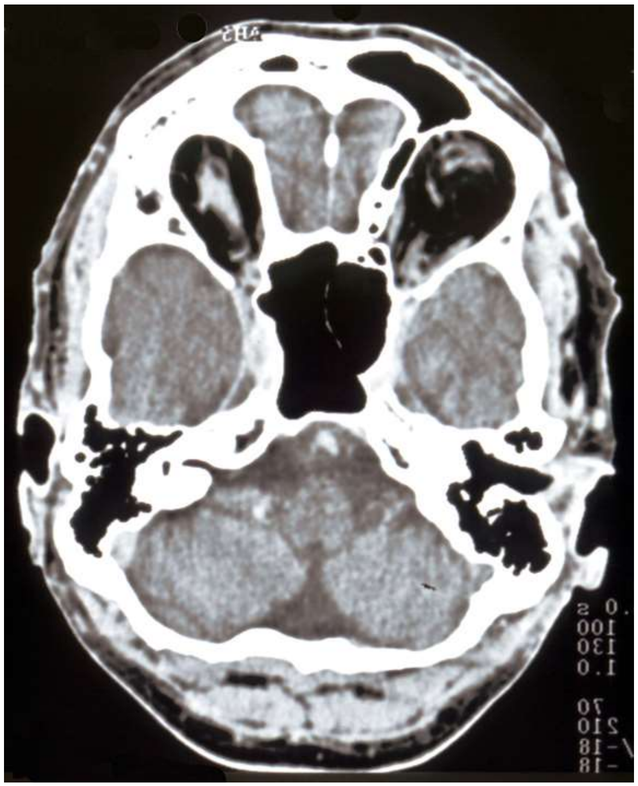
Image reconstructions

- Possibility of better topographical orientation
- Multiplanar reconstructions (axial, sagital, coronal)
- 3D (three-dimensional reconstruction)
- MIP (maximum intensity projection)

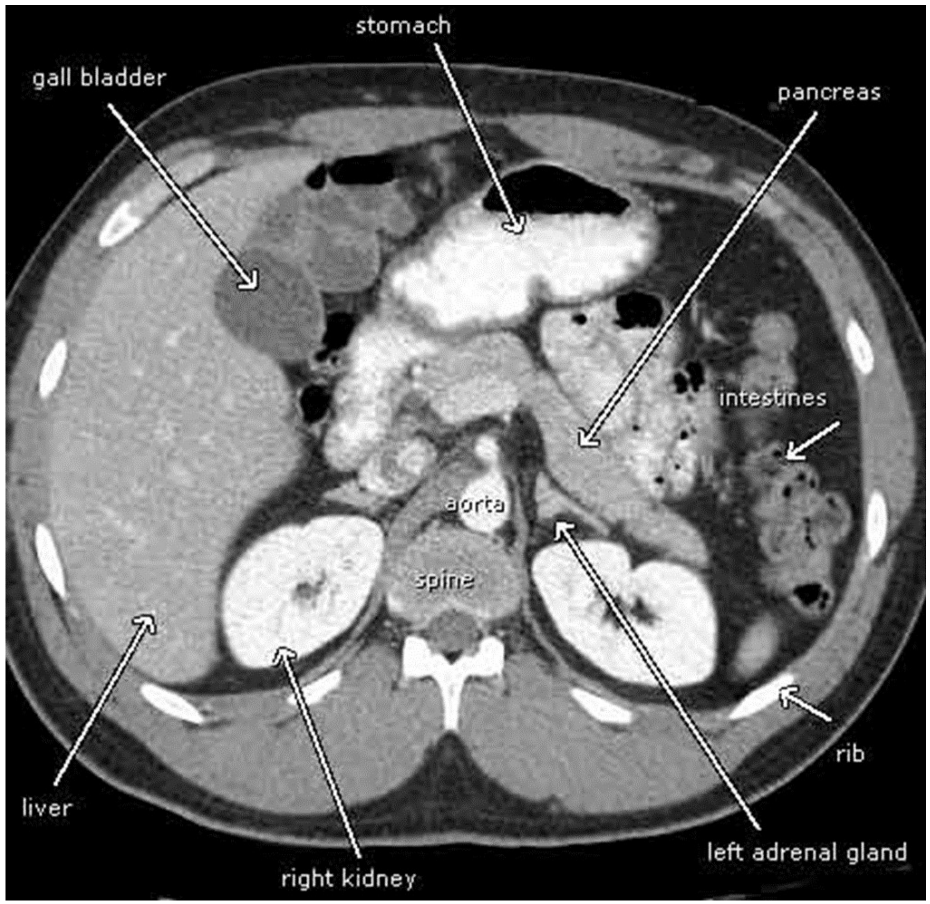
Contrast CT

- Contrast CT, or contrast enhanced computed tomography (CECT), is X-ray computed tomography (CT) using radiocontrast
- Radiocontrasts for X-ray CT are generally iodine-based types
- This is useful to highlight structures such as blood vessels that otherwise would be difficult to delineate from their surroundings
- Using contrast material can also help to obtain functional information about tissues
- Often, images are taken both with and without radiocontrast

CT of the brain



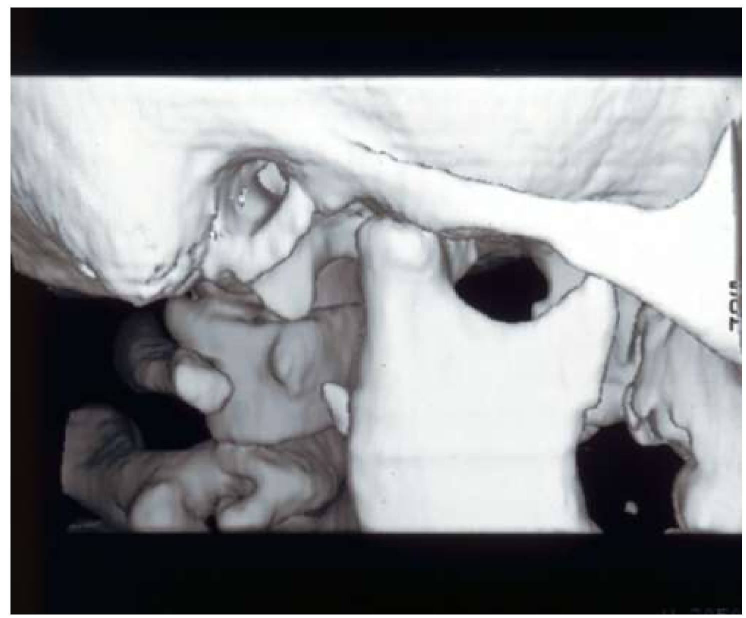
CT of the abdomen



3D reconstuction

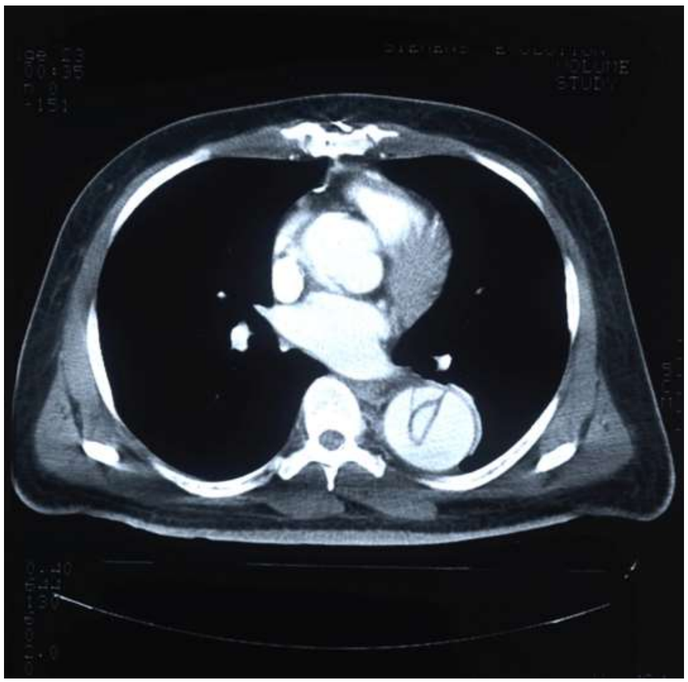
pelvis

temporomandibular joint

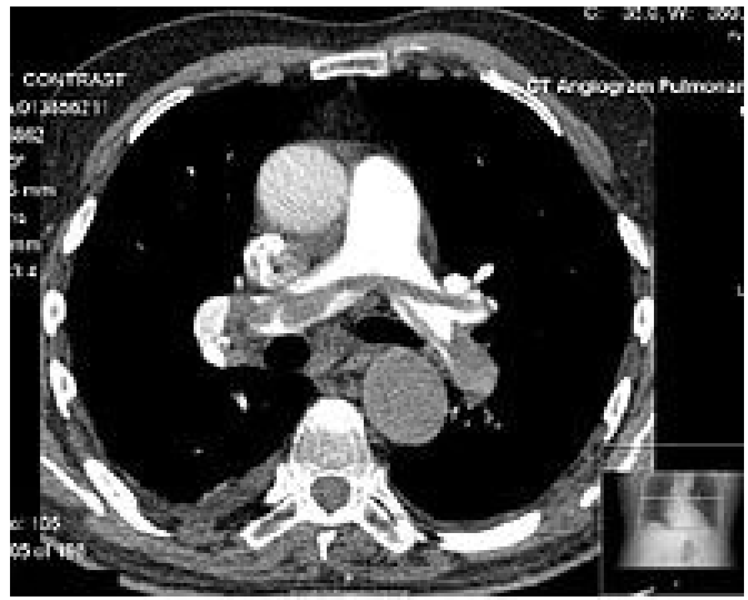


CECT

aorta



pulmonary artery



MAGNETIC RESONANCE IMAGING (MRI)

MRI

- Magnetic resonance imaging (MRI) is a medical imaging technique used in radiology to form pictures of the anatomy and the physiological processes of the body
- MRI scanners use strong magnetic fields, magnetic field gradients, and radio waves to generate images of the organs in the body
- MRI does not involve X-rays or the use of ionizing radiation, which distinguishes it from computed tomography (CT) and positron emission tomography (PET) scans
- MRI is a medical application of nuclear magnetic resonance (NMR) which can also be used for imaging in other NMR applications, such as NMR spectroscopy

MRI

- MRI is widely used in hospitals and clinics for medical diagnosis, staging and follow-up of disease
- Compared to CT, MRI provides better contrast in images of soft tissues, e.g. in the brain or abdomen
- However, it may be perceived as less comfortable by patients, due to the usually longer and louder measurements with the subject in a long, confining tube, though "Open" MRI designs mostly relieve this
- Additionally, implants and other non-removable metal in the body can pose a risk and may exclude some patients from undergoing an MRI examination safely

History of MRI

- Since its development in the 1970s and 1980s, MRI has proven to be a versatile imaging technique
- The phenomenon of magnetic resonance was discovered in 1939. – Rabi
- MR imaging was invented by Paul C. Lauterbur who developed a mechanism to encode spatial information into an NMR signal using magnetic field gradients in September 1971
- Peter Mansfield further refined the techniques used in MR image acquisition and processing

History of MRI

- The first image of a section of human tissue was obtained in 1977. – Damadian
- In 2003 Lauterbur and Mansfield were awarded the Nobel Prize in Physiology or Medicine for their contributions to the development of MRI
- The first clinical MRI scanners were installed in the early 1980s and significant development of the technology followed in the decades since, leading to its widespread use in medicine today

Basics of MRI

- MRI was originally called NMRI (nuclear magnetic resonance imaging), but "nuclear" was dropped to avoid negative associations
- Certain atomic nuclei are able to absorb radio frequency (RF) energy when placed in an external magnetic field
- The resultant evolving spin polarization can induce a RF signal in a radio frequency coil and thereby be detected

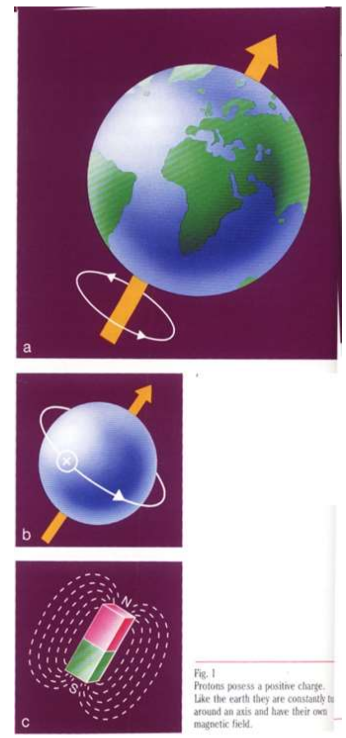
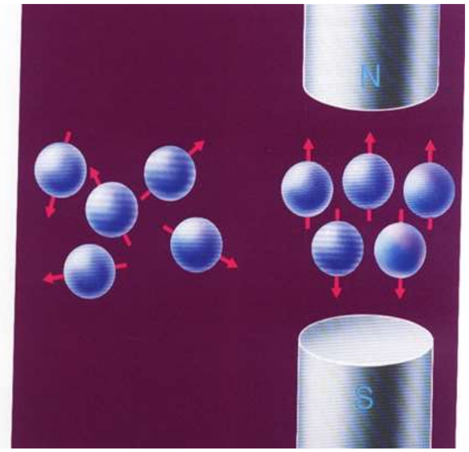


Fig. 1
Protons posess a positive charge. Like the earth they are constantly tu around an axis and have their own magnetic field.

Basics of MRI

- In a strong magnetic field, protons are oriented parallel or antiparallel to the external field
- lines of force of the magnetic field in the coordinate system (X, Y and Z axis)



2
mally protons are aligned in a random ion. This, however, changes when are exposed to a strong external netic field. Then they are aligned in two ways, either parallel or anti- llel to the external magnetic field.

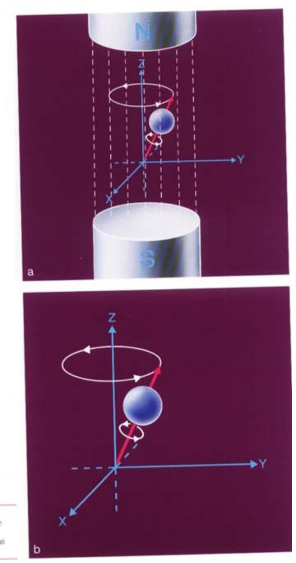
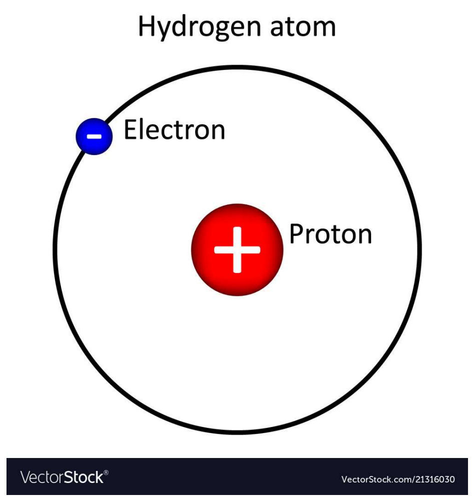


Fig. 5
Using a coordinate system makes the description of proton motion in the magnetic field easier, and also we can stop drawing the external magnet.

Basics of MRI

- In clinical and research MRI, hydrogen atoms are most often used to generate a macroscopic polarization that is detected by antennas close to the subject being examined
- Hydrogen atoms are naturally abundant in humans and other biological organisms, particularly in water and fat
- For this reason, most MRI scans essentially map the location of water and fat in the body



Basics of MRI

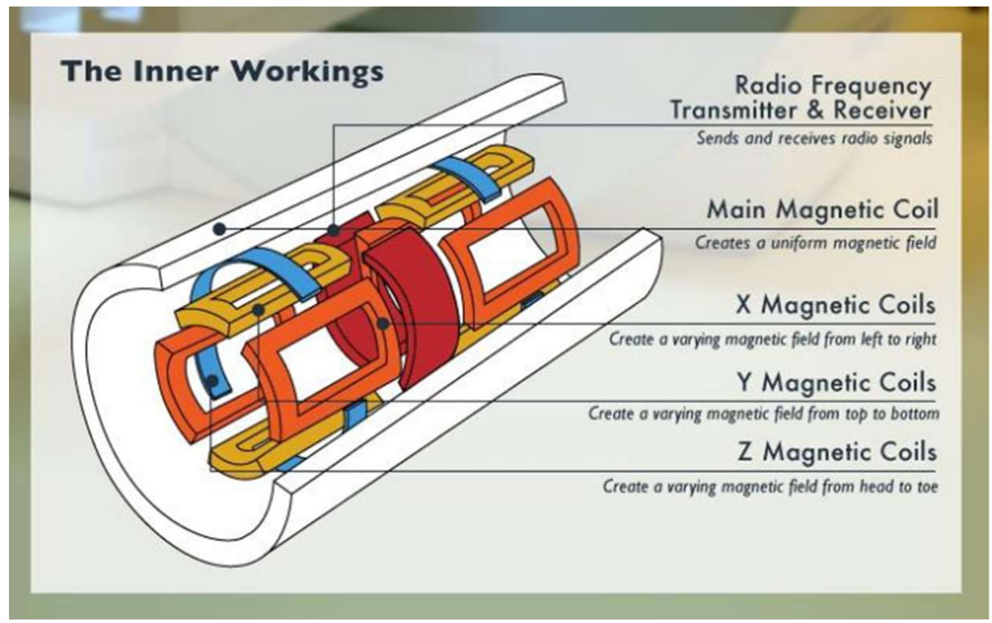
- Pulses of radio waves excite the nuclear spin energy transition, and magnetic field gradients localize the polarization in space
- By varying the parameters of the pulse sequence, different contrasts may be generated between tissues based on the relaxation properties of the hydrogen atoms therein
- This is how we arrive at the selection of numerous sequences in which the examination of the patient can be performed

Basics of MRI

- In most medical applications, hydrogen nuclei, which consist solely of a proton, that are in tissues create a signal that is processed to form an image of the body in terms of the density of those nuclei in a specific region
- Given that the protons are affected by fields from other atoms to which they are bonded, it is possible to separate responses from hydrogen in specific compounds

Basics of MRI

- To perform a study, the person is positioned within an MRI scanner that forms a strong magnetic field around the area to be imaged
- First, energy from an oscillating magnetic field is temporarily applied to the patient at the appropriate resonance frequency
- Scanning with X and Y gradient coils causes a selected region of the patient to experience the exact magnetic field required for the energy to be absorbed



Basics of MRI

- The atoms are excited by a RF pulse and the resultant signal is measured by a receiving coil
- The RF signal may be processed to deduce position information by looking at the changes in RF level and phase caused by varying the local magnetic field using gradient coils
- The contrast between different tissues is determined by the rate at which excited atoms return to the equilibrium state
- Exogenous contrast agents may be given to the person to make the image clearer

T1 and T2

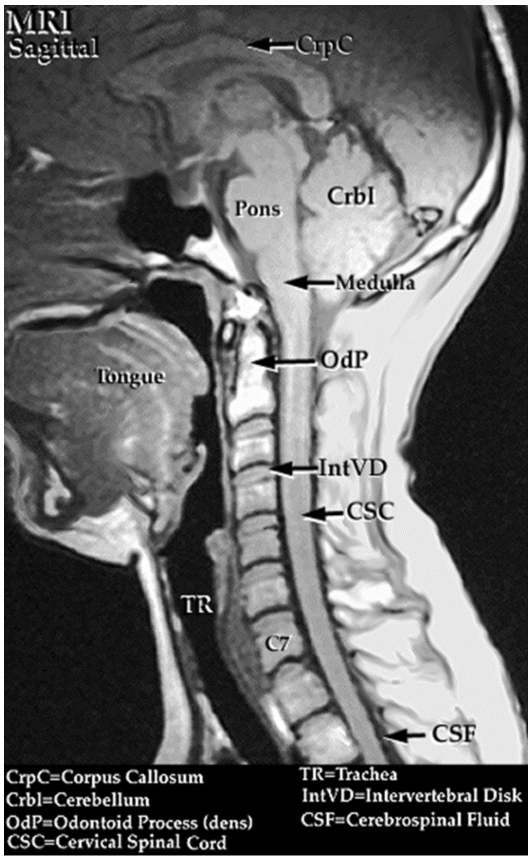
- In a strong magnetic field, a new magnetic vector is established in the patient's body, the RF pulse creates transverse magnetization, and the longitudinal magnetization decreases
- Each tissue returns to its equilibrium state after excitation by the independent relaxation processes of T1 (spin-lattice; that is, magnetization in the same direction as the static magnetic field) and T2 (spin-spin; transverse to the static magnetic field)
- To create a T1-weighted image, magnetization is allowed to recover before measuring the MR signal by changing the repetition time (TR)

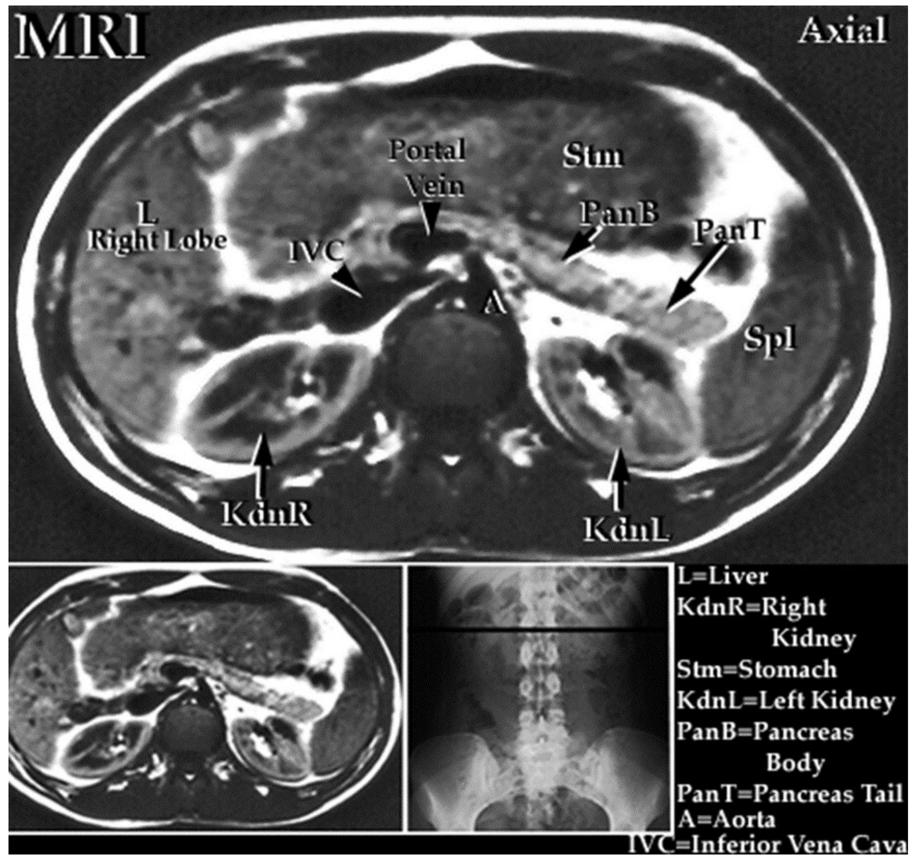
T1 and T2

- This image weighting is useful for assessing the cerebral cortex, identifying fatty tissue, characterizing focal liver lesions, and in general, obtaining morphological information, as well as for post-contrast imaging
- To create a T2-weighted image, magnetization is allowed to decay before measuring the MR signal by changing the echo time (TE)
- This image weighting is useful for detecting edema and inflammation, revealing white matter lesions, and assessing zonal anatomy in the prostate and uterus

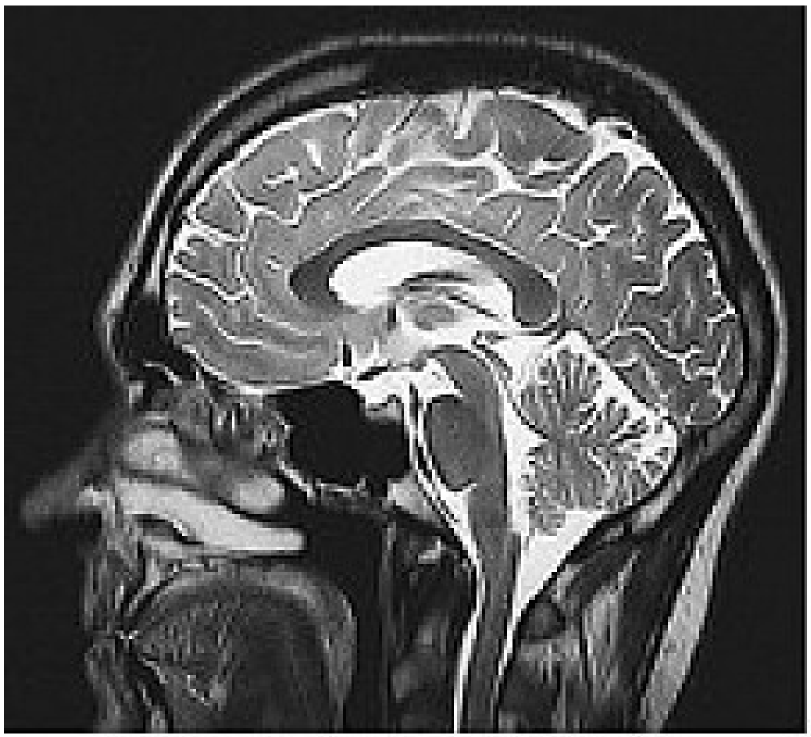
MRI today

MRI today


MRI
Sagittal
CrpC
Pons
Crbl
Medulla
Tongue
OdP
IntVD
CSC
TR
C7
CSF
CrpC=Corpus Callosum
Crbl=Cerebellum
OdP=Odontoid Process (dens)
CSC=Cervical Spinal Cord
TR=Trachea
IntVD=Intervertebral Disk
CSF=Cerebrospinal Fluid


MRI
Axial
Portal Vein
Stm
L
Right Lobe
IVC
PanB
PanT
A
Spl
KdnR
KdnL
L=Liver
KdnR=Right Kidney
Stm=Stomach
KdnL=Left Kidney
PanB=Pancreas Body
PanT=Pancreas Tail
A=Aorta
IVC=Inferior Vena Cava

MRI today



MRI scan of brain

MRI scan of knee

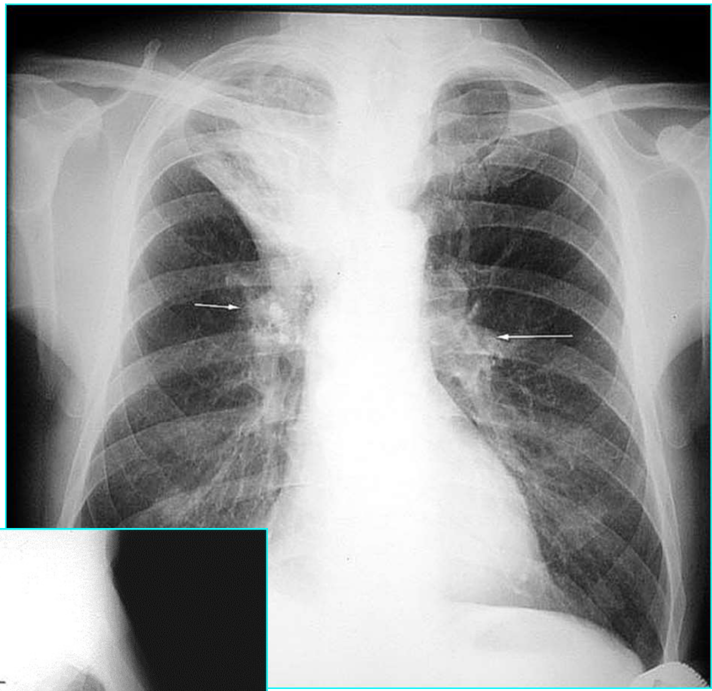
MRI today

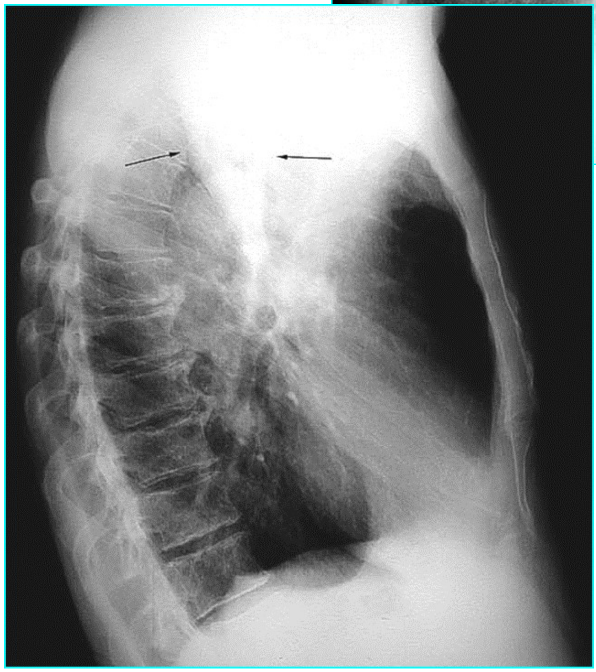
Bronchial carcinoma

- Lung cancer is the most common cause of cancer-related death in both men and women
- Four major cell types account for 95% of cases:
  - adenocarcinoma
  - squamous cell carcinoma
  - large cell carcinoma
  - small cell carcinoma
- By localization there are 3 types of cancer:
  - central tumours (75%)
  - peripheral tumours (20-25%)
  - Pancoast tumours

Central tumours

- The cardinal imaging signs of a central tumour are collapse/ consolidation of the lung beyond the tumour and the presence of hilar enlargement, signs that may be seen in isolation or in conjunction with one another
- Obstruction of a major bronchus often leads to a combination of atelectasis and retention of secretions with consequent pulmonary opacity, but collateral air drift may partially or completely prevent these postobstructive changes
- Hilar enlargement is a common presenting feature in patients with bronchial carcinoma



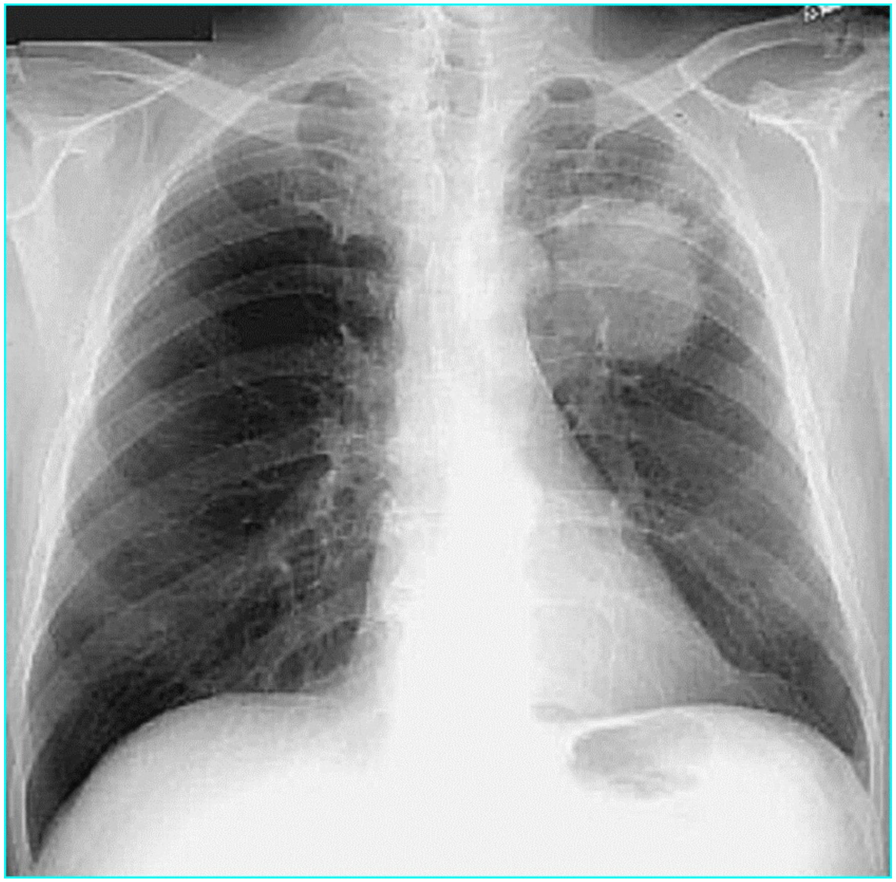


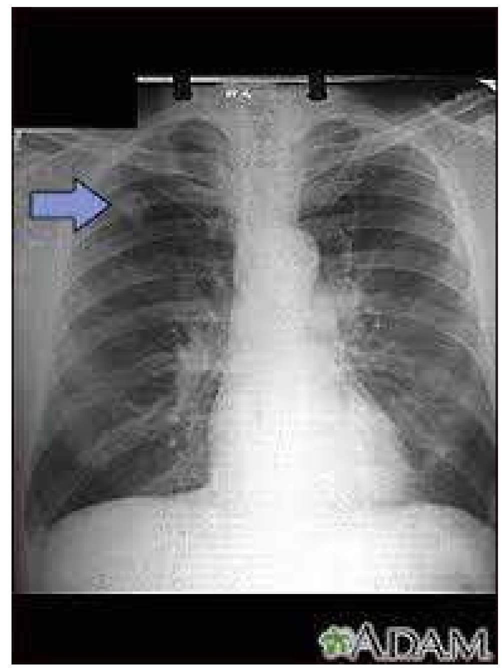
collapse RUL

Peripheral tumours

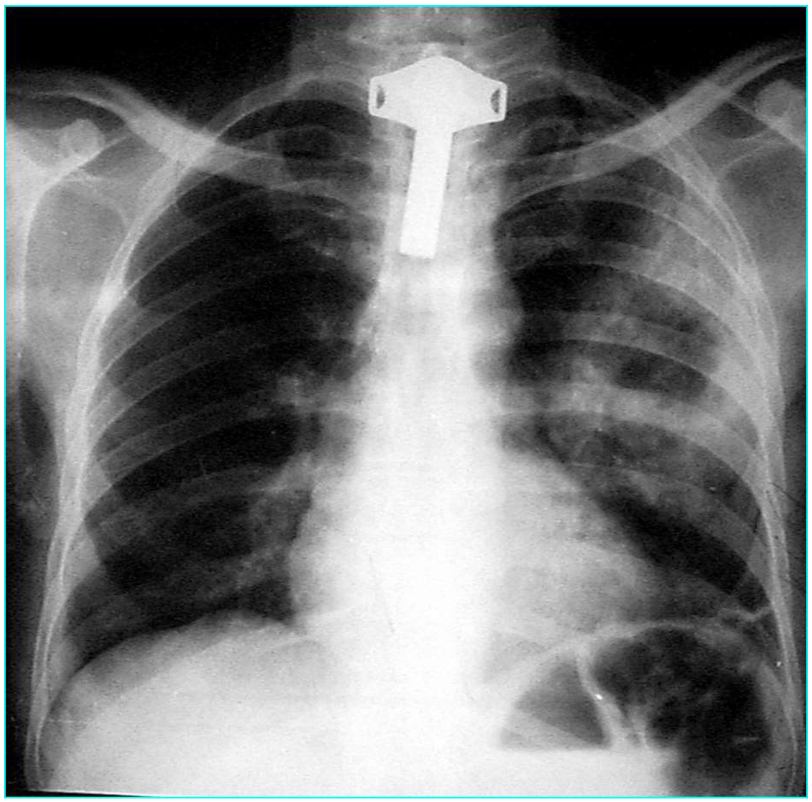
- Approximately 40% of bronchial carcinomas arise beyond the segmental bronchi, and in 30% a peripheral mass is the sole radiographic finding
- The term corona radiata is used to describe numerous fine strands radiating into the lung from a central mass, sometimes with transradiant lung parenchyma between these strands
- While not specific, this sign is highly suggestive of bronchial carcinoma
- Absolutely spherical, sharply defined, smooth-edged nodules due to carcinoma of the lung are rare
- Cavitation may be identified in tumours of any size and is best demonstrated by CT

Peripheral tumours

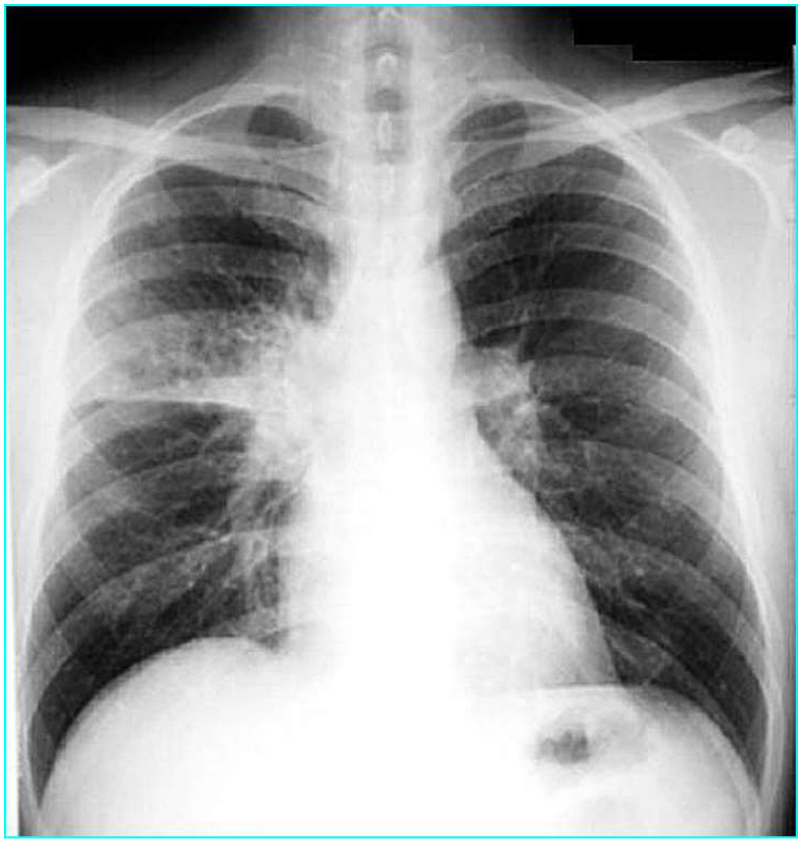


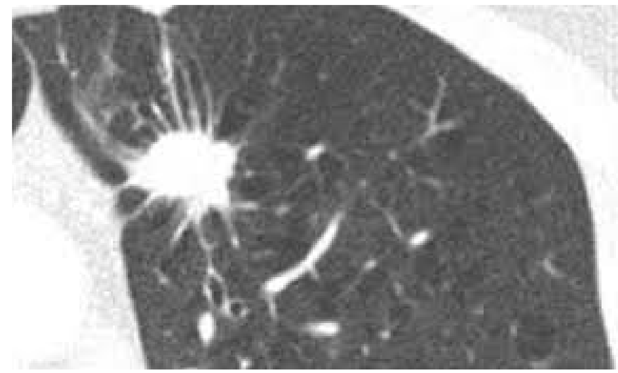


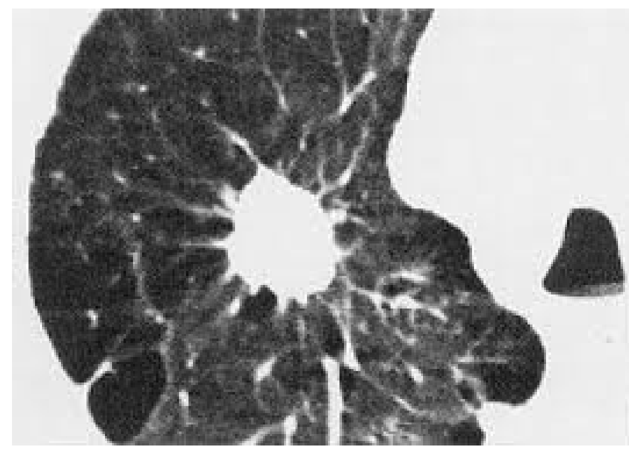
Neoplastic cavitation



Corona radiata



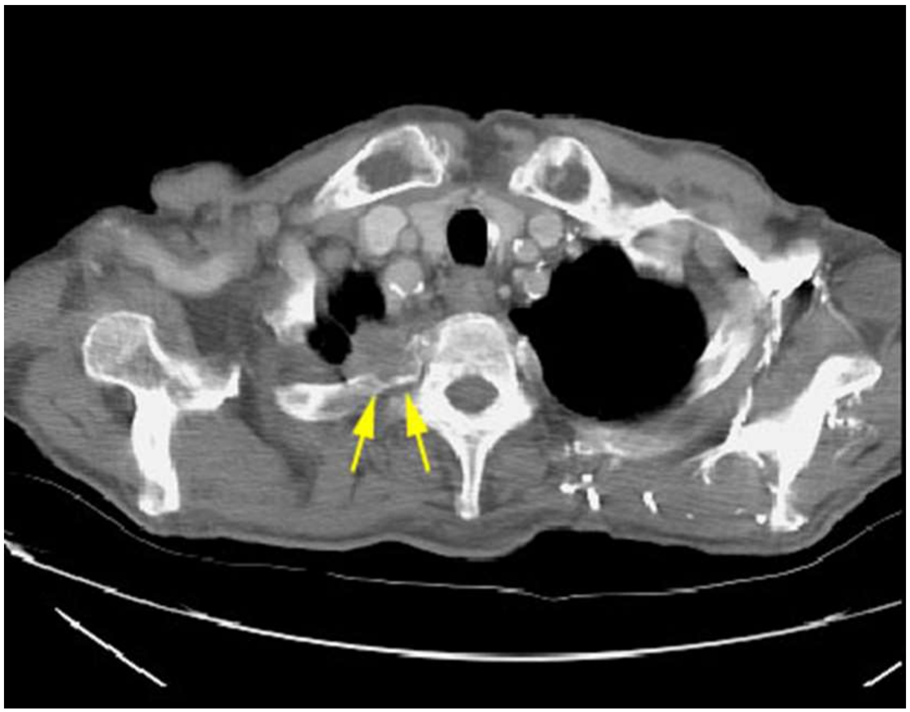




Pancoast toumors

- A Pancoast tumor is a tumor of the apex of the lung (3%)
- It is a type of lung cancer defined primarily by its location situated at the top end of either the right or left lung
- It typically spreads to nearby tissues with localized destruction of ribs and vertebrae
- Most Pancoast tumors are non-small-cell lung cancers
- The growing tumor can cause compression of a sympathetic ganglion (the stellate ganglion), resulting in a range of symptoms known as Horner's syndrome (ptosis, miosis, anhidrosis)

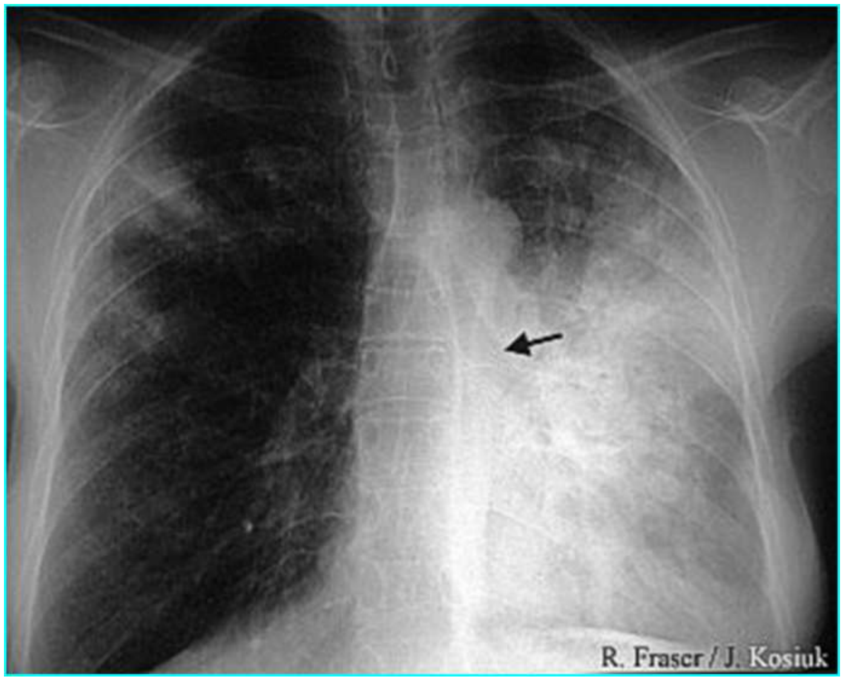
Pancoast toumors

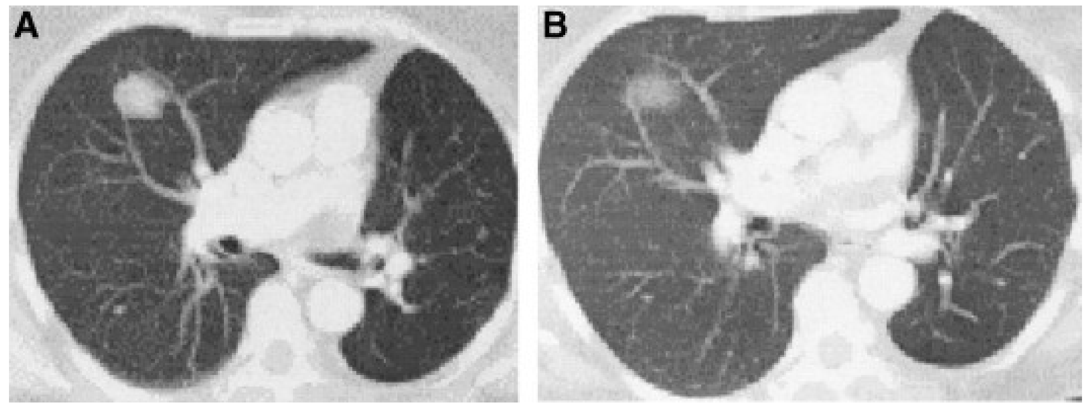


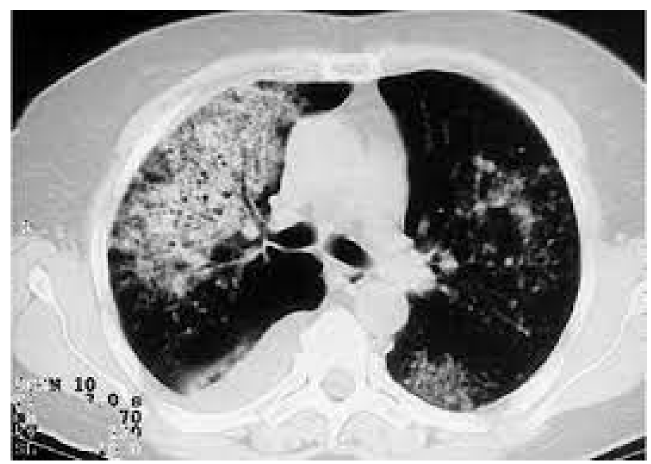
Bronchiolo-alveolar carcinomas

- Bronchiolo-alveolar carcinomas arise from the alveoli and the immediately adjacent small airways
- They therefore present as peripheral pulmonary opacities rather than with the effects of large airway obstruction
- The most common radiographic finding is a solitary lobulated or spiculated pulmonary mass indistinguishable from other types of carcinoma
- Bubble-like lucencies corresponding to patent small bronchi, air-containing cystic lucencies, or air bronchograms and cavitation may be seen

Bronchiolo-alveolar carcinomas







Metastases

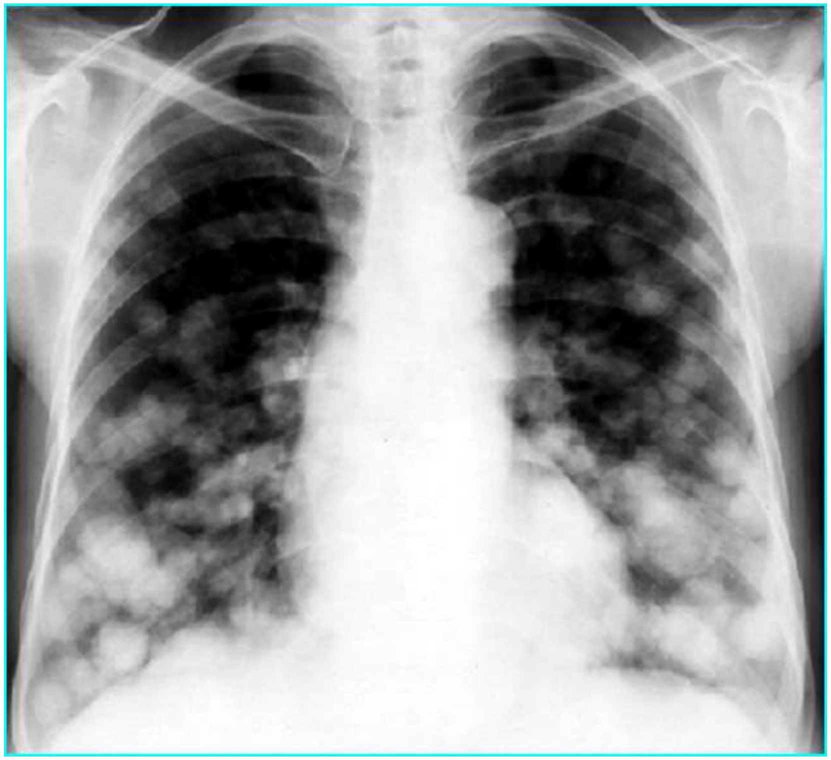
- Pulmonary metastases in adults are usually from breast, gastrointestinal tract, kidney, testes, head and neck tumours or from a variety of bone and soft tissue sarcomas
- The spread of extrapulmonary neoplasm to the lung may occur by direct invasion of the pulmonary parenchyma or as a result of hematogenous dissemination
- **Direct invasion** of the lung may occur with mediastinal, pleural, or chest wall malignancies
    - The most common mediastinal malignancies to invade the lung are esophageal carcinoma, lymphoma, and malignant germ cell tumors, or any malignancy metastasizing to mediastinal or hilar lymph nodes
- **Hematogenous metastases** to the lung may be seen with any tumor that gains access to the superior vena cava, inferior vena cava, or thoracic duct, because the pulmonal artery is the final common pathway for these channels

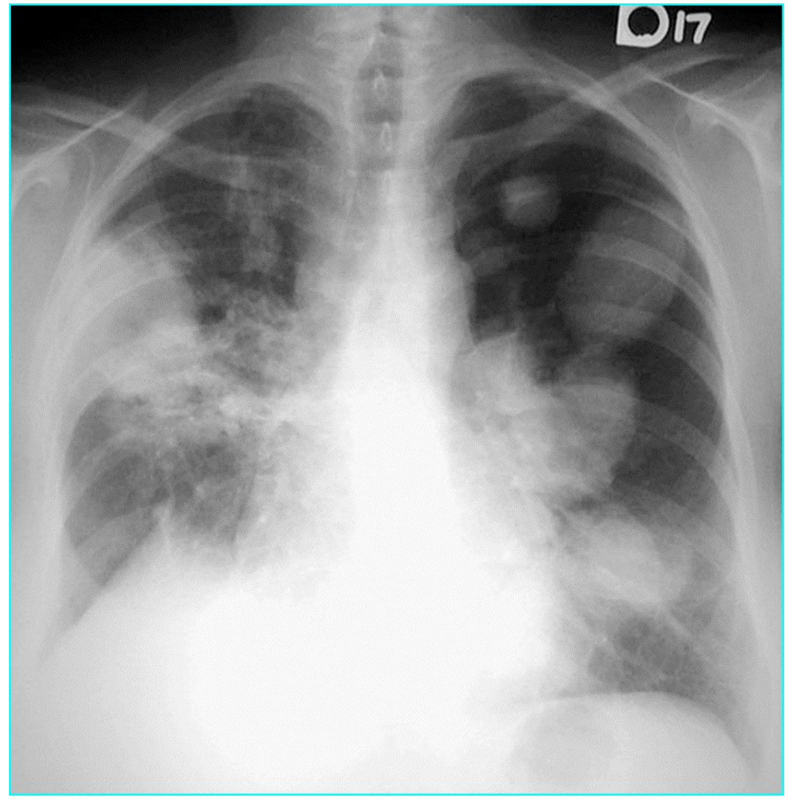
Metastases

- *Pulmonary nodules* are the most common manifestation of hematogenous metastases to the lung
- They are most commonly seen in carcinomas of the lung, breast, kidney, thyroid, colon, uterus, and head and neck
- Carcinomas of the rectosigmoid colon, osteogenic sarcoma, renal cell carcinoma, and melanoma are more likely to result in solitary pulmonary metastases
- *Lymphangitic carcinomatosis* (LC) - while direct parenchymal lymphatic invasion and obstruction of hilar and mediastinal lymph nodes by bronchogenic carcinoma is the most common cause of unilateral LC, extrapulmonary malignancies may invade pulmonary lymphatics after hematogenous dissemination to both lungs to produce interstitial deposits of tumor
- In LC, the tumor cells invade the lymphatics within the peribronchovascular and peripheral interstitium, resulting in lymphatic dilatation, interstitial edema, and fibrosis
- The most common extrathoracic malignancies to produce LC are carcinomas of the breast, stomach, pancreas, and prostate

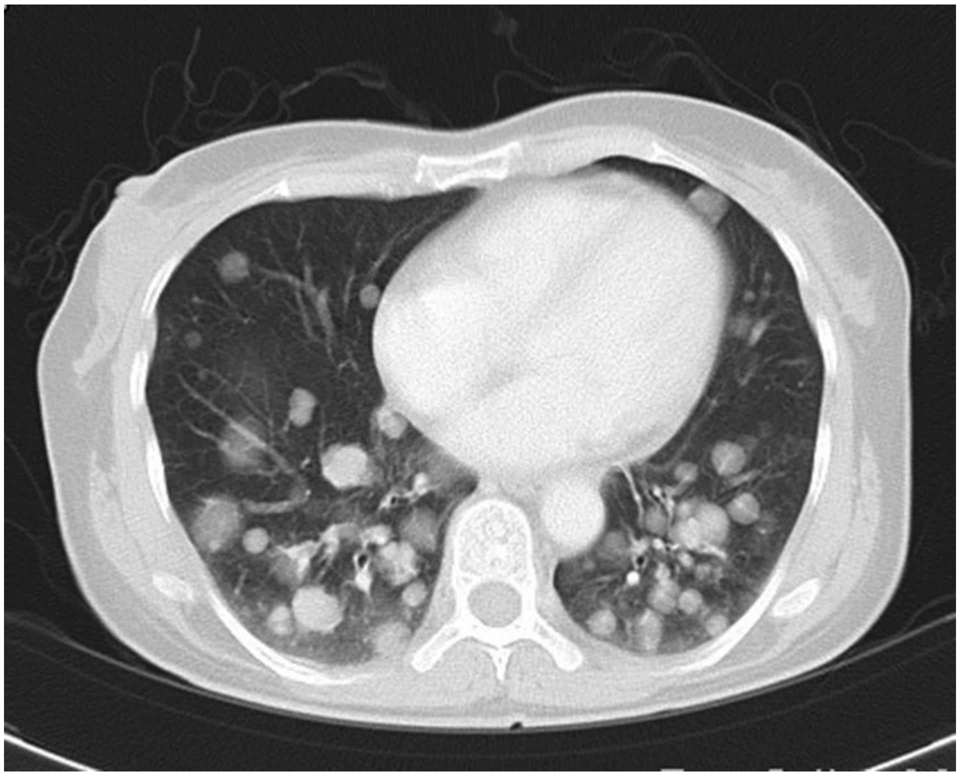
Metastases

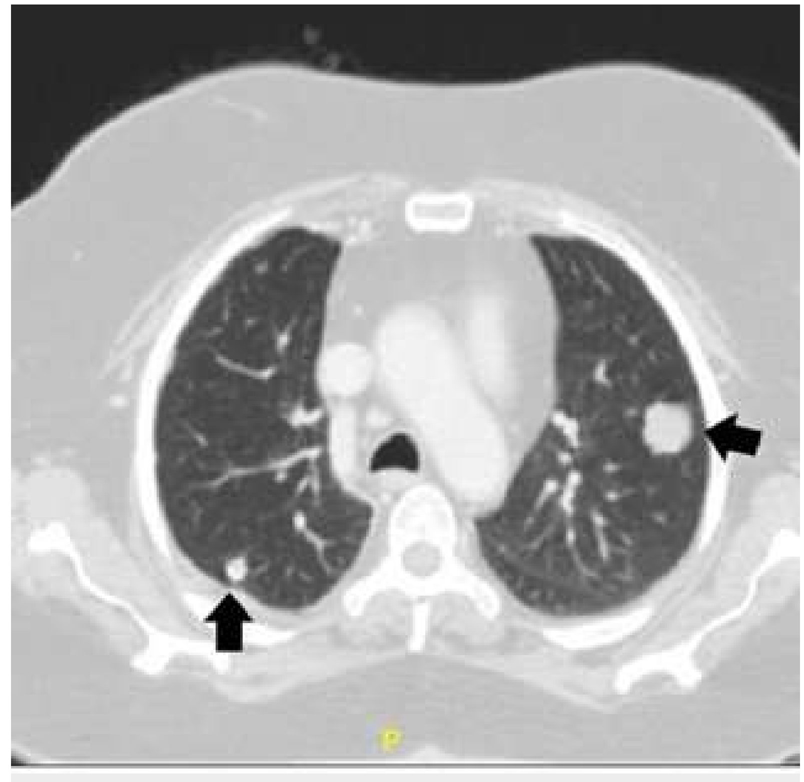
multiple nodular metastases (hematogenous)





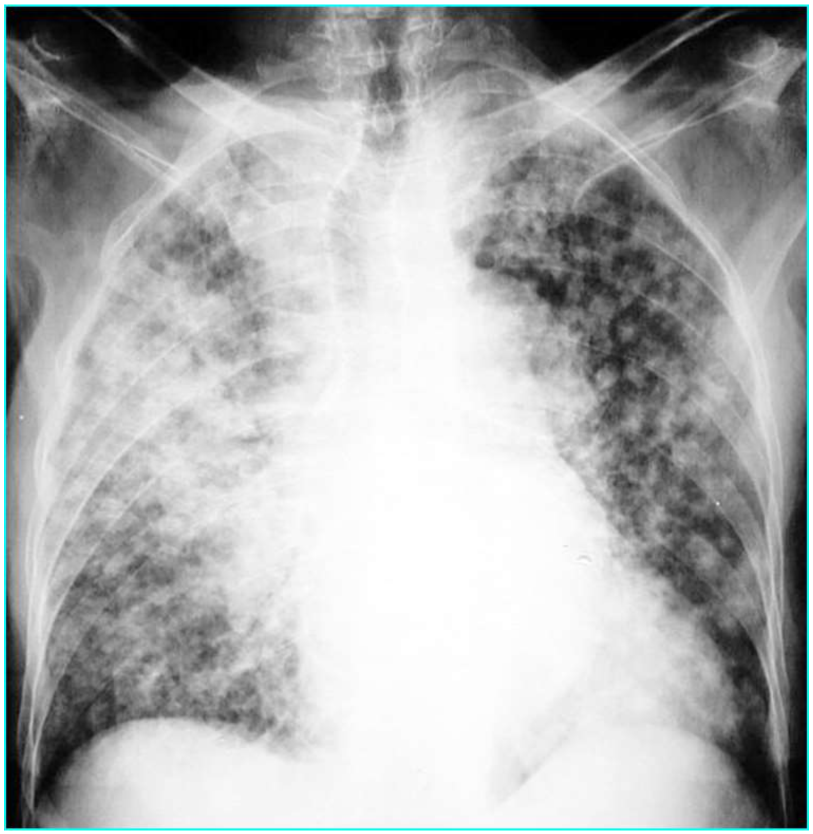
Metastases





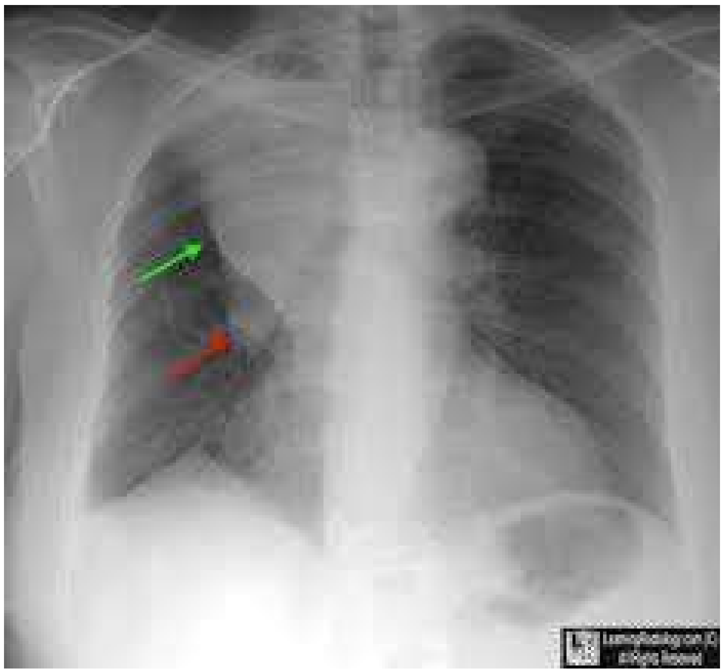
Metastases

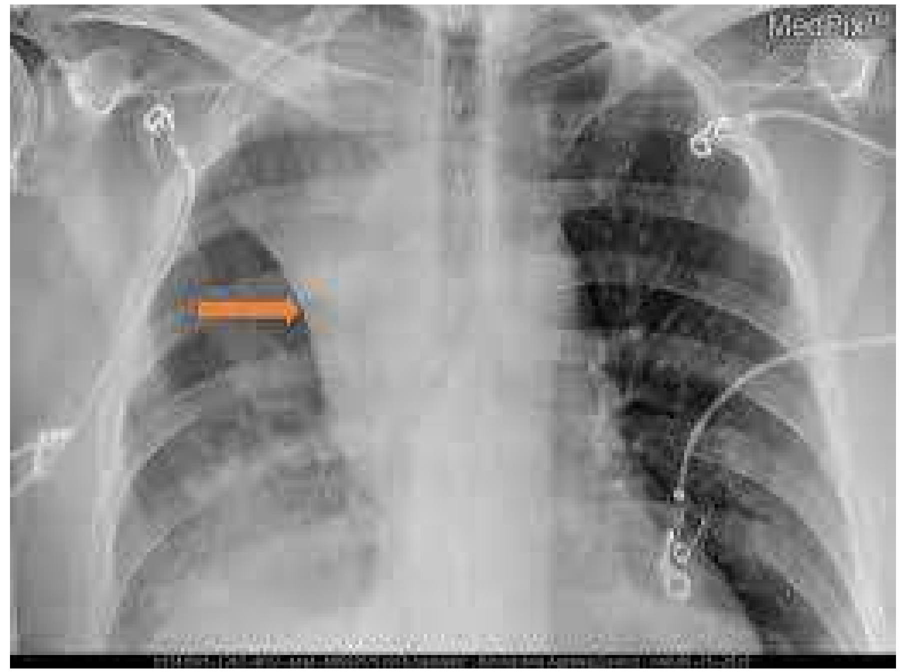
Lymphangitic carcinomatosis



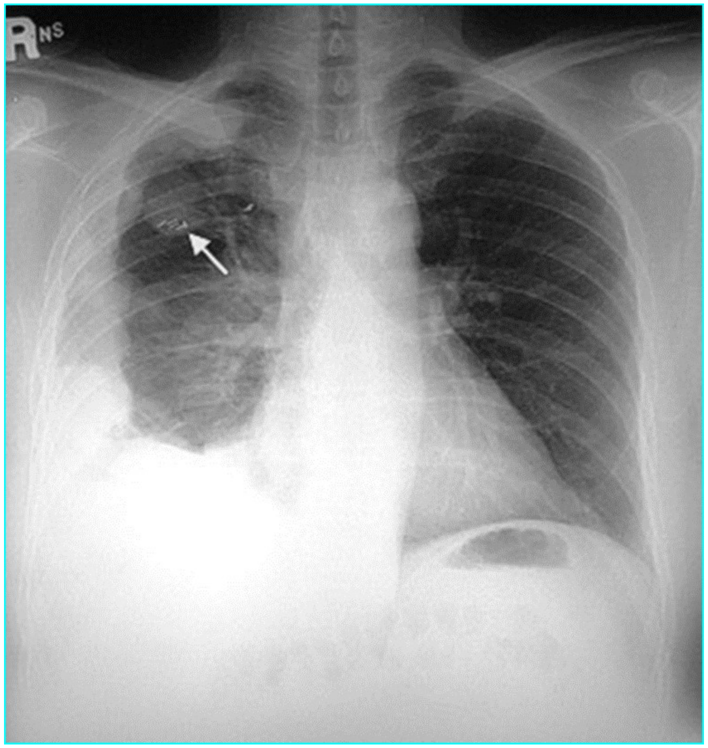
Golden S sign

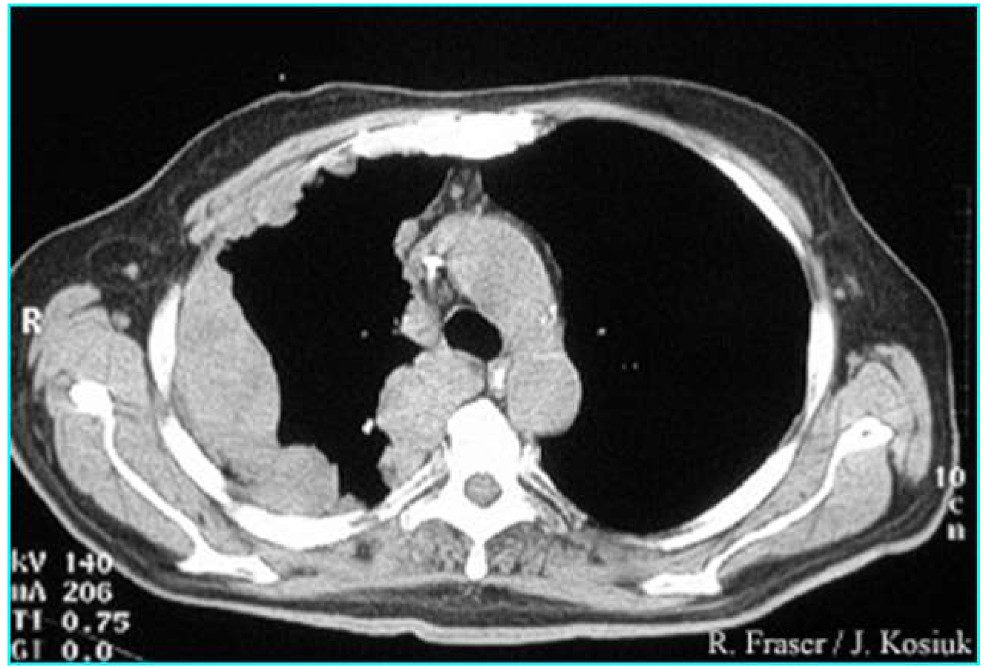
central bronchial carcinoma + atelectasis





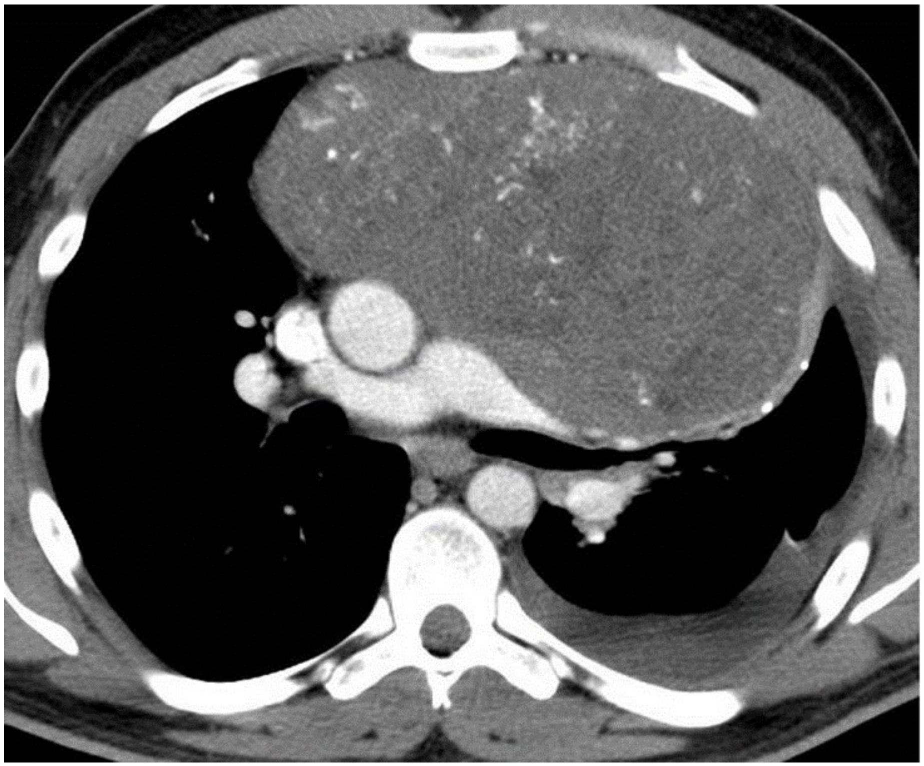
Pleural tumours – mesothelioma





Mediastinal tumours

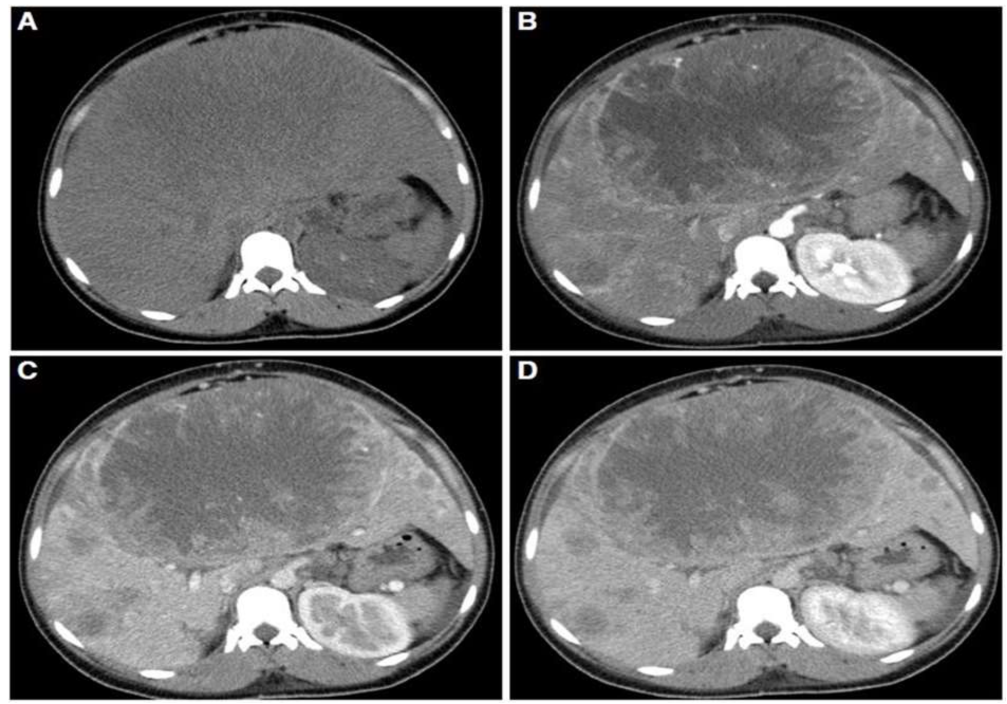
lymphoma



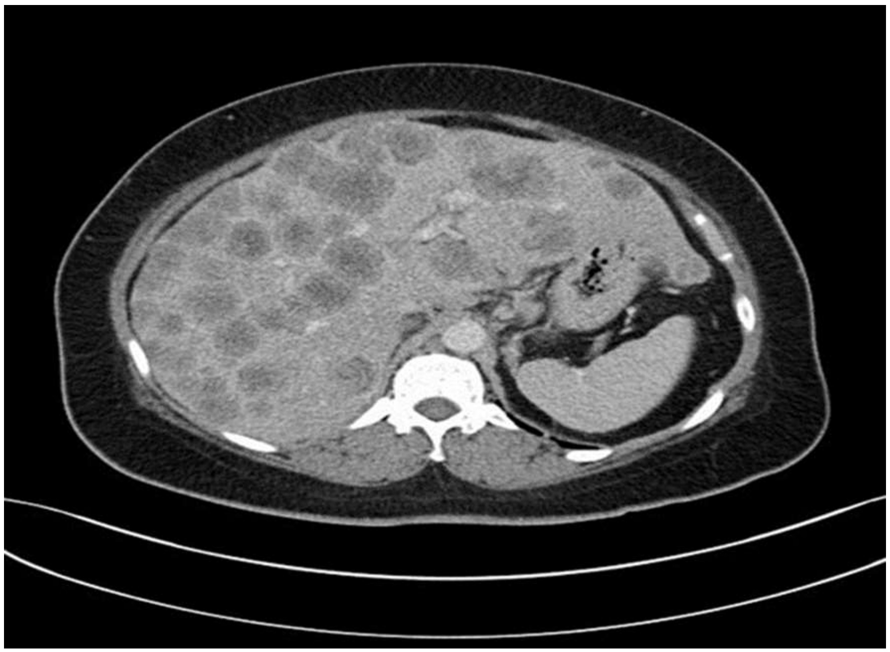
fibrosarcoma

Liver tumors

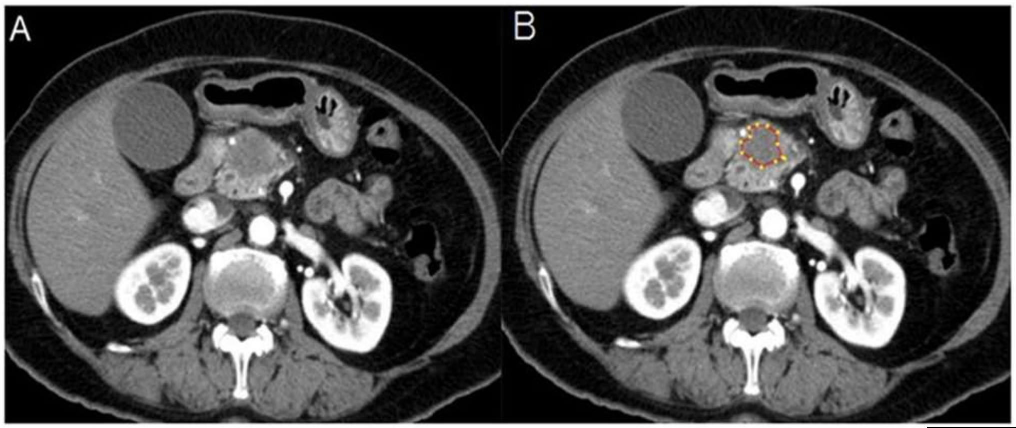
Hepatocellular carcinoma (HCC)

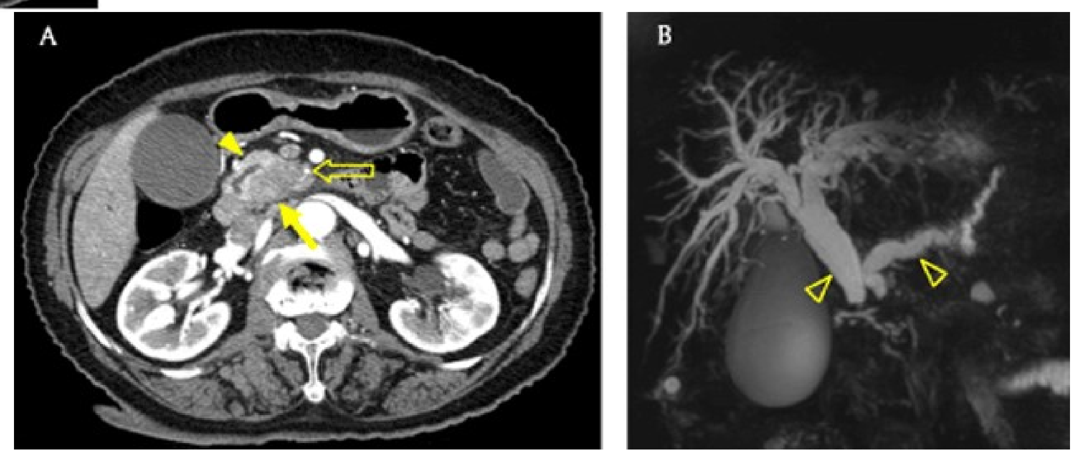


Liver metastases

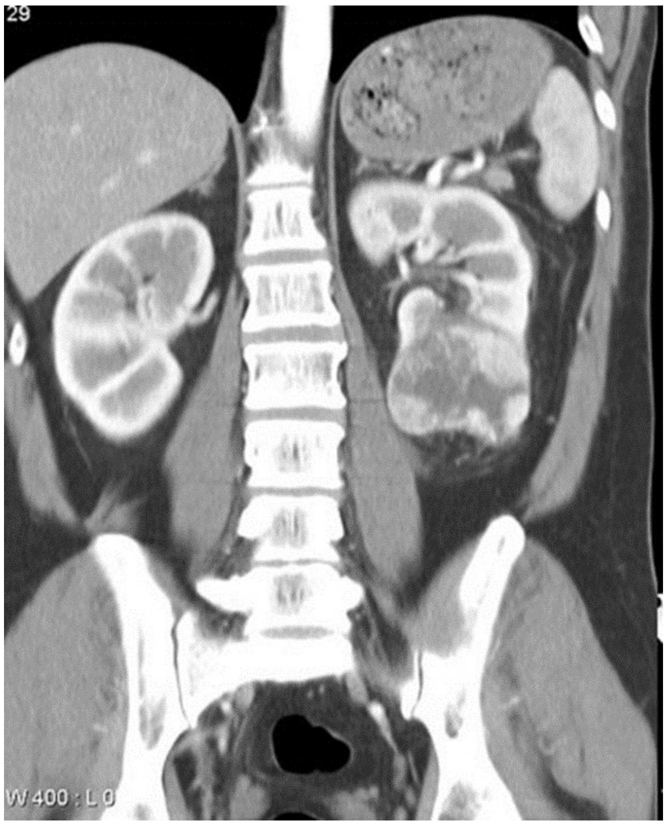


Pancreatic adenocarcinoma

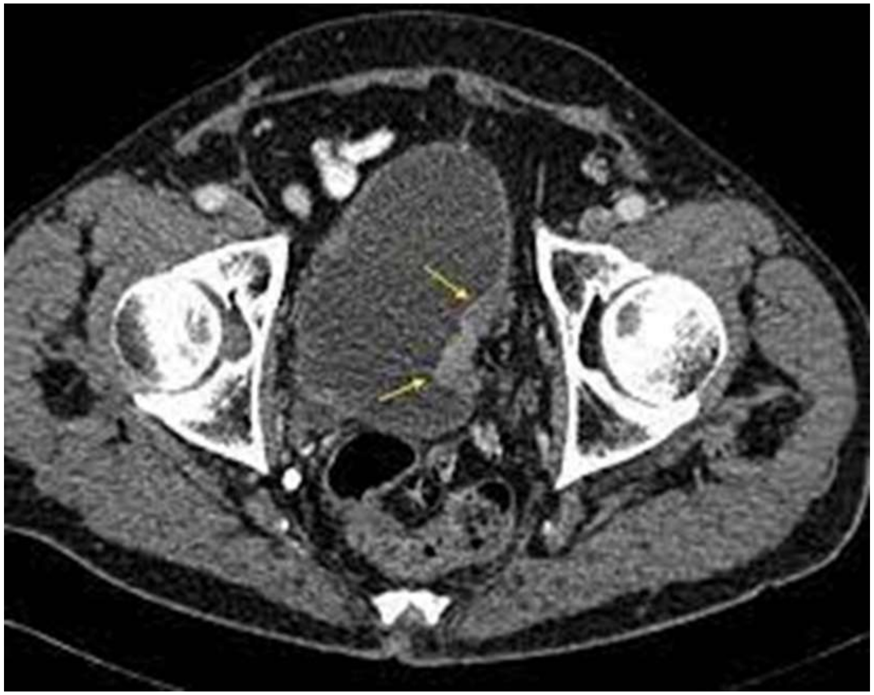


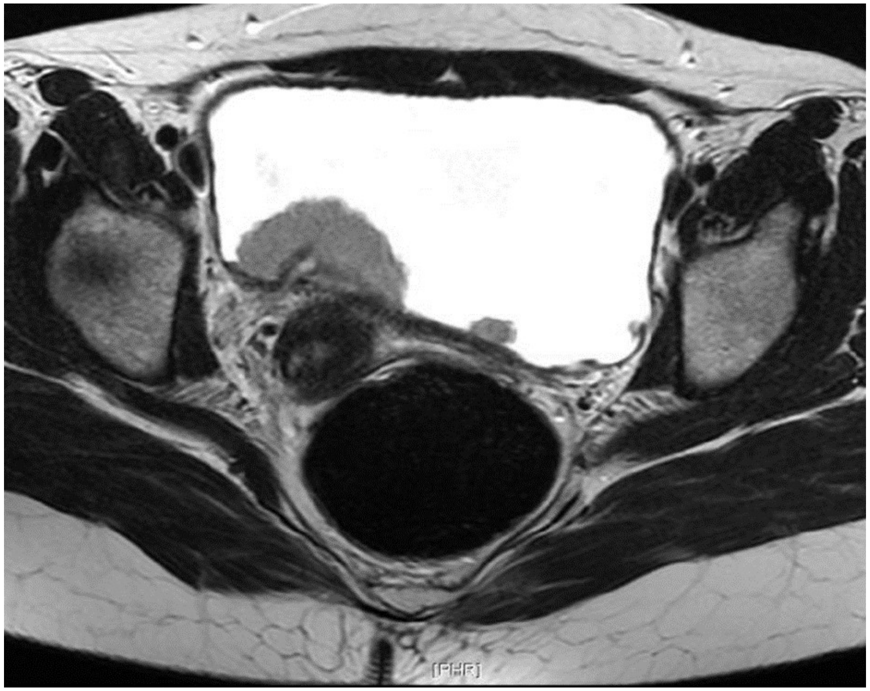


Renal cell carcinoma (RCC)



Bladder cancer





Rectal cancer