Techniques of radiology equipment

What is Radiation?

Radiation is emitted from unstable atoms, unstable atoms at said to be radioactive because they release energy (radiation). Radiation is the transport of energy through space. The radiation emitted may be electromagnetic energy x-ray and gamma ray or particle such as alpha or beta particles .radiation can also be produced by high voltage devices such as x-ray machines. The photon produced from x-ray beam can penetrate the body and are recorded on digital or film medium to produce an image of various densities that show details inside the body.

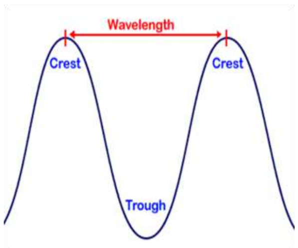
What is a wave?

A wave is a transfer of energy from one point to another via a traveling disturbance.

A wave is characterized by its wavelength, frequency, and amplitude

Wavelength (λ)

- Distance from successive crest to crest or trough to trough.



- Measured in meters, nm, A^o

Frequency (f)

Number of crests passing by per second.

Measured in Hertz (Hz) defined to be one cycle per sec.

Equal to the inverse of the amount of time it takes one wavelength to pass by.

Imaging Techniques

Imaging Techniques is the technique and process used to create images of the human body (or parts) for clinical purposes (medical procedures seeking to reveal, diagnose, or examine disease) or medical science (including the study of normal anatomy and physiology).

To obtain these images, different rays are used, like x-rays, ultrasonic waves, etc. The methods are known as imaging techniques ad are classified according to the rays that are used.

The **electromagnetic wave** is the principal source of images.

Fig.(1) shows the electromagnetic spectrum which contain: Radio wave, Microwave Wave, Infrared, visible light, ultra violet, x-ray, gamma ray

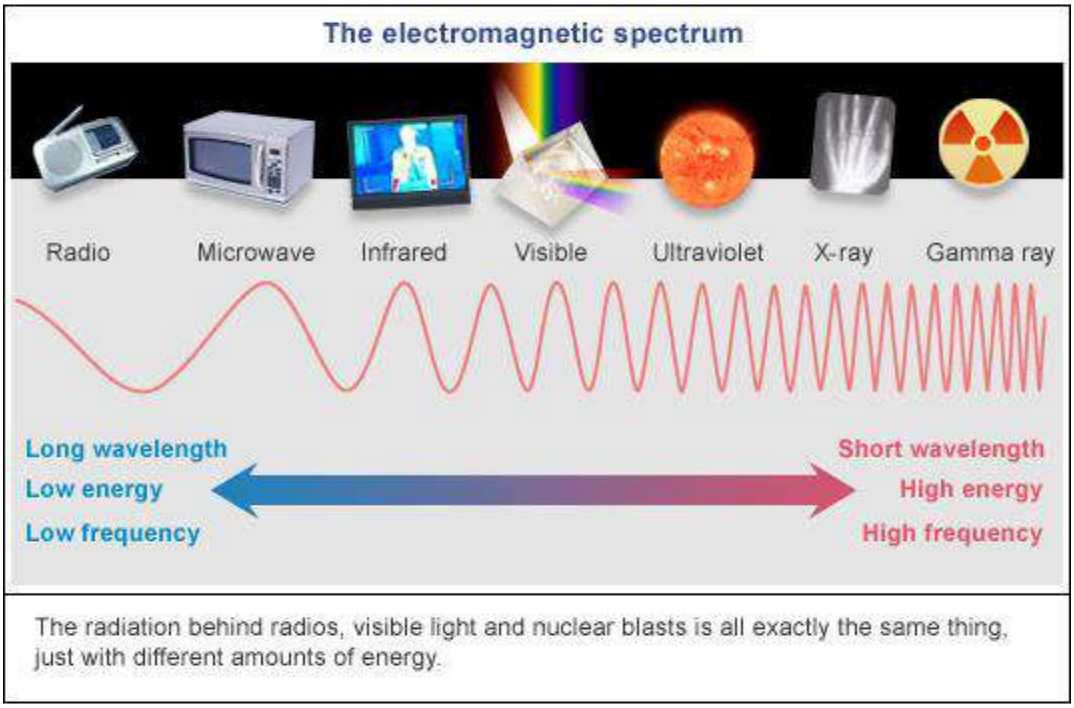


Fig.(1): electromagnetic spectrum

Electromagnetic wave

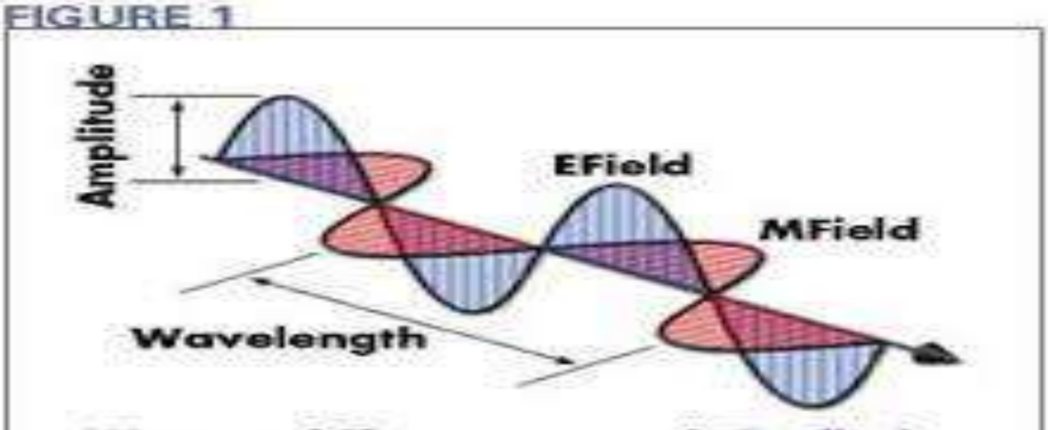
Electromagnetic waves or EM waves are waves that are created as a result of vibrations between an electric field and a magnetic field. In other words, EM waves are composed of oscillating magnetic and electric fields.

Description: Electromagnetic waves are formed when an electric field comes in contact with a magnetic field. They are hence known as 'electromagnetic' waves. The electric field and magnetic field of an electromagnetic wave are perpendicular to each other. They are also perpendicular to the direction of the EM wave.

EM waves travel with a constant velocity of $3.00 \times 10^8\ ms^{-1}$ in vacuum. An electromagnetic wave can travel through anything - be it air, a solid material or vacuum. It does not need a medium to propagate or travel from one place to another. Mechanical waves (like sound waves or water waves), on the other hand, need a medium to travel. EM waves are 'transverse' waves. This means that they are measured by their amplitude (height) and wavelength (distance between the highest/lowest points of two consecutive waves).

The highest point of a wave is known as 'crest', whereas the lowest point is known as 'trough'. Electromagnetic waves can be split into a range of frequencies. This is known as the electromagnetic spectrum. Examples of EM waves are radio waves, microwaves, infrared waves, X-rays, gamma rays, etc

FIGURE 1



Waves of Electromagnetic Radiation

History of X-ray

The x-ray photon is a member of the electromagnetic family that includes light of all types (infrared, visible, ultraviolet). Radio waves, radar and television signals and gamma ray.

In 1895, the x-ray machine one of the most important technological inventions in the medical field was created when William Roentgen found that x-rays could be used to give pictures of the internal structures of the body. Thus the x-ray machine was the first imaging to be created.

The field of radiology has three major branches:

1- Diagnostic radiology: fixed picture like normal x-ray and CT scan and moving picture- fluoroscopy. The wave lengths are the same as in fixed picture but with lower energy levels
2- Radiation therapy like linear system used to treat cancer disease
3- Nuclear medicine

The three areas have relatively little in common except that each uses a part of the electromagnetic spectrum and the time when the radiologist practiced in all three areas is gone.

The X-ray Technique

The technique of producing x-ray beam by a very quick accelerated electron exits from a cathode hitting an anode and produce electromagnetic wave of high energy that can penetrate any material with different degree.

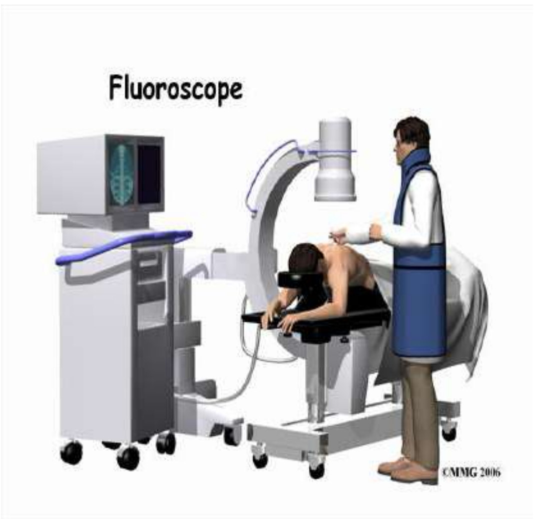
In medicine, when x-rays hit the film (cassette), they expose it just at light, since bone, fat, muscle, tumors and other masses all absorb x-rays at different levels the image on the film lets you see different structures inside the body because of the different levels of exposure on the film

Application of x-ray techniques in Medicine:

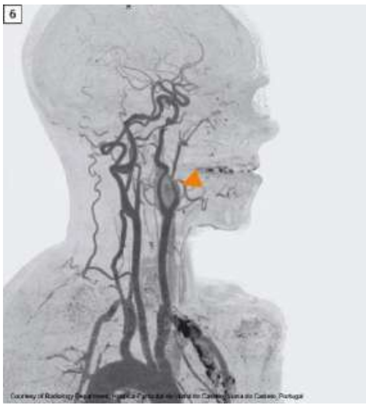
1- **Stationary x-ray machine (traditional):** diagnostic x-rays are useful in detecting abnormalities within the body. They are a painless, noninvasive way to help diagnose problems such as broken bones, tumors, and the presence of foreign bodies.

2- **CAT scan:** (computed axial tomography)**.** This noninvasive or minimally invasive test uses multiple x-ray images, taken from different angles to great three dimensional images of body structures it may be performed alone or with the use of a special dye called a contrast medium.

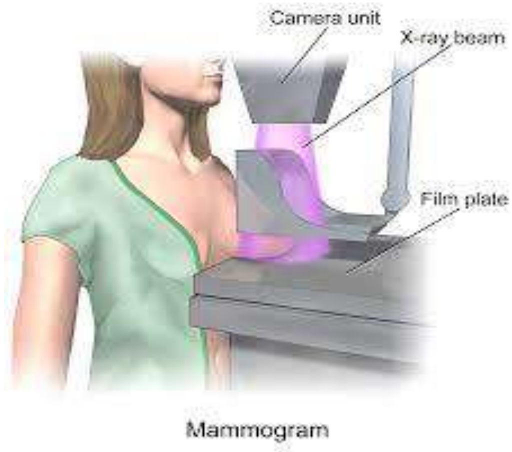
3- **Fluoroscopy:** This type of test uses x-rays to image internal body organs while they are in motion. A continues x-ray beam is focused on the part of the patient being examined to great a detailed, moving image that appears on a monitor, much like a movie, an example for fluoroscopy in used for cardiac surgery



Angiography: Angiography is a type of x-ray used to check blood vessels. Blood vessels do not show clearly on a normal X-ray, so a special dye needs to be injected into your blood first. This highlights your blood vessels, allowing your physician to see any problems. The X-ray images created during angiography are called angiograms.



4- **Mammography:** Mammograms are specialized x-rays that create detailed images of the breasts. They are used to screen for a diagnose breast cancer and other breast conditions, such as cysts.

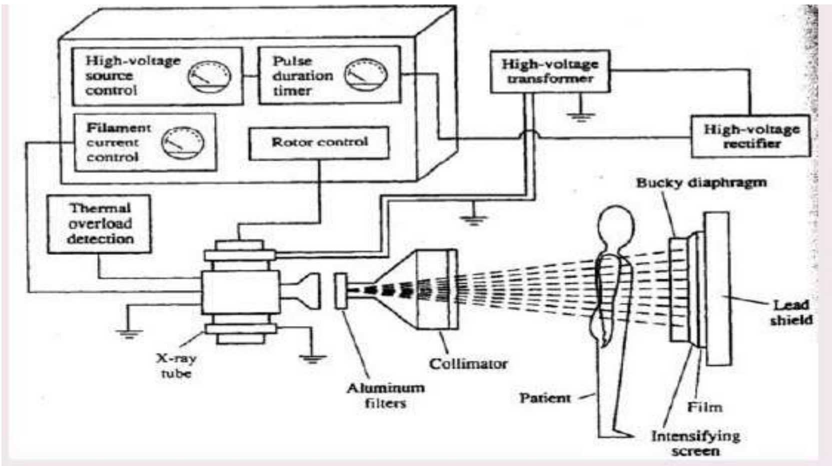


5- **Dental X-ray**: Dentists use radiographs for many reasons
: to find hidden dental structure, malignant of benign masses, bone loss and cavities. The dosage of x-ray radiation received by a dental patient is typically small.


6- **DEXA scan**: (Dual energy x-ray absorption)also known as a bone density scan, DEXA is the standard method of measuring bone mineral density. DEXA are often used to screen for the bone-thinning disease osteoporosis, especially in women after menopause. Some DEXA units use ultrasound instead of x-rays

Main Parts of the X-ray Machine

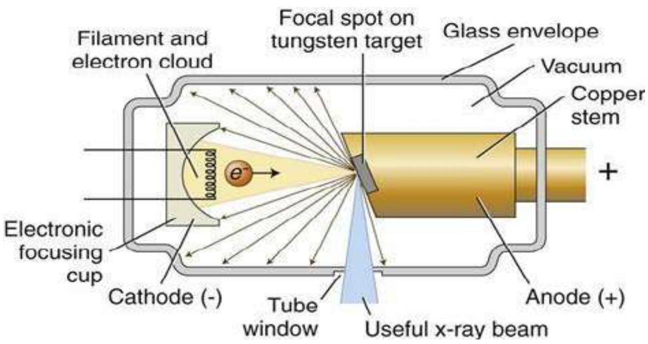
1- X-ray Tube
2- Control Panel (Operation Console)
3- High voltage transformer
4- Tube head or protective housing
5- Collimator
6- Patient table
7- Bucky
8- Grid
9- Radiographic film



1- X-Ray tube

It is the heart of the x-ray machine and it composed mainly of

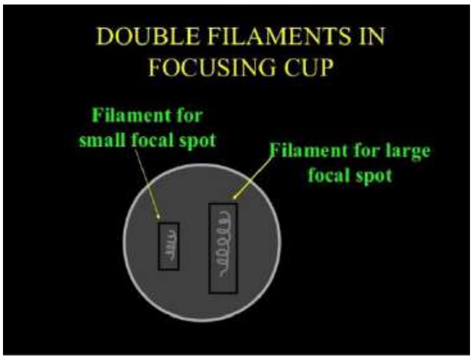
- Cathode which is negatively charged.
- Anode which is positively charged.
- Glass envelope which holds the anode and cathode structures.

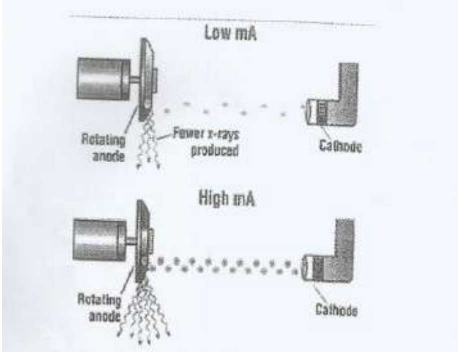


The cathode made of two major components

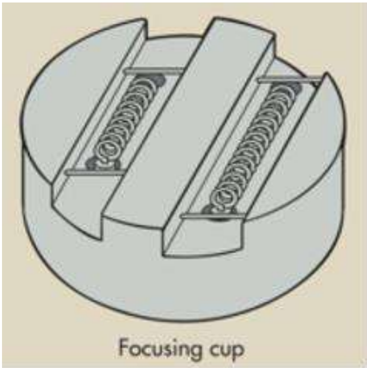
✓ **Filament**: is the source of electrons and made of coiled tungsten wire, with modern x-ray tubes having two filaments to allow a choice of two focal spot sizes.

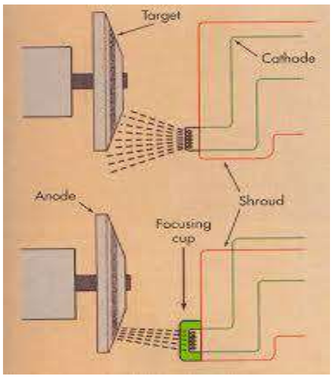
The figure shows a magnified view of the cathode face and it shows two filaments. Only one filament at a time will work. The small filament is designed to be used with relatively small parts while the large filament is used when larger body parts are being X-rayed.





✓ **The focusing cup**: the structure which supports the filament is known as the "focusing cup". it made of molybdenum nickel alloy. It is designed and shaped so that when the X-ray machine is working electrons will "boil" off the filament (heat up) ,it becomes hot and the electrons move around the filament in a "space charge" until the moment of exposure and then they accelerate very rapidly towards the anode which is not very far away.





The shape of the focusing cup is designed such that it helps "concentrate" the electron stream on the anode target .The benefits of focusing cup is

i-supports the filaments.

Ii - control the electrons direction.

Iii - help to get a clear X-ray image.

▪ **The anode**: it is the 2nd major part of the x-ray tube is the Anode. The anode has a positive electrical charge and attracts electrons. The anode is a disc made of Tungsten because of its thermal qualities. The disc is designed to rotate during operation,

<u>The anode made of:</u>

i. Anode: target material=high atomic number and high melting point, Tungsten.
ii. Copper anode: conduction of heat.
iii. Anode hood: prevents electrons from hitting the walls or other non target component.

- **Glass envelope**: the type of glass that is used in the X-ray tubes is pyrex. The anode and cathode are contained in an evacuated envelope to prevent the electrons from colliding with gas molecules. The envelope is contained in a tube housing that protects and insulates the tube and provides shielding to prevent leakage radiation

The glass envelope is immersed in oil to ensure that it is electrically insulated and so that the oil will also help cool down the tube during operation. The cooling of the oil is sometimes assisted with a cooling fan.

Focal Spots: the focal spot is the apparent source of x-rays in the tube, focal spot size is a result of the filament shape, focusing cup and electric field created between cathode and anode.

2- Operation Consul : The consul controls

- ✓ Kvp
- ✓ mA
- ✓ Exposure time

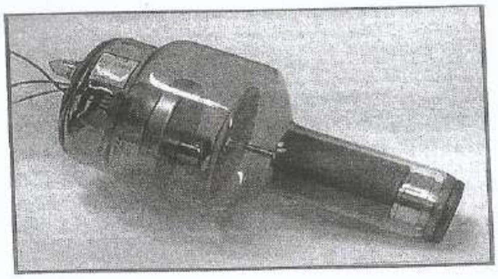
An x-ray generator provides power to the x-ray tube and permit x-ray controls by three key parameters of x-ray operation, x-ray tube voltage (kilovolts or Kv) which affects the x-ray energy; tube current (milliamperes or mA) which controls the number of electrons crossing from cathode to anode and affects the radiation quantity; and Exposure time it consist of mechanical or electronic device whose action to make and break the high voltage.

3- High voltage transformer : is one major requirement of a generator is to produce high voltage a transformer changes the size of the input voltage and is used to produce high and low voltage there are two types of transformers:

a- Step-up transformers increase the voltage
b- Step-down transformers decrease the voltage
The high voltage transformer is a step-up transformer

4- **protective housing (glass involve):** As mentioned earlier x-ray tube mounted inside a lead- lined protective housing that is designed to;
a- prevent excessive radiation exposure
b- Prevent electric shock to the patient and operator (technologist)

The primary x-rays exit through a window in the tube housing, the x-ray window may be a thinner area in the glass or a different material such as beryllium, which absorbs fewer low-energy, x-rays housing



5- **Collimator:** The collimator is attached to the x-ray tube below the glass window where the useful beam is emitted, lead shutters are used to restrict the beam. its purpose is to minimize field to view, to avoid un necessary exposure by using the lead plates

6- **Patient Table:** Table: it is designed to hold patients during x-ray image. It must be have these specification:

- Strong to carry the big patients.
- Bucky or cassette tray should be fitted
- Can be tilted
- Electrically safe
- Moves up and down

Types of table:
a) Fixed table: simple and easy to use

b) Moving table: It's good for trauma patient (accident) and when several and when several parts of the body are to be x-rayed.

c) Tilting table: used with fluoroscopy.

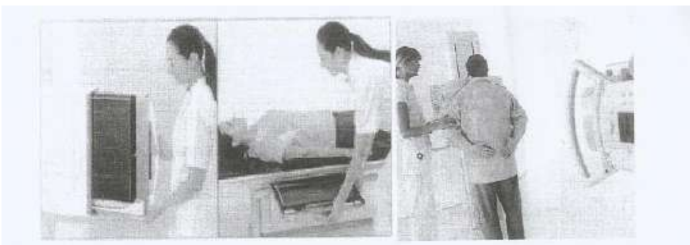
7- Bucky

A Bucky is a component of the x-ray units that holds the x-rat film (cassette) and moves the grid during the exposure, typically used for table or wall

- Table Bucky
- Stand Bucky

Specification of Bucky

- Lock mechanism for cassette security
- Grid mechanism cassette tray
- Important that x-ray tube and cassette tray are aligned (alignment).



8 -Grid

The Bucky-potter grid is a device invented by German radiologist **Gustav Bucky** and improved by American radiologist **Hollis F.potter** that increase the quality of diagnostic medical x-ray image.

The grid position is above the film to reducing the amount of scattered x-rays increases the image quality and the visibility of soft tissues.

Grid Design

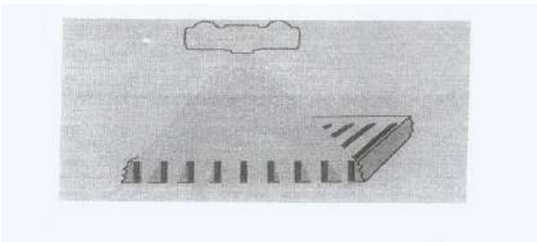
- Aluminum, plastic or carbon fiber for interspaces
- lead, tungsten, platinum, gold strips
- Transmits x-rays traveling in a straight line

As lead content increases, scatter decreases and therefore contrast increases.

Grid Types:

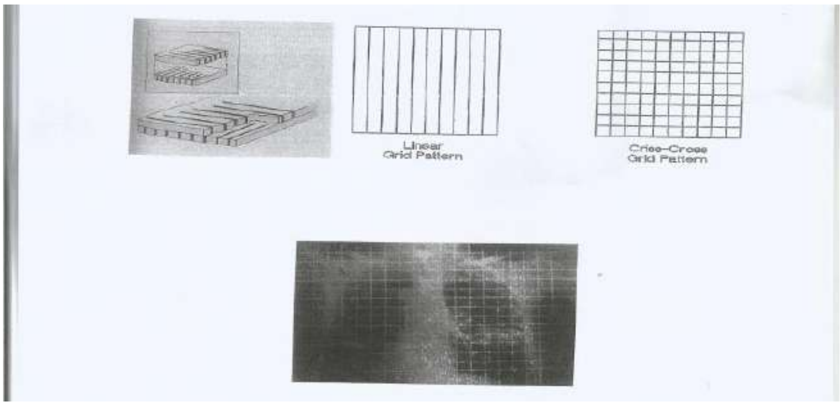
1- Linear grid

- Vertical lead strips.
- Absorption of beam



2- Crossed grid

- Two parallel grids perpendicular
- High Grid cut-off
- Efficiency higher than linear grid.



8- **radiographic film**: Two types of x-ray photon are responsible for density, contrast and image on a radiograph those that pass through patient without interacting and those that scattered in the patient through Compton interaction, together these x-rays that exit from patient and intersect the film called Remnant x-rays

- **A light beam diaphragm (LBD**): Is generally attached at the output port of the x-ray tube to allow the beam dimensions to be adjusted using collimators, the diaphragm is placed between The tube and the collimator to reduce off-focus rays, it is made of absorbing material (lead)
- **Rectification:** Rectification changes the AC voltage into DC across the x-ray tube, is achieved using diodes, which permit current to flow in one direction because the electric current from an AC power supply flows alternately in both directions, resulting in a voltage waveform shaped like a sine wave.
- **Quantity:** intensity refers to the quantity or number of x-ray photon produced intensity is affected by the generator type, beam filtration, and distance from the beam (inverse square law). **X-**ray output is directly proportional to the current (mA), and the exposure time(s) milliamperes (mA). The quantity of electrons is determined by the filament (large or small)

[mAs =mA* s], it means the tube current multiplied by the exposure time. (mAs) defends the number of x-ray photons emitted an the density on the film, for any radiographic test, the number of x-rays reaching the image receptor (cassette)is directly related to the tube current ant the time that the tube in energized.

Increasing the mA and mAs, increases the number of x-ray production

- **Quality**: quality refers to effective photon energy of the x-ray produced, and relates to their ability to penetrate the patient, x-ray beam in diagnostic radiology Increasing beam quality increases x-ray beam penetrating power because the average photon energy is higher. For increasing the quality of beam

- By increasing the peak voltage by 15% has the same effect on film density as that doubling the mAs, for example; changing tube voltage by 10 Kvp(from 65 to 75kvp) normally has the same effect on film density as doubling the mAs
- Increasing X-ray tube filtration also increase beam quality.
- Reducing the wave voltage waveform ripple increases average photon energy and thus x-ray beam quality.

Computed Tomography

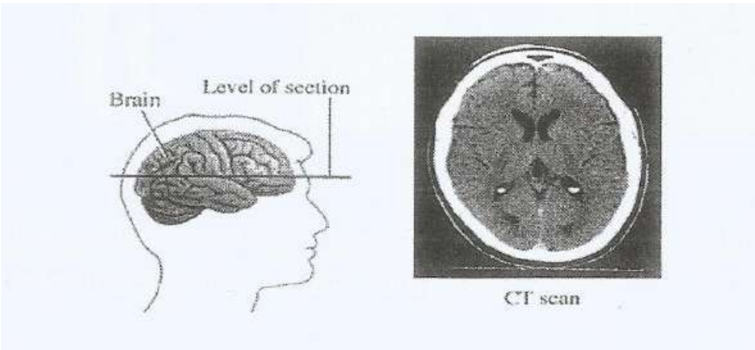
Or computerized axial tomography CAT, is an examination device that uses x-ray and computer to get a cross-sectional image of the human body.

C= Computerized

A= axial

Tomo= slice

So we can say that CAT scan is : imaging an object by slicing it.

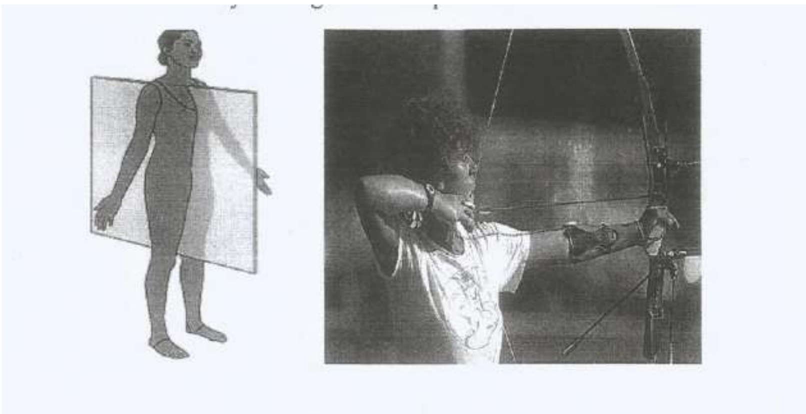


In traditional x-ray imaging, the film directly absorbs penetrated x-rays. in CAT scanning, an electronic device called a "detector array" absorbs the penetrated X-rays, measured the X-ray amount, and transmits the data to a computer system. A computer system calculates and analyzes data from each detector in each level, and finally reconstructs multiple, two-dimensional, cross sectional images.

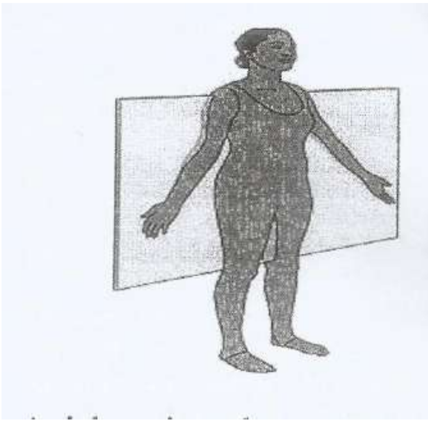
Main anatomical planes:

The human body is intercepted by three main planes:

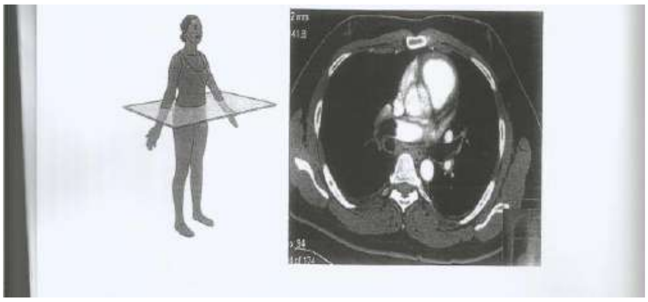
1- Sagital section: the name comes from arch and dart; this plane divides the body into right and left parts.



2- Coronal section: the name comes from corona or crown, this plane divides the body the body into anterior and posterior parts.



3- Axial section: the name comes from the axis of the body, this plane divides the body into superior and inferior parts.

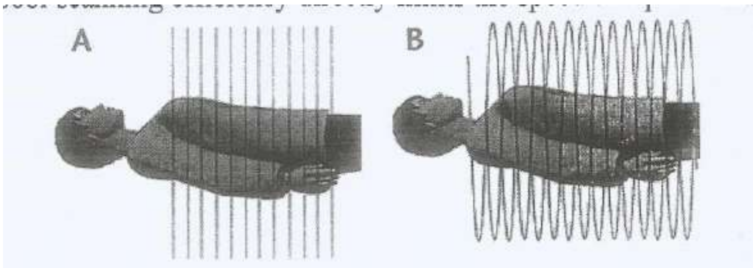


Modes of CT scan:

a- **Step- and shoot CT**: it consists of two shoot stages: data acquisition and patient positioning.

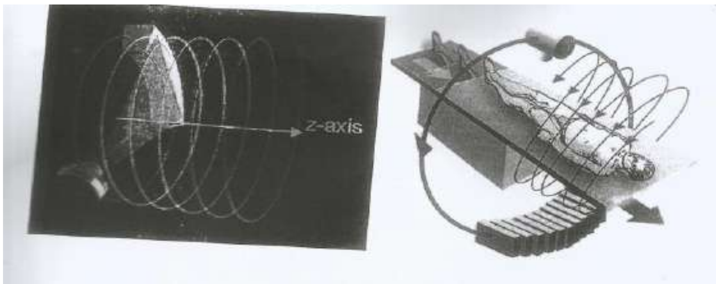
During the data acquisition stage, the patient remains still and the x-ray tube rotates about the patient to get a complete set of projections at a scanning location.

During the patient positioning stage, no data are acquired and the patient is transported to the next scanning location. The data acquisition stage typically takes one second or less while the patient positioning stage s around one second.



Thus, the duty cycle of the step-and shoot CT is 50% at best. This poor scanning efficiency directly limits the speed and performance.

b- **Spiral (Helical) scanning:** X-ray tube/detector rotates continuously and the patient moves continuously.
Most modern scanner operate in a helical or spiral mode where the x-ray tube and detector system rotate continuously during data acquisition as the patient table moves through the scanner. Under these conditions.

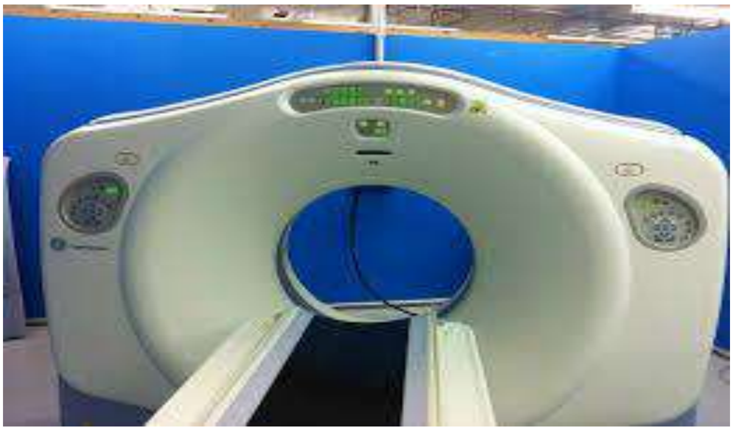


Helical or spiral CT was introduced around 1990. In this mode, the data are continuously acquired while the patient is moving through the gantry at a constant speed. The patient translating distance per gantry rotation in helical scan is referred to as the table speed.
Because the data are continuously collected without pausing, the duty cycle of the helical scan is improved to nearly 100%.

The main parts of CT scanners:

1- Gantry:

The gantry is the ring- shaped part of the CT scanner. It has many of the components necessary to produce and detect x-rays. Components are built in a rotating scan frame. Gantries vary in total size as well as in the diameter of the opening, or aperture. The range of aperture size is typically 70-90 cm. the CT gantry can be tilted either forward or backward as needed to the case of the patients and examination protocols. The degree of tilt ranges from ±15 to ±30

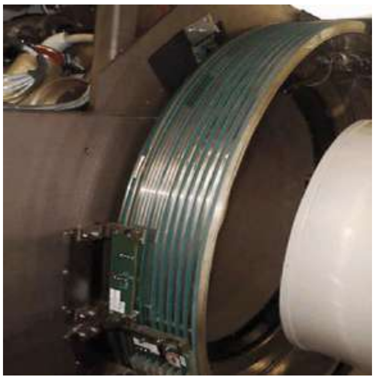


The gantry also includes a laser light that is used to position the patient within the scanner. Control panels located on both sides of the gantry opening to allow the technologist to control the
Scanners, this function may also be controlled via the operator's console. A microphone is also built-in the gantry to allow communication between the patient and the technologist during the scan procedures.

The main components that are found inside the gantry are:

a- Slip-rings:

It is an electromechanically brush- like device use to provide continuous electrical communication across rotating surface. They allow the gantry frame to rotate continuously



b- X-ray sources:

X-ray tubes produce the x-ray photons that great the CT image. Their design is a modification of a standard rotating anode tube. Tungsten, with an atomic number of 74, is often used for the anode target material

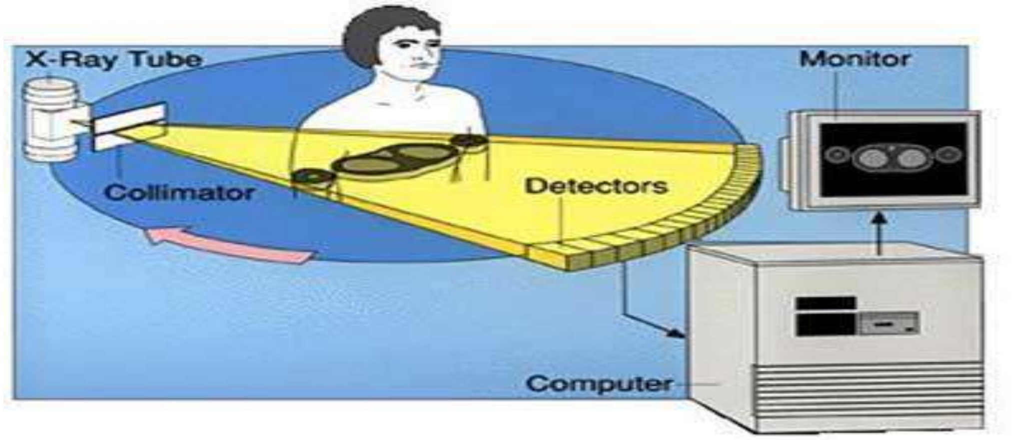
A large amount of stress is placed on the CT tube because of the scanning protocols that want multiple long exposures for many patients per day. A CAT tube must be designed to handle such stress.

c- Cooing Systems

Cooling mechanism is included in the gantry. They come in different forms, such as blowers, filters, or oil. Cooling mechanism is important because many imaging components can be affected by unstable temperature.

d- Collimation

Collimation makes the x-ray beam to project on a specific area, in order to reduce the scatter radiation. Scatter radiation reduces image quality and increases the radiation dose to the patient.



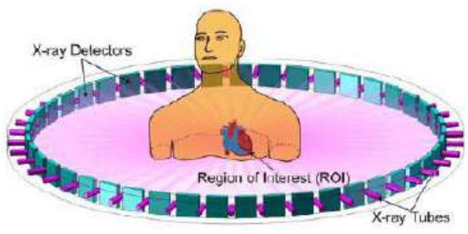
The benefits of reducing the scatter radiation:

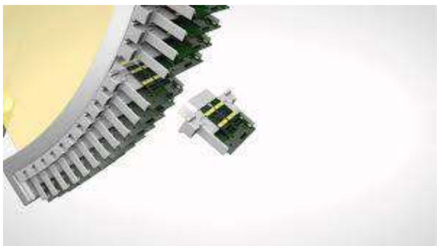
1- Improves contrast resolution.
2- Decrease patient dose.

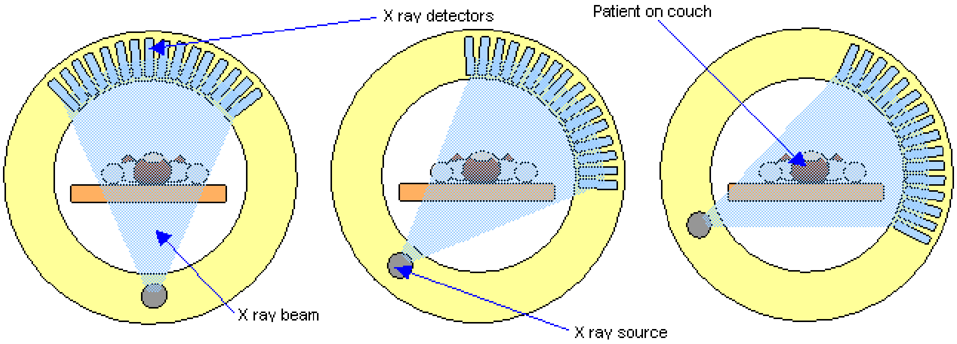
The collimator is located near the x-ray source,

Detectors:

As the x-ray beam passes through the patient t is absorbed by the different body components. Regarding to this different degree of absorption and the information of each anatomic structure an x-ray image is built. The detector measure the intensity of transmitted x-ray radiation beam projected from the x-ray source.







CT scanner with the X ray source and detectors shown in three positions

The characteristics of detectors are:

1) The detector efficiency, defined as the ability of the detector to capture transmitted photons and change them to electronic signals.

2) High scatter reduction

3) High stability, which allows a system to be used without the interruption of frequent calibration.

Contrast-Die

A special dye called contrast material is needed for some CT scans to help highlight the areas of the body being examined. The contrast material blocks X-rays and appears white on images, which can help emphasize blood vessels, intestines or other structures.

There are several types of contrast materials:

- Iodine-based and barium-sulfate compounds are used in x-ray and computed tomography (CT) imaging exams.

Contrast materials can have a chemical structure that includes iodine, a naturally occurring chemical element. These contrast materials can be injected into veins or arteries, within the disks or the fluid spaces of the spine, and into other body cavities.

- Barium-sulfate is the most common contrast material taken by mouth, or orally. It is also used rectally and is available in several forms, including:

- powder, which is mixed with water before administration
- liquid
- paste
- tablet

Contrast material might be given to the patient:

- **By mouth.** If your esophagus or stomach is being scanned, you may need to swallow a liquid that contains contrast material. This drink may taste unpleasant.
- **By injection.** Contrast agents can be injected through a vein in your arm to help your gallbladder, urinary tract, liver or blood vessels stand out on the images. You may experience a feeling of warmth during the injection or a metallic taste in your mouth.
- **By enema.** A contrast material may be inserted in your rectum to help visualize your intestines. This procedure can make you feel bloated and uncomfortable.

When iodine-based and barium-sulfate contrast materials are present in a specific area of the body, they block or limit the ability of x-rays to pass through. As a result, blood vessels, organs and other body tissue that temporarily contain the iodine-based or barium compounds change their appearance on x-ray or CT images.

DETERMINANTS OF AN OPTIMAL IMAGE

Determinants of an optimal image in CT as in any image acquisition system are:

1. Spatial resolution
2. Contrast resolution
3. Temporal resolution.

1. Spatial Resolution

The ability of a CT system to distinguish two small, high contrast objects located very close to each other under noise-free conditions. • The axial or x-y plane spatial resolution is dependent on the pixel size.

2.Temporal Resolution

Refers to the ability of a CT scanner to capture objects that change shape or position over time. • The temporal resolution is determined by 1.The gantry rotation time, (330 to 370 msec) 2.Acquisition mode, becomes especially important in cardiac CT to overcome the cardiac motion,

3.Contrast Resolution
Contrast resolution is the ability of a CT scanner to differentiate small attenuation differences on the CT image. • The ability of the scanner to differentiate small differences in attenuation between closely spaced objects.
Being able to differentiate between two tissues with similar attenuation is a crucial aspect of a CT scanner. This ability is often what allows for the diagnosis of certain pathologiesthe linear attenuation coefficient is an absorption measurement and it is dependent on
1. thickness of a material,
2. density of a material,
3. atomic number and
4. photon energy.

Factors that impact contrast resolution include:

- **Object Contrast**-the natural contrast of an object being imaged can impact the level of contrast resolution. In these instances, contrast media may be given to the patient to assist with differentiation of tissues.

- **Scatter**-reducing the radiation beam will also reduce the scatter radiation, which will improve contrast resolution.

- **Image reconstruction**– use of reconstruction algorithms similar to a soft tissue kernel, will help to improve contrast resolution.

- **Detector size**-smaller detectors improve contrast resolution as thinner slices reduce the variation of attenuation within each pixel.
- **Noise**-the level of noise in an image directly impacts the contrast resolution. *Decreasing* the noise in an image will improve the contrast resolution. .

MRI (Magnetic Resonance Imaging)

Introduction

Magnetic Resonance Imaging (MRI) is an imaging technique used primarily in medical setting to produce high quality images of the soft tissues of the human body. MRI is considered ideally suited for soft tissue problem

•Diagnosing multiple sclerosis (MS)

•Diagnosing brain tumors

•Diagnosing spinal infections

•Visualizing torn ligaments in the wrist, knee and ankle

•Visualizing shoulder injuries

•Evaluating bone tumors, and herniated discs in the spine

•Diagnosing strokes in their earliest stages


Magnetic resonance imaging is based on the absorption and emission of energy in the radio frequency range of the electromagnetic spectrum. It is clear from the attenuation spectrum of the human body.

The human body is primarily fat and water. Fat and water have many hydrogen atoms which make the human body approximately 63% hydrogen atoms. Hydrogen nuclei have an NMR signal. For these reasons magnetic resonance imaging primarily images the NMR signal from the hydrogen nuclei. Each voxel of an image of the human body contains one or more tissues. For example here is a voxel with one tissue inside. Zooming in on the voxel reveals cells. Within each cell there are water molecules. Here are some of the water molecules. Each water molecule has one oxygen and two hydrogen atoms. If we zoom into one of the hydrogen's past the electron cloud we see a nucleus comprised of a single proton. The proton possesses a property called spin which:

1. can be thought of as a small magnetic field, and
2. will cause the nucleus to produce an NMR signal.

Not all nuclei possess the property called spin.

Spin & Moment

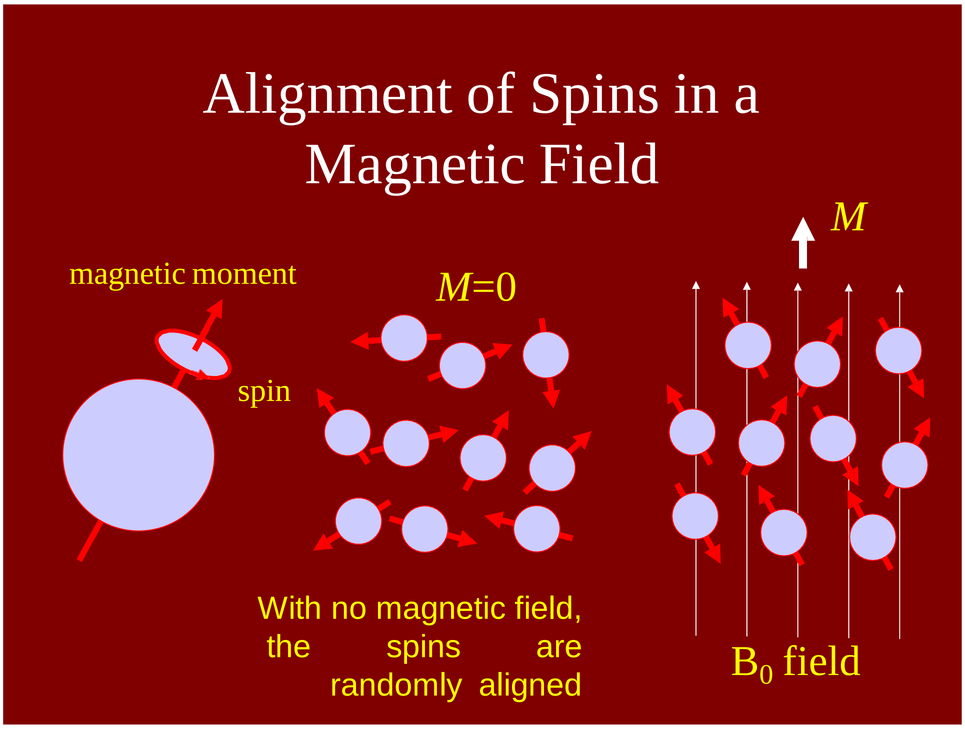
- All nuclei have spin – multiples of ½
- Combined with charge →moment
- Nucleus with odd spin acts like a small dipole magnet
- If nucleus has *S* spin states, the moment (magnet) has 2*S*+1 stable state in an external magnetic field
- Hydrogen (proton): *S* = ½ → 2 states

The hydrogen nucleolus has a large magnetic moment, and its abundance in the body makes it the basis of most clinical magnetic resonance (MR) imaging

Magnetic moment is a vector that represents the strength and orientation of the **magnetic dipole:** which is a result of proton and neutrons nuclear spin and charge distribution produced a magnetic field called magnetic dipole, nuclei with an even number of protons or neutrons have no net magnetic moment because the proton and neutrons pair up with their magnetic moments aligned in opposite direction and cancel each other while nuclei with an odd number of protons or neutrons have a net magnetic moment and behave like **a bar magnet**

There are more than 10^{20} hydrogen protons in each cubic centimetre of tissue, nuclear spins of these protons are normally randomly oriented and thus produced no net magnetic moment (**magnetisation vector**)

In magnetic field hydrogen nuclei (protons) may be orientated either spin up (i.e. aligned along the field) or spin down (i.e. aligned opposite to the field) spin down alignment have slightly more energy a small excess



Any tissue placed in a large magnetic field therefore has a small net magnetization vector of unpaired hydrogen protons aligned in the direction of the external field;

Magnets field strength :

Imaging 0.2T to2.0 T

- Low field 0.5 -0.2T
- Intermediate 0.5-1.5T
- High field 1.5 - 4 T
- Ultra high < 4T

Earth's magnetic field = $5x10^{-5}$ T

Resonance:

Resonance occurs when the net magnetization vector is perturbed from its equilibrium orientation. Electromagnetic radiation applied at the Larmor frequency (f_L); the Larmor frequency is the frequency (MHz) of nuclei in a magnetic field and perpendicular to the external magnetic ,this electromagnetic radiation is in radiofrequency (RF) part of the electromagnetic spectrum.

How dose MRI works?

Most of the human body is made up of fat and water which consist of hydrogen and oxygen atoms, fat and water have many hydrogen atoms, 63%of human body is hydrogen atoms

MRI uses hydrogen because it has only one proton and it aligns easily with the MRI magnet.

At the centre of each hydrogen atom there is an even smaller particle called a proton. Protons are like small magnets and are very sensitive to magnetic fields.

When a patient lies under the powerful magnets, the protons in our bodies line up in the same direction (alignment), in the same way that a magnet can pull the needle of a compass.

Short pulses of radio waves are then sent to certain areas of the body, pushing the protons out of alignment. When the radio waves are turned off, the proton realign and in doing so send out radio signals, which are detected byreceivers

How to understand the signals?

The radio signals provide information about the exact location of the protons in the body. They also help to distinguish between the various types of tissue in the body, because the protons in different types of tissue realign at different speeds and produce distinct signals

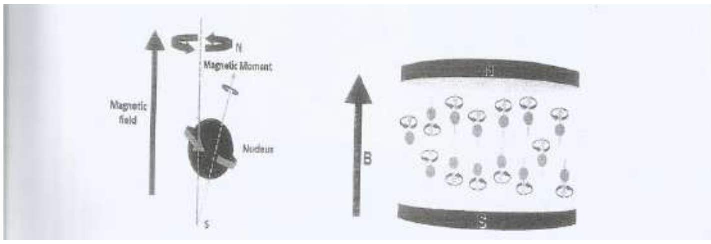
The signals from the millions of protons in the body are combined to create a detailed image of the inside of the body.

Origin of the MRI signals

Hydrogen nuclei (also called protons) behave as small compass needles that align themselves parallel to the field. This is caused by an intrinsic property called nuclear spin; the spin causes the nucleus to behave as a small magnet (it has a magnetic moment)

Properties of Hydrogen:

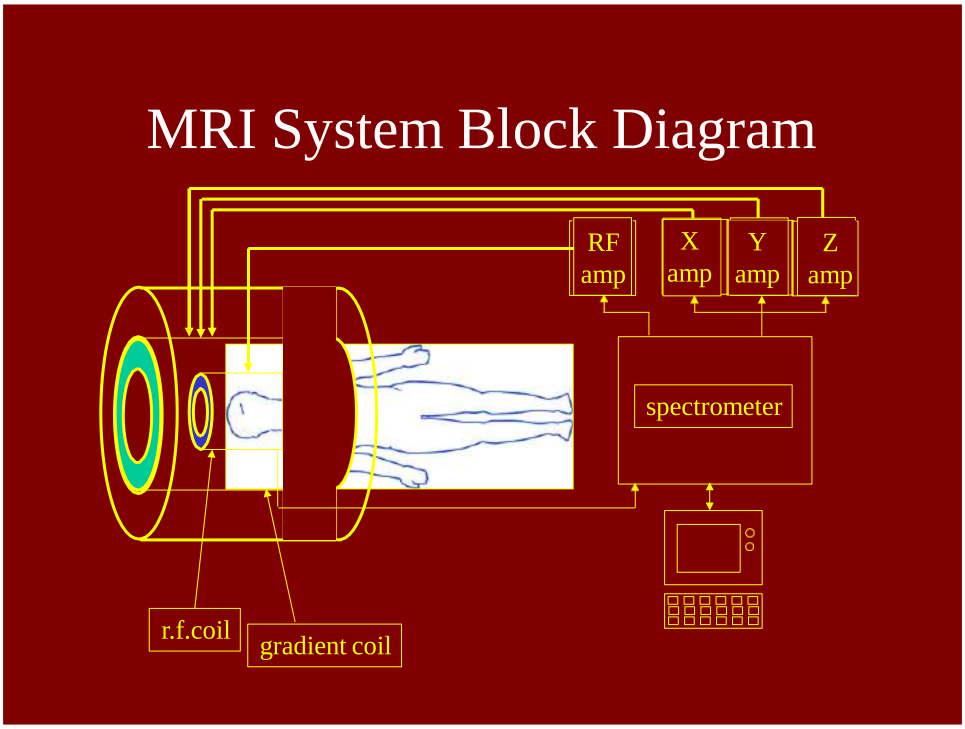
- It has 1 proton and 0 neutrons(both the neutrons and protons spin about their axis
- Has magnetic moment
- Present in living matter
- Good quantity to provide strong MRI signal



The main parts of MRI system:

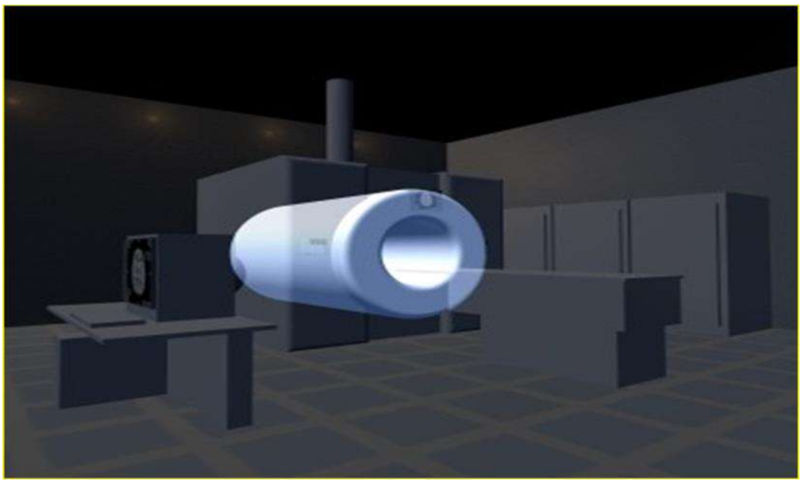
1- Magnet
2- RF coils
3- Gradient
4- Electronics coils

A schematic representation of the major system parts of MRI



1- Magnet:

The most expensive component of the imaging system. Most magnets are of the super conducting, the type of magnets defines the type. Atypically MRI unite is a magnet which produce the magnetic field, The complete MRI system is in a shielded room, the shielding is to cut off any interaction by external radio frequency.



2- RF coils:

Radio frequency (RF) coils are a necessary component of magnetic resonance imaging (MRI) systems. The function of RF coils is used for transmitting energy and receiving signals from the body.

RF coils can be divided into three general categories

a) Transmit and receive coils
b) Receive only coils
c) Transmit only coils

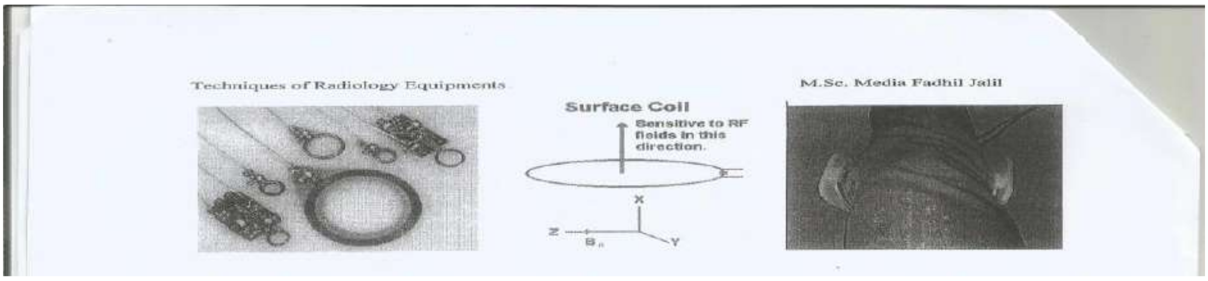
A radio frequency transmitter (RF coil) providing the RF excitation pulse and an RF receiver used for detection and processing of the NMR signals.

RF coils for MRI

- Surface coil
- Volume coil
- Solenoid coil
- Bird cage coil

Surface coil

❖ The most basic and fundamental RF coil system in MRI, which include various shapes
❖ Placed on or around the surface of patient
❖ Detects noise from limited volume.



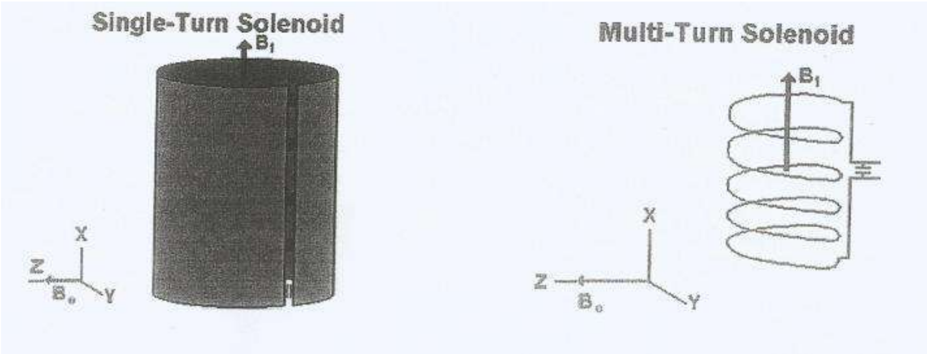
Volume Coil

Used for surrounding either the whole body or a specific region

- ❖ Used for the big body volume
- ❖ Has better magnetic field homogeneity than surface coil.

Solenoid coil

- ❖ Multiple turn solenoid and signals turn solenoid.
- ❖ Produce very good magnetic field homogeneity.

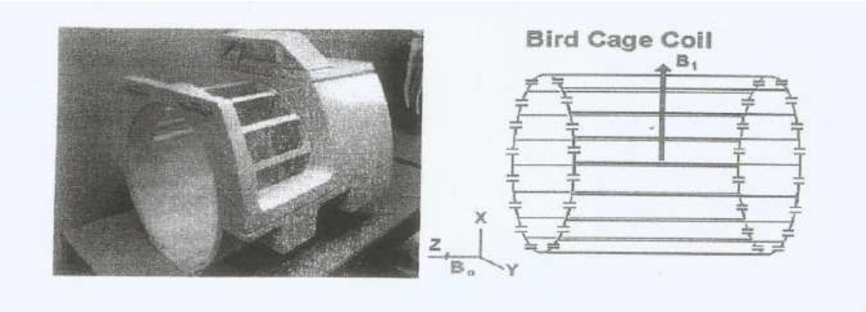


Bird cage coil

❖ The Bird cage coils are extensively used in MRI systems

❖ Introduction a high signal.

❖ High radio frequency magnetic field homogeneity that guarantee a large field view.



Coil sensitively:

- Defined as how weak signals the coils can detect.
- The higher the coil sensitively, the lower signals we can detect
- The higher the coil sensitively, the higher amount of noise is detected.
- Coil sensitively is not uniform within the coil.

Safety

Thermal injuries caused by sensors, cables, MRI accessory (e.g. surface coil) or other accessories placed on the patient may come from the electricity induced in the conductive medium by the MRI environment.

Gradient system and coils

The gradient coil system is used to encode the positions of protons by varying the magnetic field across body, gradient is built with the main magnet

Gradient coils

The gradient coil is the key to MRI imaging, to form an image it is necessary to perform position localization of the MRI signals, which is achieved using gradient coils

MRI also requires the use of gradient coils that generate magnetic fields which moves linearly with position over the body.

Specification of gradient coils:

1- Must have high current efficiency

2- Stability over a large number (large part body)

3- Minimum interaction with other equipment (low noise)

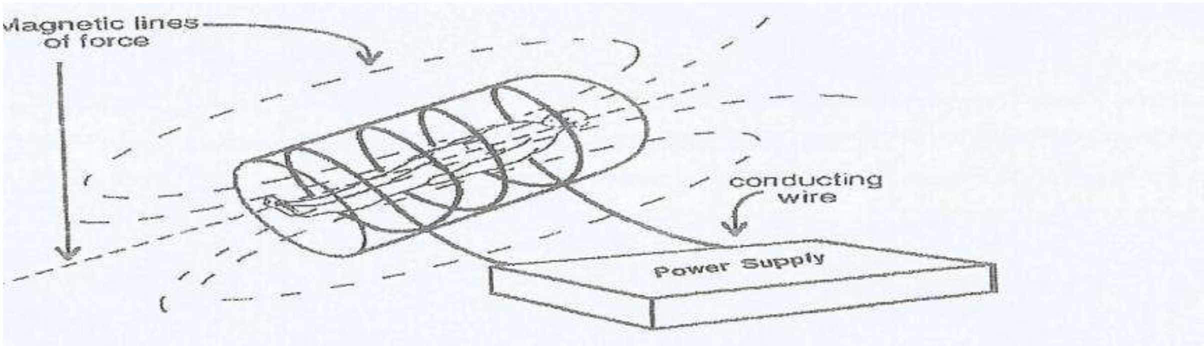
Types of MRI i

a- Closed MRI: Temporary Magnet: a superconducting magnet is an electromagnet made of superconducting wire, the magnetic field of this type ranges from o1 to 5 Tesla.

Superconducting wire has to be cooled to a zero K temperature (- 273C$_o$ or 0K, by emersion in liquid helium).

Once current flows in the coil, it will continue to flow as long as the coil is kept at liquid helium temperature.

An electromagnet is formed by twisting conducting wire, any wire that carriers an electric current is surrounded by a magnetic field. The magnetic field is strongest at the centre of the magnet.



- **The cooling:** Liquid helium is circulated around the superconducting wire in an insulating chamber called a dewar. Second insulating chamber containing liquid nitrogen at – 196C, is used to help maintain the helium in its liquid state.

The problem is that helium is running out because it is very light. Heluim level should be monitored periodically to ensure the system safety.

- **Advantage:**

- High image quality
- Good for all tissue types (deep tissue)

- **Disadvantage:**

- High cost (cooling & power system)
- Heavy
- High risk for metal implants

b- Open MRI:

Permanent Magnet: Permanent Magnet is composed of ferromagnetic materials that maintain their magnetic properties naturally.
The field Strengths ranges from 0.2 to 1Tesla. In such a system the patient is placed between the poles of the Permanent magnet with the direction of magnetic field lines perpendicular to the axis of the patient.

 Advantages:

- Low power consumption
- Low operating cost
- Suitable for claustrophobic, children, obese and pregnant patients.

 Disadvantages:

- Limited field strength (low image quality)
- Magnet is always ON

Noise in MRI

The MRI machine uses a combination of a strong magnet, radio transmitter and receiver. When the sequences are performed, electric current is sent through a coiled wire-an electromagnet. The switching of the currents causes the coils to expand making loud clicking sounds. The sounds vary depending on the type of sequences being used and some are louder than others. While the noise is produced by turning on and off the currents the MOST important factor to remember is that the **MAGNET IS ALWAYS ON**. The main magnet is always on and this is why everyone entering the scan room must be safely screened to ensure their safety. All equipment used in the MRI environment is special (nonferrous) for MRI

How Loud Is an MRI?

The loudness of an MRI scan depends on the specific procedure and the machine used. MRI noises can range anywhere from 65 decibels to 130 decibels. They can often go above 90 to 100 decibels, requiring the patient to wear ear protection., common loud noises measure at these decibel levels:

- **70 decibels:** Alarm clock or vacuum cleaner
- **94 decibels:** Food processor or blender
- **112 decibels:** Rock concert or chainsaw
- **120 decibels:** Jet plane takeoff

Magnetic field to create images of patient body's tissues. Many scanners have magnets that produce fields as much as 60,000 times the strength of the earth's magnetic field.

Every MRI machine has metal coils known as gradient coils that create the noises we associate with MRIs. When the gradient coils receive electrical pulses, they generate a magnetic field. Each pulse makes the coils vibrate and create loud noises. Since the scanner has a hollow inside, these sounds echo and become louder.

Types of MRI Noises to Expect

The patient may hear different kinds of noises during an MRI scan. Every electric pulse sequence creates a distinct sound based on the waveform of the current. MRI technologists use different pulse sequences and orientations to capture the angle, contrast and area they need. Patients use different words to describe the sounds they hear, including:

- Banging
- Clicking
- Whirring
- Clanging
- Beeping

How Will the Technologist Protect patient Ears?

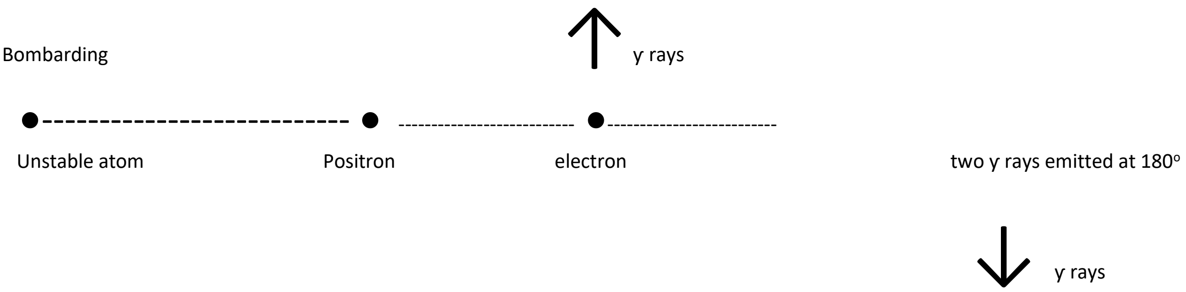
During an MRI scan, the technologist will provide headphones to protect patient ears from loud MRI sounds. At Envision Imaging, our technologists provide headphones that play music during the scan.

Will future MRI technique become quieter?

Some MRI machines have a design meant to reduce the noise it makes during scans. Currently, this technology tends to compromise image quality in exchange for less noise. As MRI technology develops, researchers hope to create a quieter machine with clear images.

tomography (PET) i

Positron emission tomography, also called PET imaging or a PET scan, is a type of nuclear medicine imaging it uses a radioactive substance called a tracer.
Nuclear medicine is a branch of medical imaging that uses small amounts of radioactive material to diagnose or treat a variety of diseases, including many types of cancers, heart disease, neurological disorders and other abnormalities within the body.
Because nuclear medicine procedures are able to pinpoint molecular activity within the body, they offer the potential to identify disease in its earliest stages
PET scan is an imaging technique which produces images of the body by detecting radiation or gamma rays emitted from the body after the patient injected which a radioactive tracer.
When a positron emitted by a radioactive substance bombards an electron in the tissue, two gamma rays are emitted in the opposite direction as shown in below figure



These rays are detected by a detector, when the gamma ray strikes the detector; it emits a pulse of light. This is amplified in a photomultiplier tube and the resulting signal goes to the computer for processing

How the Test is performed

A PET scan uses a small amount of radioactive material (tracer).Radiotracers are molecules linked to, or "labeled" with, a small amount of radioactive material that can be detected on the PET scan. They are designed to accumulate in cancerous tumors or regions of inflammation. The most commonly radiopharmaceutical used is radionuclide combined with sugar fluorodeoxyglucose, or FDG, Cancer cells may absorb glucose at a higher rate, being more metabolically active. This higher rate can be seen on PET scans, and that allows identifying disease before it may be seen on other imaging tests. FDG is just one of many radiotracers in use or in development for a variety of conditions throughout the body Depending on the type of nuclear medicine exam, the radioactive atom is either Carbon-11, Fluorine-18, oxygen-15or Nitrogen-13. The radiotracer is either injected into the body, swallowed or inhaled as a gas and eventually accumulates in the organ or area of the body being examined this helps the radiologist see certain areas more clearly.

A PET scan creates pictures of organs and tissues in the body. First, a technician gives an injection of a small amount of a radioactive substance. The organs and tissues pick up this substance. And areas that use more energy pick up more. Cancer cells pick up a lot, because they tend to use more energy than healthy cells.

Radioactive emissions from the radiotracer are detected by a special camera or imaging device that produces pictures and provides molecular information. Then, the patient lie on a narrow table that slides into a large tunnel-shaped scanner. The PET detects signals from the tracer. A computer changes the signals into 3D pictures. The images are displayed on a monitor for patien health care provider to read.

Specification of PET

1- A PET scan causes no pain.
2- The tracer Need about 1 hour to wait as is absorbed by the body.
3- A PET scan can reveal the size, shape, position, and some function of organs.

PET Instrumentation system

The instrument system consists of:

i. Cyclotron
ii. Bio-synthesizer
iii. Scanner Detector and
iv. Computer

Cyclotron, the cyclotron is a machine which is used to produce radioisotopes, which are then used in the Bio-synthesizer to produce radiopharmaceuticals.

Bio-synthesizer, it attaches FDG to the radionuclide to forma radiopharmaceuticals

Scanner, it is large ring-shaped with detectors

Computer, the computer terminal is located outside the room it collects the data from the scanner and the software helps highlight areas of large consumption of glucose

Compare between PET & CT

A PET scan shows how organs and tissues are working. This is different than magnetic resonance imaging (MRI) and computed tomography (CT). The amount of radiation used in a PET scan is about the same amount as used in most CT

A PET scan measures important body functions, such as blood flow, oxygen use, and sugar (glucose) metabolism, to helps evaluate how well organs and tissues are functioning.

A CT scan takes pictures of the inside of the body using x-rays taken from different angles. A computer combines these images into a detailed, 3-dimensional image that shows anything abnormal, Sometimes, a special dye called a contrast medium is given before the scan to provide better detail on the image.

CT imaging provides excellent anatomic information.

A CT scan is fast, generally they take only a matter of minutes to perform and don't require any changes in your routine, or preparations before your appointment.

A PET scan on the other hand does take longer; the entire procedure takes one to three hours, depending upon the radioactive tracer and the organ being study. A PET scan also requires the patient receive a very small dose injection of a radioactive chemical known as a radiotracer. A PET scan requires the patient eat a high protein diet and stay away from carbohydrates such as bread and pasta the day before. Also the patient should not eat or drink for 8 to 12 hours before the test and avoid drinking alcohol; caffeine and smoking or take medicines 24 hours before the test.

After the test, the patient is asked to take a lot of fluids to eliminate the tracer from the body, it generally takes 6 to 24 hours for elimination

Single Photon Emission Computed Tomography (SPECT)

The SPECT scan is similar to the PET scan expect that the radio nuclide is different and has a large decay time (half-life period). In this scanning the radioactive substance used are Idone-123, Xenon-133 and Technetium-99, when a positron strikes an electron it emits a single gamma ray instead of two rays at 180_o. Hence for each ray, there is only one detector the image obtained with SPECT gives less detail compared to a PET. However, the technique is less expensive as compared to a PET. Another advantage is that the cyclotron or particle accelerator need not be located in the same room as the patient

Mammography

Mammography (also called autography) is the process of using low-energy X-rays (usually around 30 kVp) to examine the human breast, The goal of mammography is the early detection of breast cancer, typically through detection of characteristic masses, like all X-rays, mammograms use doses of ionizing radiation to create images. These images are then analyzed for any abnormal findings.

Properties of Mammography

- Mammography is a low-cost and low -dos producer
- Modern mammography equipment uses small focal spots, low tube voltages techniques, low ratio grids
- Typically x-ray tube currents are 80-200 mA and exposure times are usually about 1s but can be as long as 4s for
dens thick breast
- A beryllium (Z=4) x-ray tube window is used to minimize x-ray beam attenuation

Image quality and Dose

Magnification imaging with a small focal can improve the achievable spatial resolution, increasing voltage reduces exposure time and patient dose when film density kept constant, low-voltage techniques increase contrast but also increase patient dose.

Grids may improve the contrast by a factor of two, but also increase the radiation dose by a factor of two or three.

-the film cassettes must be meticulously cleaned carefully handled to minimize artifacts and maintain high image quality.

Ultrasound

Medical ultrasound (also known as diagnostic sonography or ultrasonography) is a diagnostic imaging technique based on the application of ultrasound. It is used to obtain images of a internal body and organs in the abdomen including the liver, kidney, spleen pancreas, bladder and the fetus during pregnancy. It is used to detect cysts, tumors and cancers structures such as tendons, muscles, joints, vessels and internal organs.

Advantages of Ultrasound

- Non-invasive technique which does not injecting a dye.
- Patient is far away from x-rays harmful
- Different soft tissues can be seen with excellent clarity
- The power level is 1watt/cm_2 do not cause any damage to any tissue

Physics of Ultrasound

Ultrasound is sound waves with frequencies which are higher than those audible to humans (>20,000 Hz), they require a medium for transmission. They can be focused into abeam which obeys the law of diffraction and reflection. Ultrasound waves may be longitudinal or transverse. For medical dignostic application, only the longitudinal model of wave propagation is used
When a beam of ultrasound wave passes from on medium to another, a portion of the sonic energy is reflected and the remaining is refracted the amount of reflected depends upon the difference in density of the two media and the angle of incidence. If the difference in densities is very large and if the angle of incidence is near normal to the interface, a greater portion of energy is reflected. Iif the difference in the densities between two media is very large, e.g., tissue and bone, or tissue and gas, all the energy is reflected and the ultrasound beam will not continue through the second medium. Therefore,

when ultrasound is applied to the body, an airless contact of the tissue with transducer is made by using an aqueous gel between transducer and the skin. The velocity of sound through any medium depends upon the following:

(i) density of the medium

(ii) elasticity of the medium and

(iii) temperature

Velocity through water is 1529 m/sec, through soft tissue it is 1550 m/sec, and through bone is 3360 m/sec

Every material has an acoustic impedance, acoustic impedance or characterstic impedance is given by

=

$= \rho \upsilon$

Where

ρ =Density of the medium, and

υ= Velocity of sound through it

Attenuation constant α= cfß

Where

c =Constant of proportionality

f= Frequency

ß= exponential term determined by the properties of the material

This means that attenuation increases with increase in frequency. Thus, as the frequency rises, the wave can penetrate a smaller distance. Therefore, for deeper penetrations, lower frequencies are used. Frequencies used range from 1 MHz to 15 MHz. At 2 MHz, distinct echoes can be recorded from interfaces 1mm apart. Another important term is the half value layer. It is the depth of penetration at which ultrasound energy is attenuated to half the applied amount.

Tissue half value layer (cm) frequency

Blood 35.0 1MHz

Bone 0.23 0.8MHz

Muscle 2.1 0.1 MHz

Ultrasonic images are made by sending pulses of ultrasound into tissue using a probe. The sound echoes off the tissue; with different tissues reflecting varying degrees of sound. These echoes are recorded and displayed as an image to the operator.

Tissue reflection

Air-tissue interfaces reflect virtually the entire incident ultrasound beam and bone-tissue interfaces also reflect substantial fractions of the incident intensity, gel is applied between the transducer and skin to displace the air and minimize large reflections that would interfere with ultrasound transmission in to the patient, the lack of transmission beyond this interfaces results in an area void off echoes called **shadowing**

Doppler Effect

The frequency of the reflected ultrasound wave is increased or decreased by a moving interface like blood.

Δf

Where

Δf=change in frequency of the reflected wave

V=velocity of the interface

λ =wavelength of the transmitted ultrasound.

The frequency increases when the interface moves towards the transducer and decreases when it moves away. This increase or decrease is measured.

The Doppler ultrasound is a test can be used to estimate the blood vessels flow through your blood vessels by bouncing high-frequency sound waves by circulating red blood cells