Techniques of radiology equipment

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, a magnetic field strength is 1 Tesla.

1T=10,000 gauss (G), the Earth's magnetic field is weak 50uT or 0.5G

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

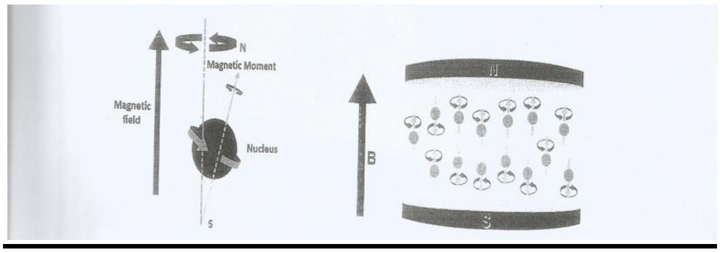
The signals from the millions of protons in the body are combined to create a detailed image of the inside of the body.

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:

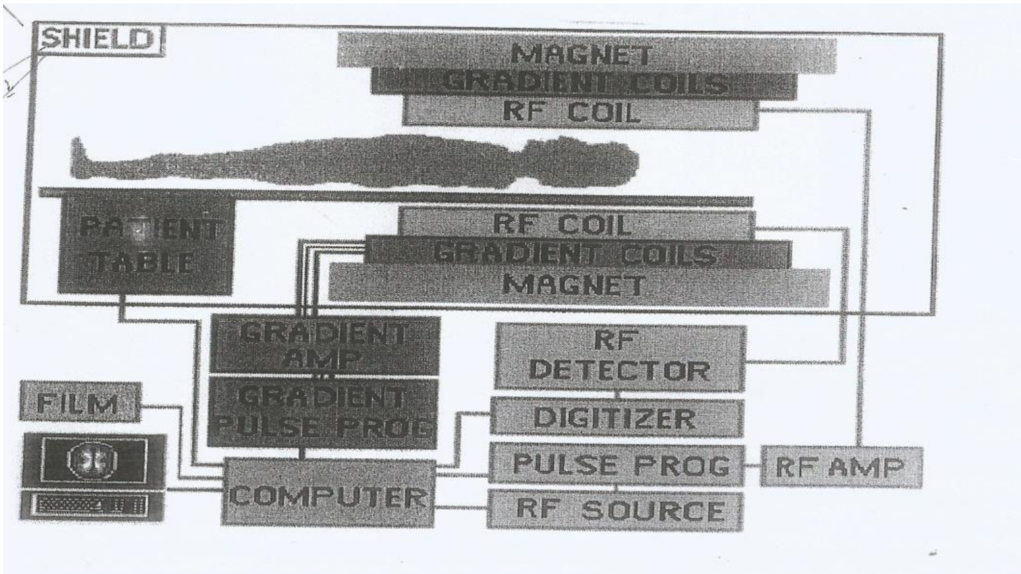
- It has 1 proton and 0 neutrons(both the neutrons and protons spin about their axis
- Has magnetic moment
- Present in living matter
- Good quantity to provide strong MRI signal



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

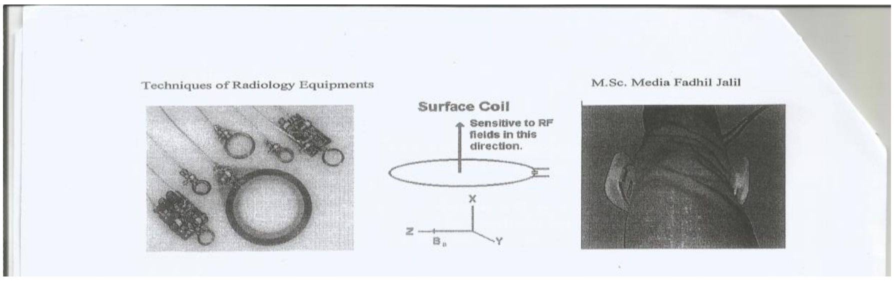
A radio frequency transmitter (RF coil) providing the RF excitation pulse and an RF receiver used for detection and processing of the NMR signals.

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.

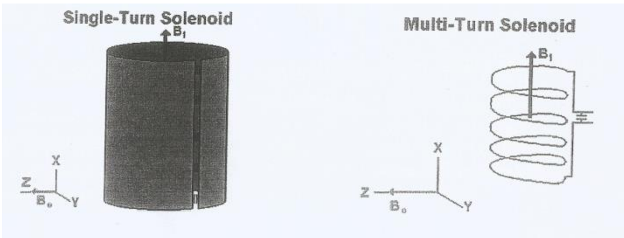


a- Volume Coil

- ❖ 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.

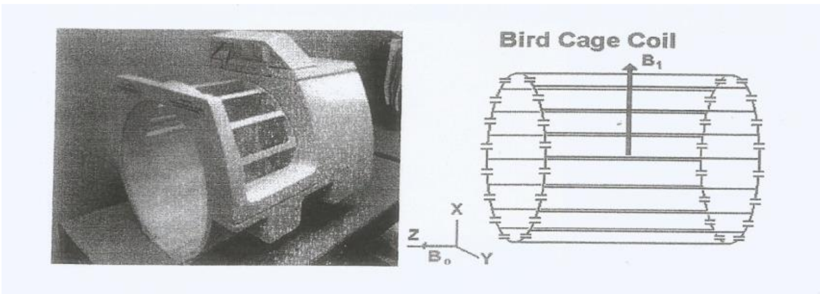
b- Solenoid coil

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



c- 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)

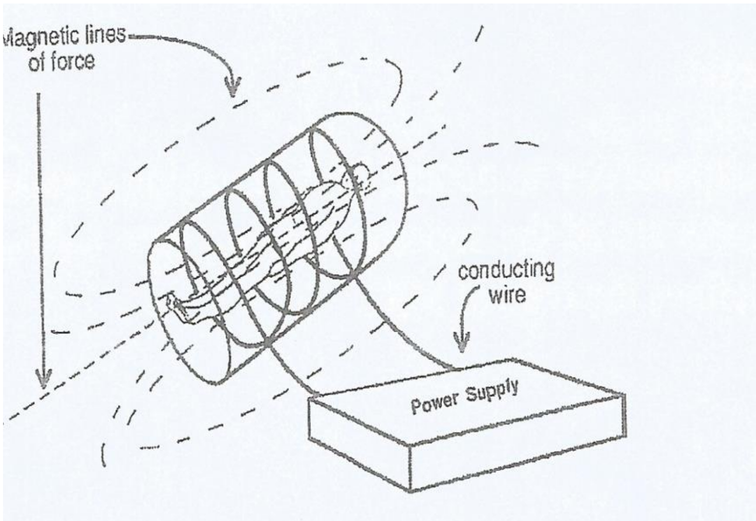
3- Minimum interaction with other equipment (low noise)

Types of MRI

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. Magnetic field "lines "are invisible lines in space that define the direction of force of the magnetic field upon a ferromagnetic object such as iron.



- **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.

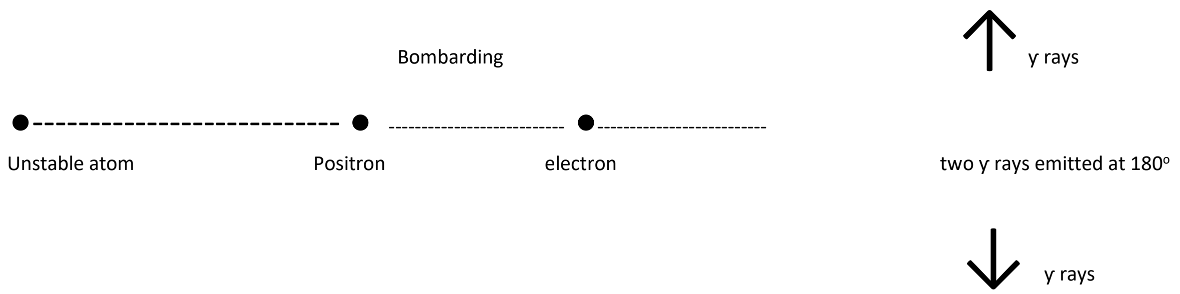
Positron emission tomography (PET)

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

Mammography

Mammography (also called autography) is the process of using low-energy Xrays
(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.

Techniques of radiology Equipment Radiology department/Snd Stge
L. cheman Baker
46

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 $\alpha = cf\beta$
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

Techniques of radiology Equipment Radiology department/Snd Stge
L. cheman Baker
48

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 highfrequency sound waves by circulating red blood cells