



EQUIPMENT TECHNIQUES OF MAGNETIC RESONANCE IMAGING

3.ST STAGE **LECTURE 1- THEORY**

INTRODUCTION AND OVERVIEW OF MRI

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Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) is based on the principles of nuclear magnetic resonance (NMR), a spectroscopic technique used by scientists to obtain microscopic chemical and physical information about molecules. The technique was called magnetic resonance imaging rather than nuclear magnetic resonance imaging (NMRI) because of the negative connotations associated with the word nuclear in the late 1970's. MR detects subtle changes in the magnetism of the nucleus, the tiny entity that lies at the heart of the atom. This is probing deeper than X-rays, which interact with the clouds or shells of the electrons that orbit the nucleus. MR is a truly powerful modality. At its most advanced, MR can be used not just to image anatomy and pathology but to investigate organ function, to probe in vivo chemistry and even to visualize the brain thinking.

- MR involves an amazing combination of advanced science and engineering, including the use of superconductivity, cryogenics, quantum physics, digital and computer technology.**
- It is an imaging method based principally upon sensitivity to the presence and**

properties of water, which makes up 70–90% of most tissues.

- **Energy Used : Magnetic Field and Radio Waves.**

Magnetic Resonance Imaging

Closed MRI

Open MRI



Magnetic Resonance Imaging



An example of a niche magnet for imaging extremities. This scanner is a high - field (1.0 T) superconducting imaging system. Image courtesy of ONI Medical Systems Inc, MA, USA .

Magnetic Resonance Imaging

**0.6 T Fonar upright positional system,
electromagnet with horizontal B0
(courtesy of Medserena Upright MRI
Centre, London);**



CT vs. MRI

CT

- ❖ CT scans utilize X-rays to form images inside the body
- ❖ Exposure to ionizing radiation (X-rays)
- ❖ CT scans are quick, painless, and noninvasive.
- ❖ MRI scans are costlier than CT scans.
- ❖ different soft tissues can be seen but not well characterized

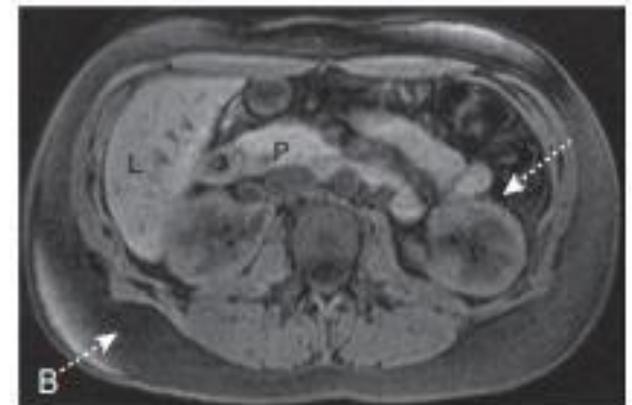
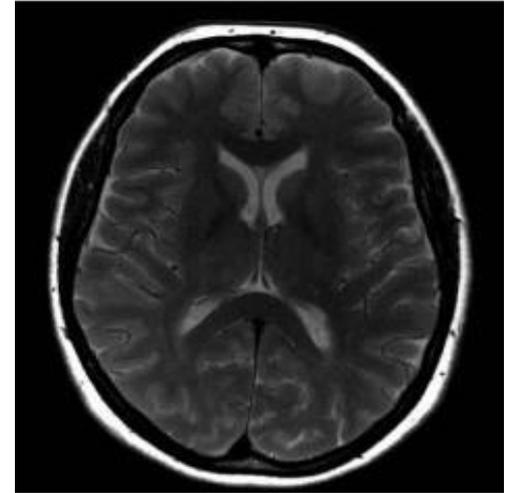
MRI

- ❖ while MRI (magnetic resonance imaging) uses powerful magnetic fields and radiofrequency pulses
- ❖ MRIs do not use ionizing radiation (X-rays).
- ❖ MRI scans are not invasive, but they are noisy, take more time, and may cause claustrophobia (anxiety due to being in the enclosed space of the machine).
- ❖ MRI scanners may cause a safety issue due to their strong magnets.
- ❖ MRIs provide more detailed information about the inner organs (soft tissues) such as the brain, skeletal system, reproductive system and other organ systems than is provided by a CT scan.

CT

VS.

MRI



CT scan (Computed Tomography) work

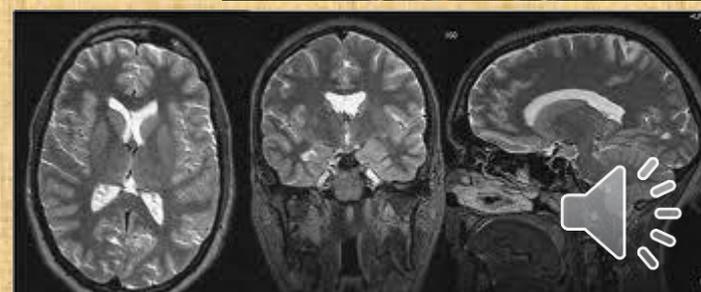
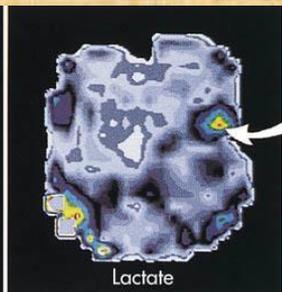
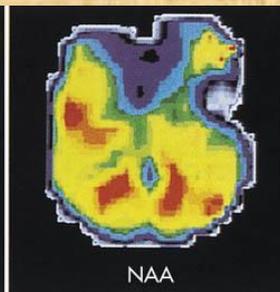
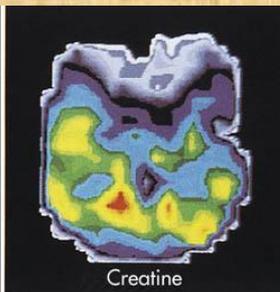
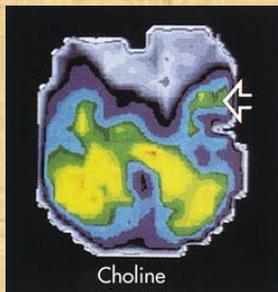
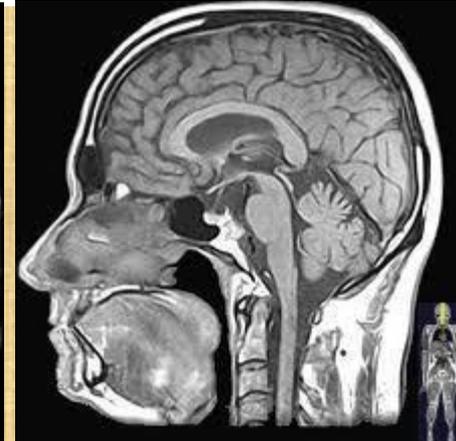
CT scan works by taking multiple X-rays at various angles and then utilizes those X-rays to form a three-dimensional image of whatever organ system is being examined. A computer examines all of the various X-rays taken at different angles and synthesizes the images to form a three-dimensional computer model of internal organs.

MRI (Magnetic Resonance Imaging) scan work

MRIs use and send superconducting magnet and radiofrequency waves into the body. The magnetic field lines up atoms either in a north or south position with a few atoms that are unmatched (keep spinning in a normal fashion). When radiofrequency is added, the unmatched atoms spin in an opposite direction, and when the radiofrequency is turned off those unmatched atoms return to the normal position emitting energy. The energy emitted sends a signal to the computer and the computer uses mathematical formulas to convert the signal into an image.

Magnetic Resonance Imaging

- Anatomy
- Physiology (function)
- Angiography
- Diffusion
- Perfusion
- Spectroscopy

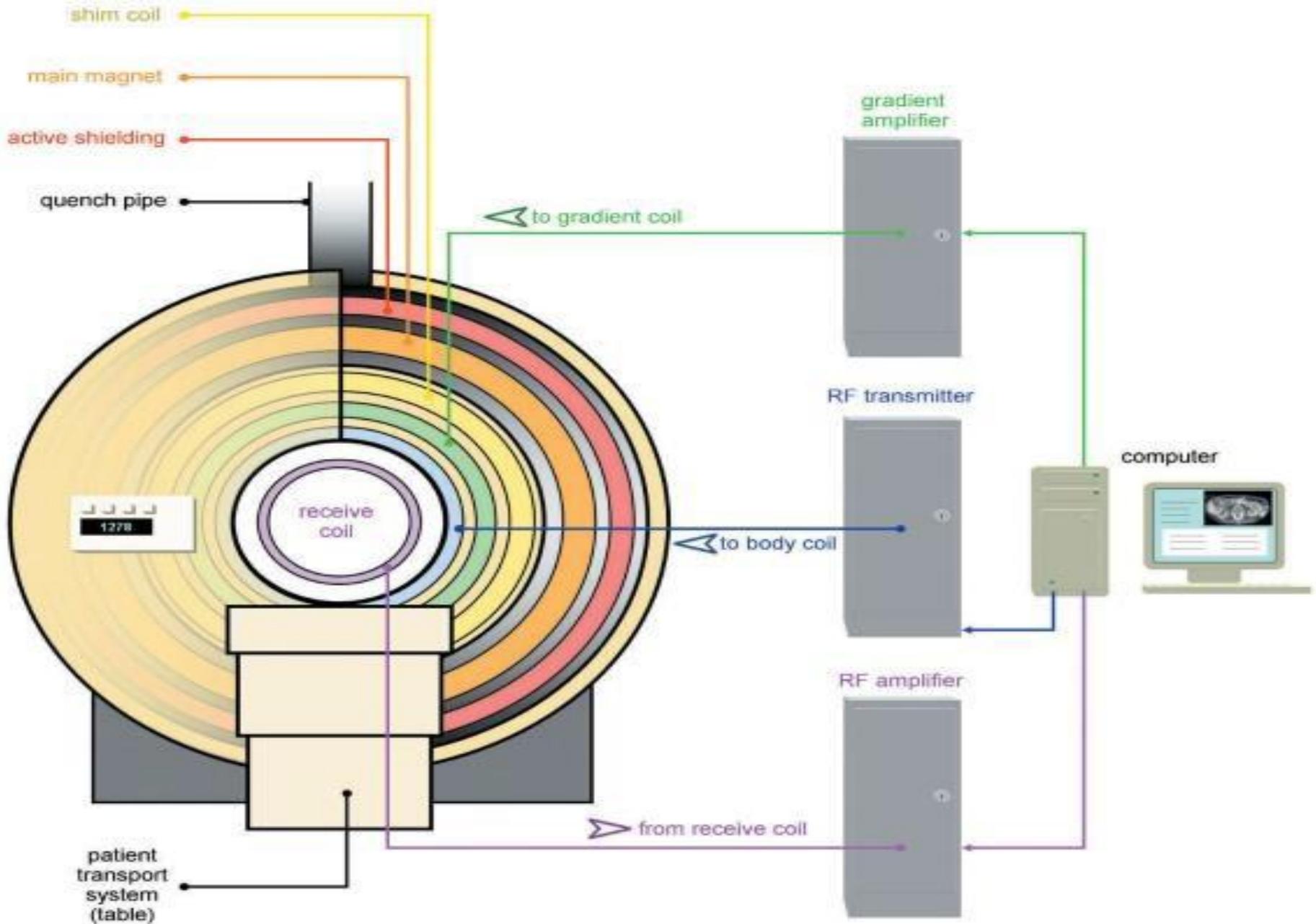


Contraindications and Caution

MRI examinations are usually contraindicated for patients with:

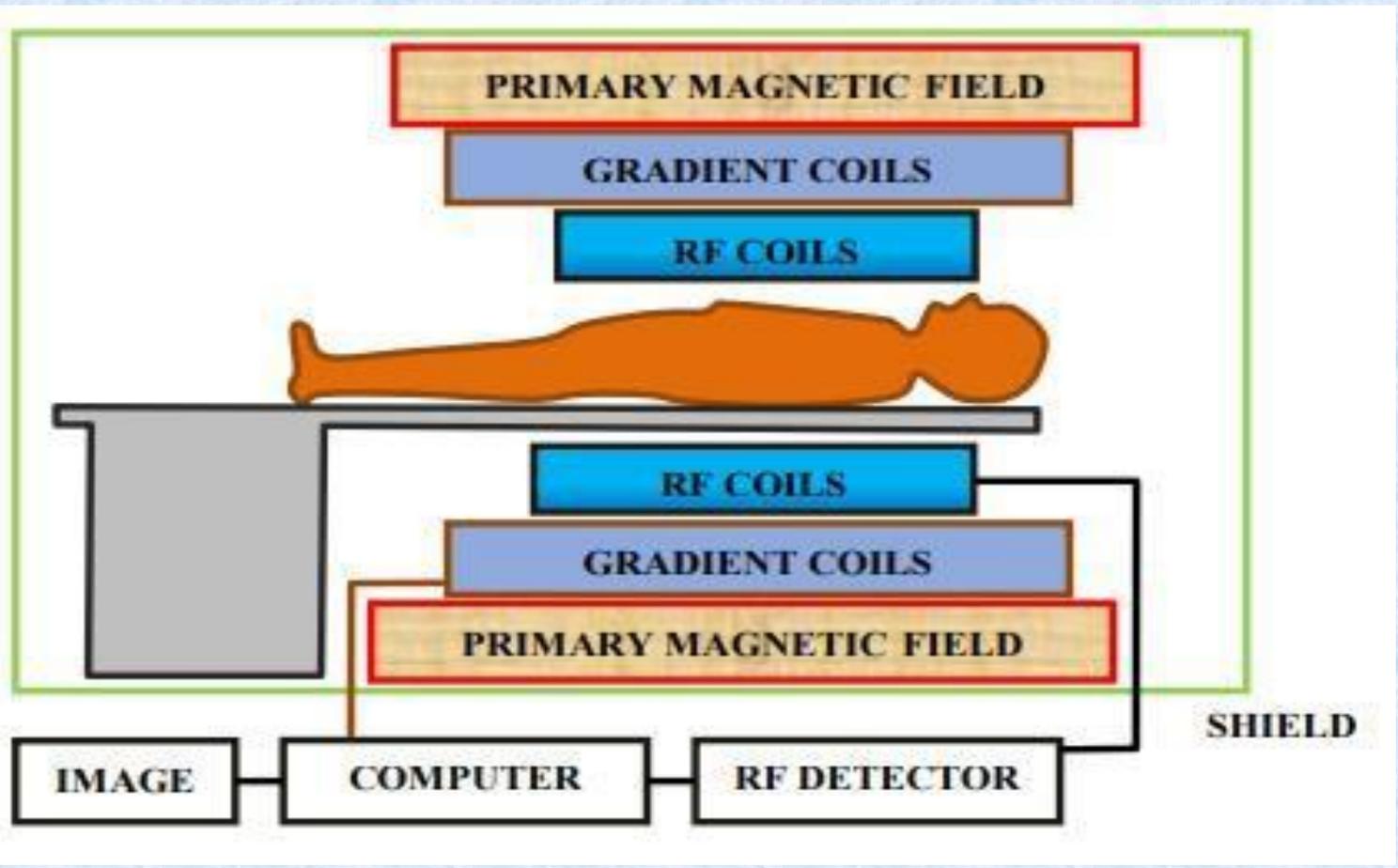
- **Ferromagnetic Objects**
- **conventional cardiac pacemakers**
- **Aneurysm clips**
- **Biopsy needles**
- **Bullets**
- **AIMDs, e.g. neuro-stimulators**
- **Cochlear implants**
- **Heart valve prosthesis**
- **pregnant patients**
- **patients with tattoos, including permanent eye-liner;**
- **patients with compromised thermoregulatory systems, e.g. neonates, low-birth-weight infants, certain cancer patients;**
- **neonates and infants, for whom data establishing safety are lacking;**

Hardware That Makes Up An MRI Scanner



Hardware That Makes Up An MRI Scanner

- 1- **A magnet – for nuclear alignment.**
- 2- **A radio frequency source for -RF excitation.**
- 3- **A magnetic field gradient system – for spatial encoding.**
- 4- **A computer system – for the image formation process and the user interface.**
- 5- **An image processor – to convert ‘ signals ’ into images.**



The magnet

- The magnet is the heart of the MR system. The size of an MR system is expressed in terms of its operating magnetic field strength.
- Once a ferromagnetic material is exposed to an external magnetic field it retains magnetization and therefore becomes magnetized.
- The magnetic field strength is measured in one of two units: gauss (G), or tesla (T).
- (the unit for magnetic field strength is Tesla: 1 Tesla = 10000 Gauss).
- For example, the strength of the Earth 's magnetic field is approximately 0.6 G.

The principal types of magnet used in MRI are:

1. Permanent magnets – capable of sustaining fields up to about 0.3 T;
2. Resistive electromagnets – capable of fields up to about 0.6 T.
3. Superconducting electromagnets – typically with fields of 1.5 or 3 T;

1. Permanent magnet

- These types of magnets are usually limited to maximum field strengths of 0.3 T. Although they have the advantage of being inexpensive and easy to maintain, they are very heavy and weak in intensity, cannot be switched off in an emergency.
- Permanent magnets occur naturally, or they can be synthesized



ADVANTAGES

- Low power consumption
- Low operating cost
- Small fringe field
- No cryogen

DISADVANTAGES

- Limited field strength (<0.3T)
- Very heavy
- No quench possibility

Open permanent magnet systems also make claustrophobic or anxious patients more comfortable. So, the open design accommodates extremely large patients and dramatically reduces anxiety for all patients especially those who have claustrophobic tendencies or have larger body structures.

2. Resistive electromagnets

Electromagnets use regular resistive coils wound around iron pole pieces. When an electric current flows through the coils the iron becomes a Magnet. They are lower in cost, but need a lot of power to run, that means, large current values which runs through loops of wire because of the natural resistance of the wire. Therefore they produce a lot of heat, which requires significant cooling of the magnet coils.

Resistive magnets come in two general categories: **iron-core and air-core**

- The principal disadvantage of this type of imaging system is electric power consumption and require a cooling system.
- field strength can be adjusted and the magnet switched off safety after use.



ADVANTAGES

- Low capital cost
- Light weight
- Can be shut off

DISADVANTAGES

- High power consumption
- Limited field strength (<0.2T)
- Water cooling required
- Large fringe field

Open systems are often based on permanent magnets or iron-cored electromagnets, designed to operate primarily between 0.1 T and 0.3 T.

3. Superconducting

The most commonly used magnets are superconducting electromagnets. These superconductors, such as niobium-tin and niobium-titanium are used to make the coil windings for superconducting magnets. These consist of a coil that has been made superconductive by helium liquid cooling, and immersed in liquid nitrogen. They produce strong, homogeneous magnetic fields up to 12 Tesla (are most used in clinical environments), but are expensive and require regular upkeep (namely topping up the helium tank).

- Superconductivity allows for systems with very high field strengths up to 12 Tesla.
- In 1997 Toshiba introduced the world's first open superconducting magnet. The system uses a special metal alloy, which conducts the low temperature needed for superconductivity. The advantage of this is that the system does not need any helium refills, which dramatically reduces running costs. The open design reduces anxiety and claustrophobia. Figure shows Toshiba's OPART 0.35 Tesla system, which combines an open design with the advantages related to superconducting magnets.



ADVANTAGES

- High field strength
- High field homogeneity
- Low power consumption
- High SNR
- Fast scanning

DISADVANTAGES

- High capital costs
- High cryogen costs
- Acoustic noise
- Motion artifacts
- Technical complexity



Figure: Toshiba's OPART 0.35 Tesla system, which combines an open design.

Radiofrequency Coils

- The MR signals that provide the diagnostic information are produced within the patient's tissue in response to Radio Frequency (RF) pulses. These are generated by a transmitter coil which surrounds the whole or a part of the body.



Examples of coils: (a) head coil, (b) knee coil, (c) shoulder coil, (d) torso coil. Courtesy of Siemens Healthcare.

Gradients Coils

- ❖ The localization of the MR signals in the body to produce images is achieved by generating short-term variations in magnetic field across the patient.
- ❖ The strength of steepness of the gradient is measured in milli-tesla per metre (mT m^{-1}) and the magnitude of the gradient magnetic field is in the region of tens of mT, much smaller than the main B_0 field. There is one set of gradient coils for each direction, x, y, z, built into the bore of the magnet. The gradients are applied repeatedly in a carefully controlled pulse sequence.
- ❖ Ear protection is usually required for the patient or anyone remaining in the room during scanning you can hear the gradients, even though you can't see them

MRI Scanner Gradient Magnets

Y magnetic coils
(Creates a varying magnetic field from top to bottom)

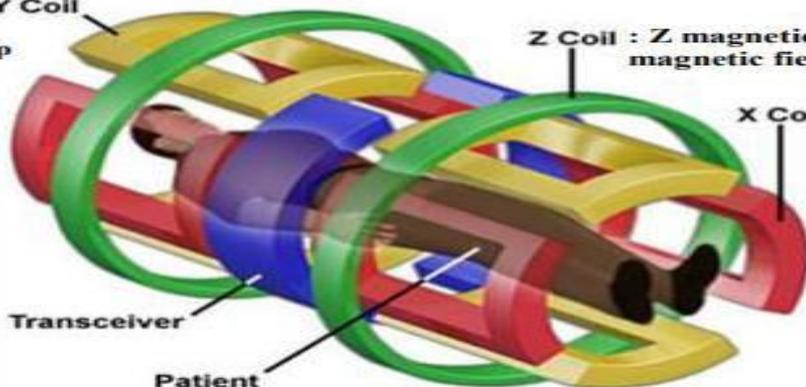
Y Coil

Z Coil : Z magnetic coils (Creates a varying magnetic field from head to toe)

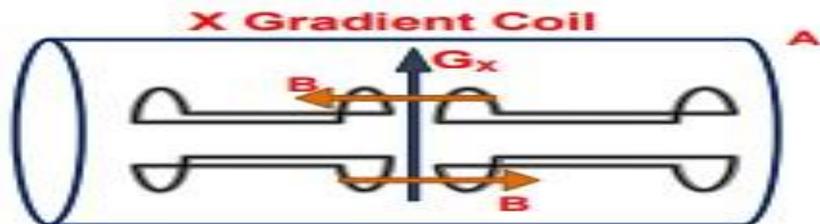
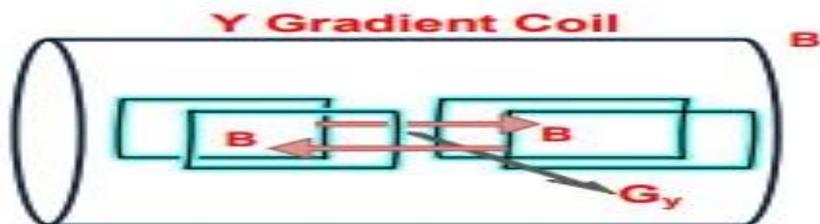
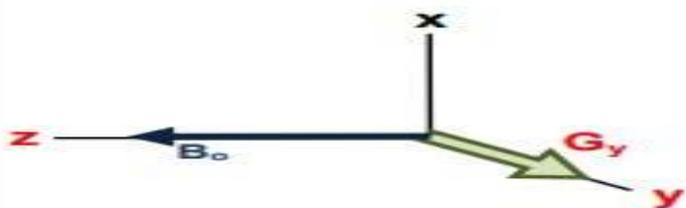
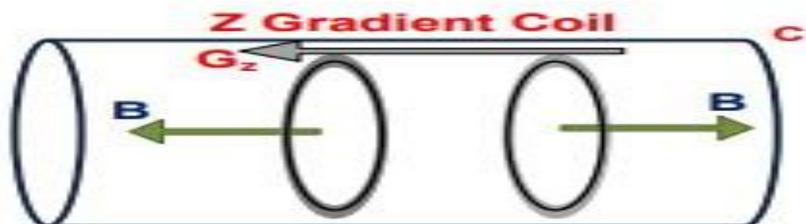
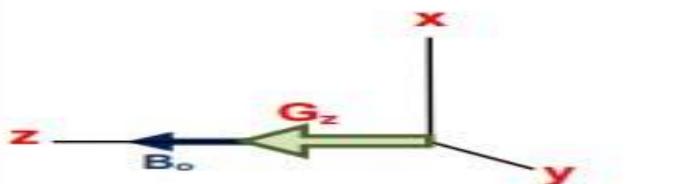
X Coil: X magnetic coils (Creates a varying magnetic field from left to right)

Transceiver

Patient



Individual gradients



MCQs for this Lecture :

1. The main types of energy used in MRI are:

- A. X-rays and gamma rays
- B. Magnetic fields and radio waves
- C. Sound waves
- D. Light waves
- E. Heat energy

2. The emitted energy from hydrogen atoms is converted into images by a:

- A. Magnet
- B. Cooling unit
- C. Computer
- D. X-ray tube
- E. Transformer

3. The main magnet of an MRI system is measured in units of:

- A. Volts
- B. Watts
- C. Tesla or Gauss
- D. Hertz
- E. Joules

4. Superconducting magnets require cooling with:

- A. Water
- B. Oil
- C. Liquid helium
- D. Air
- E. Carbon dioxide

5. The loud knocking sound during MRI scanning is mainly caused by:

- A. RF pulses
- B. Patient movement
- C. Cooling pumps
- D. Gradient coils switching
- E. Magnet vibration from helium