MRI Machine

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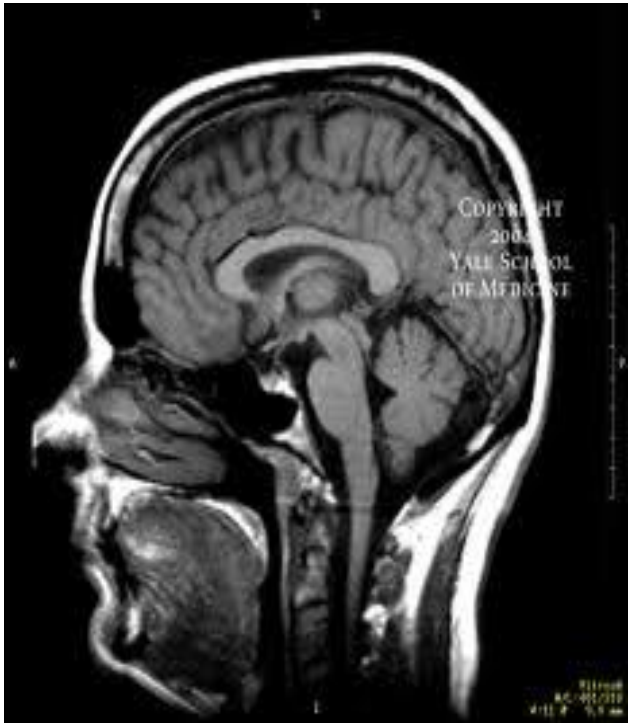
In a Tunnel, of course!

Magnetic Resonance Imaging



Introduction

- MRI scan is a painless radiology procedure that lasts 15 to 90 minutes, depending on the size of the area being scanned and the number of images being taken.
- MRI uses a **powerful magnetic field**, **radio frequency pulses** and a computer to produce remarkably clear & detailed pictures of internal organs, soft tissues, bone and almost all other internal body structures. The images can then be examined on a computer monitor, transmitted electronically, printed or copied to a CD.
- MRI does not use ionizing radiation (x-rays).
- Detailed MR images allow physicians to evaluate various parts of the body and determine the presence of certain diseases.
- In many cases MRI gives information that cannot be seen well with an x-ray, ultrasound or CT scan.

- MRI is a non-invasive imaging modality based on an interaction between transmitted radiofrequency (RF) waves and hydrogen nuclei in human body under the influence of a strong magnetic field.
- MRI excites and detects the change in the direction of the rotational axis of protons found in the water that makes up living tissues.
- MRI produces three dimensional detailed anatomical images, without the use of damaging radiation.
- MRI is often used for disease detection, diagnosis, and treatment monitoring.

MRI invention

- **Raymond Damadian** is an Armenian-American medical practitioner.
- In 1977 Damadian was the first to perform a full body scan of a human being to diagnose **cancer**.
- Damadian discovered that **tumors** and normal tissue can be distinguished in vivo by **nuclear magnetic resonance** (NMR) because of their relaxation times.
- Damadian invented an apparatus and method to use NMR safely and accurately to scan the human body, a method now well known as (**MRI**). Damadian formed the first company FONAR to manufacture MR scanners for clinical use in 1982.
- Damadian has received several prizes

MRI invention

- Several involved:
  - **Paul Lauterbur** – 1973, Produced first image of a living mouse using 2D and 3D imaging technique
  - **Peter Mansfield** - developed a mathematical technique where scans take seconds rather than hours also producing clearer images.
- **Nobel prize** 2003,
  - ✓Paul Lauterbur
  - ✓Sir Peter Mansfield

Lauterbur

Mansfield

WE ARE MAGNETS!

Really?

We all are made up of elements

→ 92 elements occur naturally on earth.

→ Human body is built of only 26 elements.

→ Oxygen, hydrogen, carbon, nitrogen elements constitute 96 % of human body mass.

→ Oxygen is 65 % of body mass; carbon is 18.5 %, hydrogen 9.5 %, nitrogen 3.2 %.

→ Let us ignore all elements but Hydrogen.

Why hydrogen?

- Simplest element with atomic number of 1 and atomic weight of 1
- When in ionic state (H+), it is nothing but a proton.
- Proton is not only positively charged, but also has magnetic spin (wobble)!
- MRI utilizes this magnetic spin property of protons of hydrogen to elicit images!!

Why Proton only?

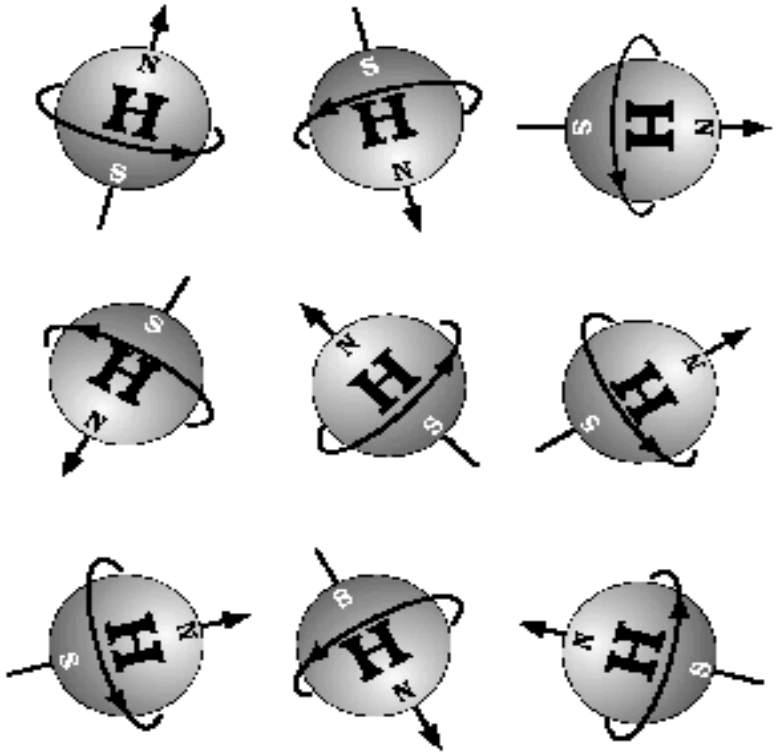
- Other substances can also be utilized for MR imaging.
- The requirements are that **their nuclei should have spin** and should have **odd number** of protons within them. Hence theoretically 13C, 19F, 23Na, 31P can be used for MR imaging.
- **Hydrogen** atom has **single proton** and is most strongly affected by the Magnetic field- It is more likely to line up than other atoms
- Hydrogen ions are present in abundance in body water.
- H+ gives best and most intense signal among all nuclei.

How do protons help in MR imaging?

- Protons are positively charged and have rotatory movement called **Spin**.
- Any moving charge generates current.
- Every current has a small magnetic field around it.
- So every spinning proton has a small magnetic field around it, also called **magnetic dipole moment.**

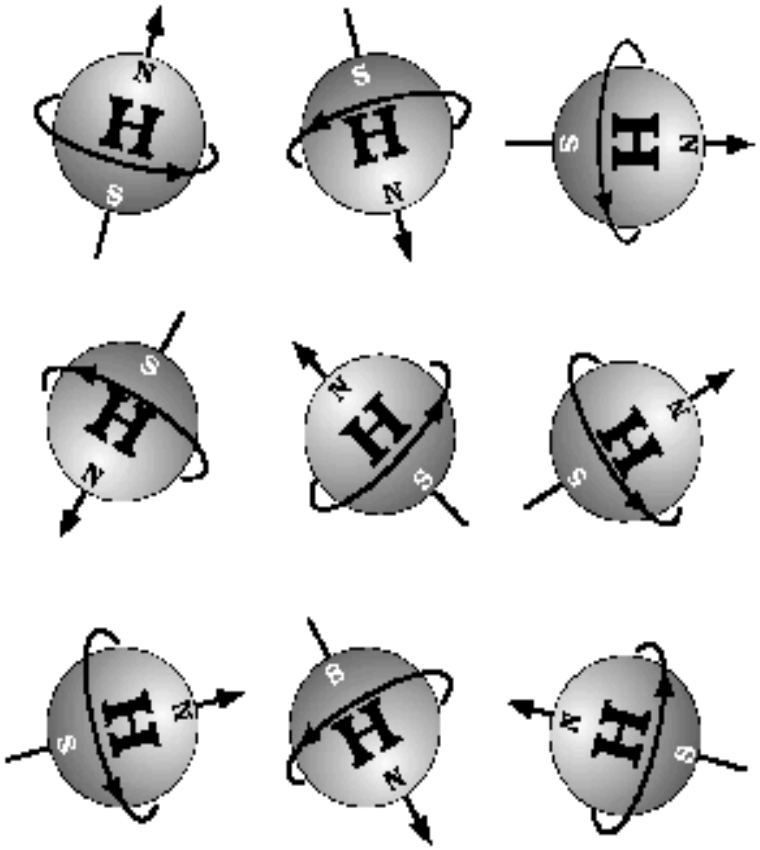
But why we can't act like magnets?

- The protons (Hydrogen ions) in body are spinning in a hap hazard fashion, and cancel all the magnetism. That is our natural state!
- In MRI, we need to discipline them first, **how?**

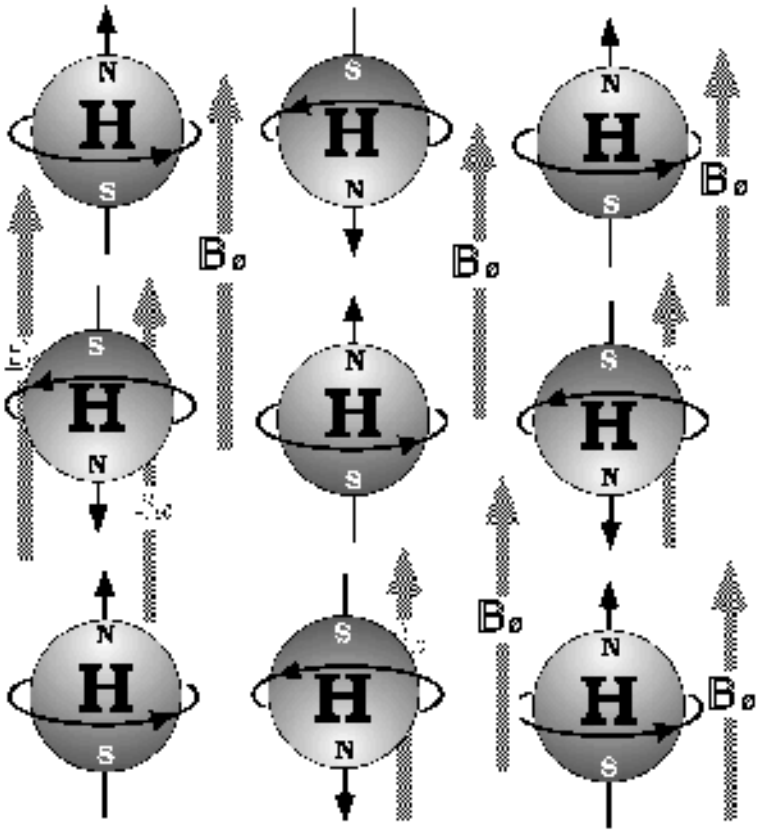


Alignment of protons using external magnetic field

No External Magnetic Field



Applied External Magnetic Field



Protons before and After applying Magnetic Field

Magnetic Field

- measured by Tesla (T).
- Clinical MRI (1.5 - 3)Tesla
- Earth Magnetic field = 0.00003 T
- 1 Tesla = 20,000 times the strength of the earth's magnetic field.

- The signal that is used in creating MRI images is derived from the energy released by molecules transitioning, or precessing, from their high-energy to their low-energy state. This exchange of energy between spin states is called resonance, and thus the name magnetic resonance imaging.

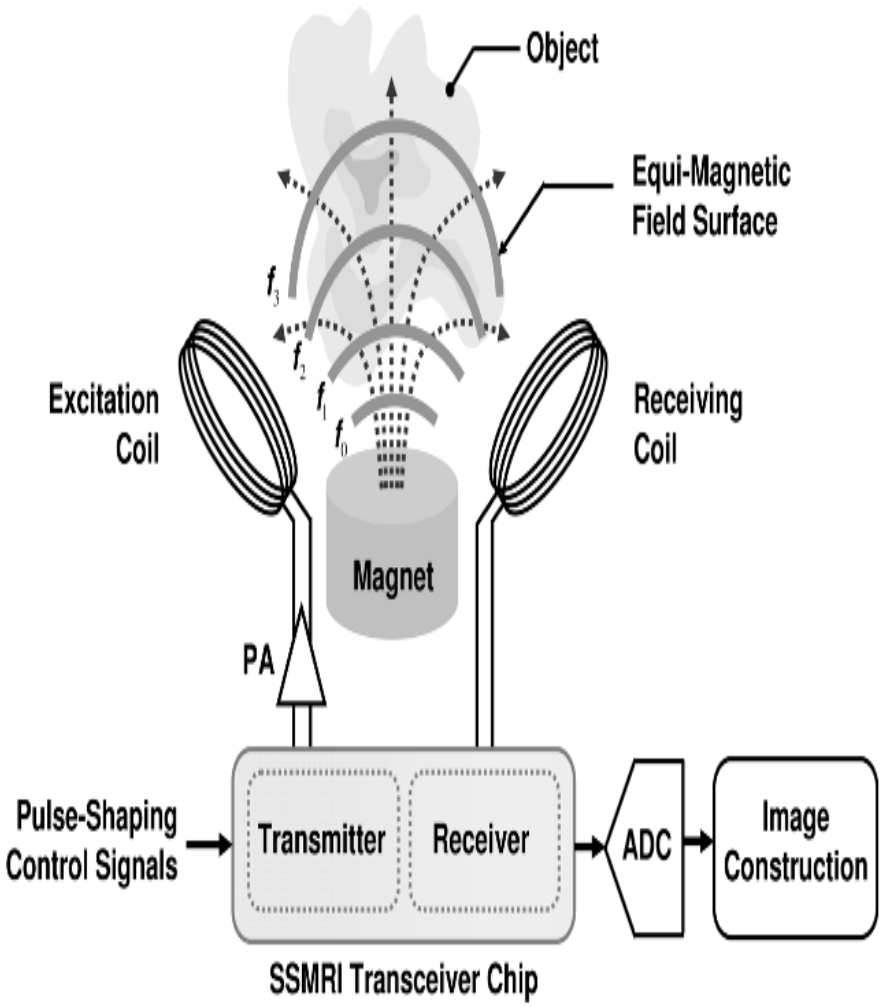
MRI scanner

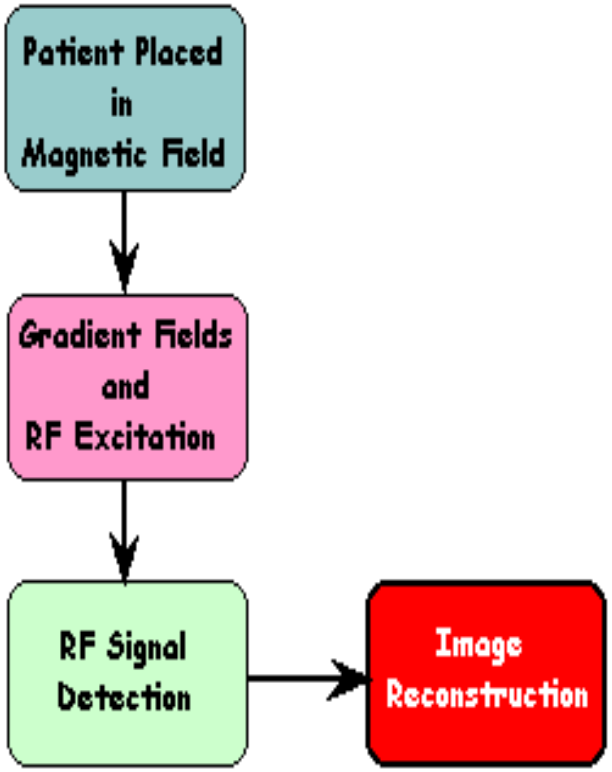
Source:

1. http://www.medphysics.wisc.edu/~block/bme_530_lectures.html
2. Ch. 5 of the book by N. B. Smith and A. Webb, Introduction to Medical Imaging, Cambridge University Press, 2011.

Working Principle of MRI

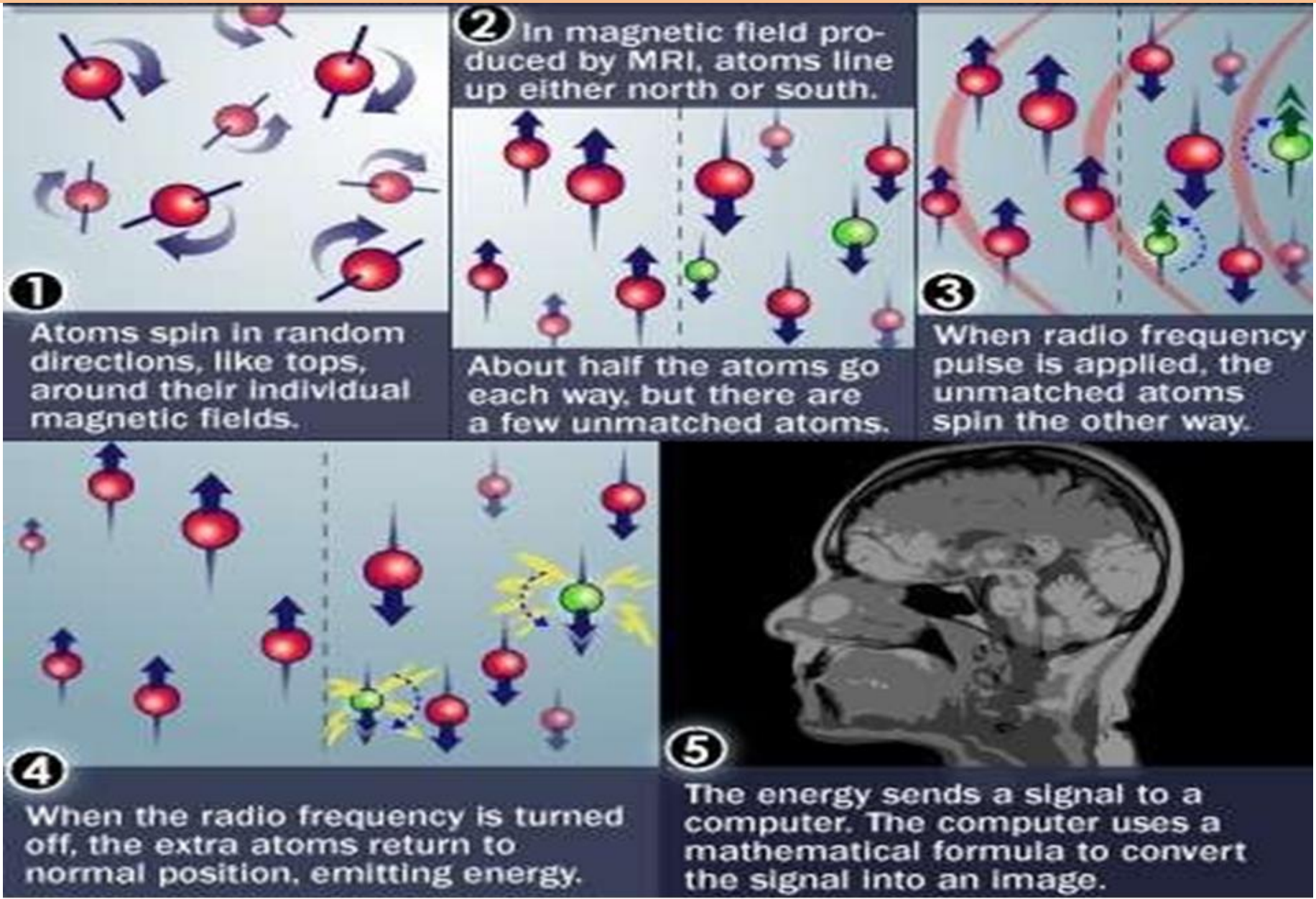
- Simply stated, MRI is based on measurements of energy emitted from hydrogen nuclei following their stimulation by radio-frequency signals.
- The energy emitted varies according to the tissues from which the signals originate.
- This allow MRI to distinguish between different tissues.





Basic principle of MRI

How does MRI work?



How does MRI work?

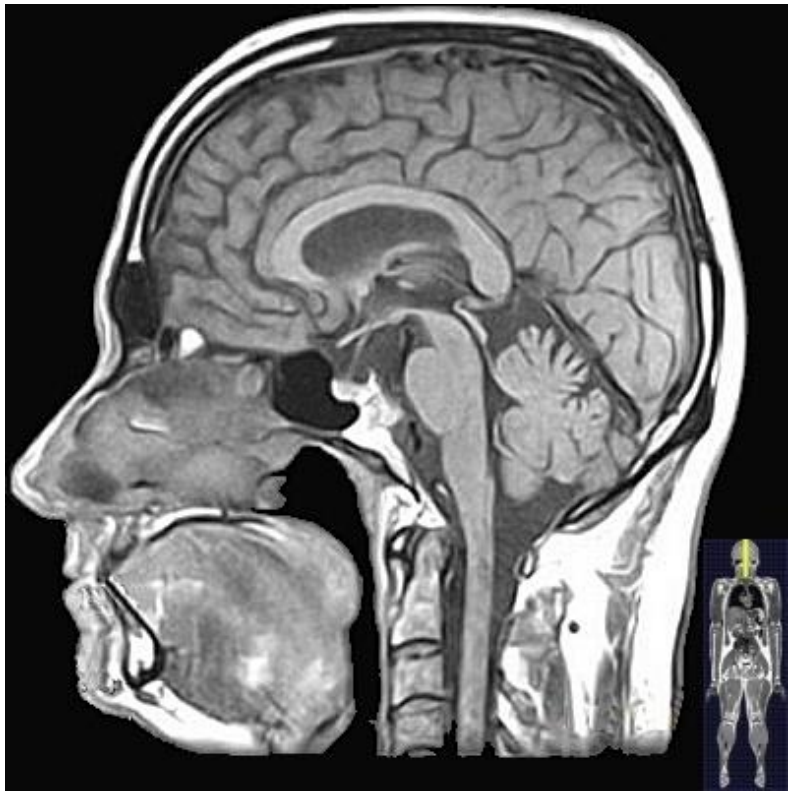
How does it work?

- Images are constructed when protons in different tissues return to equilibrium state at different rates.
- Five variables effect these rates
  - Spin Density: Concentration of nuclei in tissue processing in a given region under a magnetic field.
  - T_1: Longitudinal relaxation time
  - T_2: Transverse relaxation time
  - Flow: Shows blood flow, CSF flow
  - Spectral Shifts: Angle/zoom the picture is taken from.

- T_1-weighted: Differentiate fat from water
  - Water is Darker, fat is brighter
  - Provide good gray matter/white matter contrast in brain.
- T_2-weighted: Differentiate fat from water
  - Fat shows darker, and water lighter.
  - Good for imaging edema
    - Abnormal accumulation of fluid beneath the skin or in one or more cavities of the body

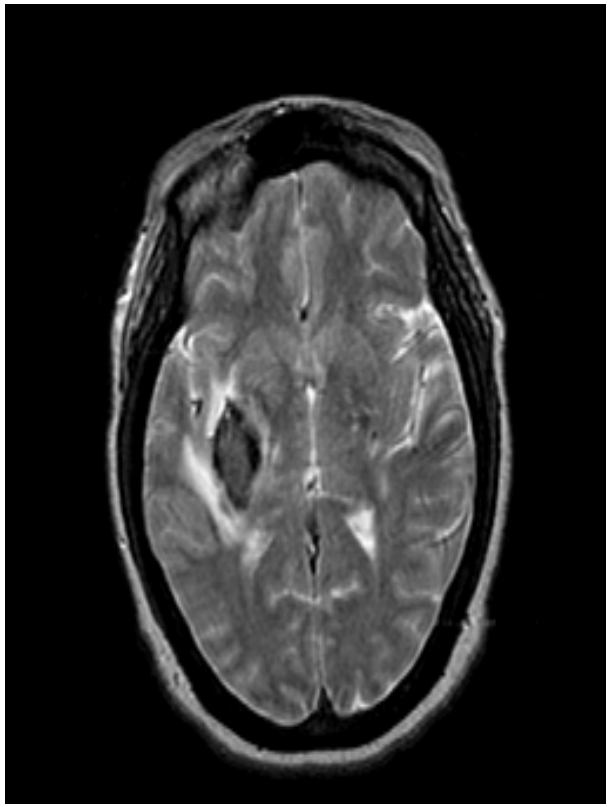
Brain MRI

T_1 weighted image

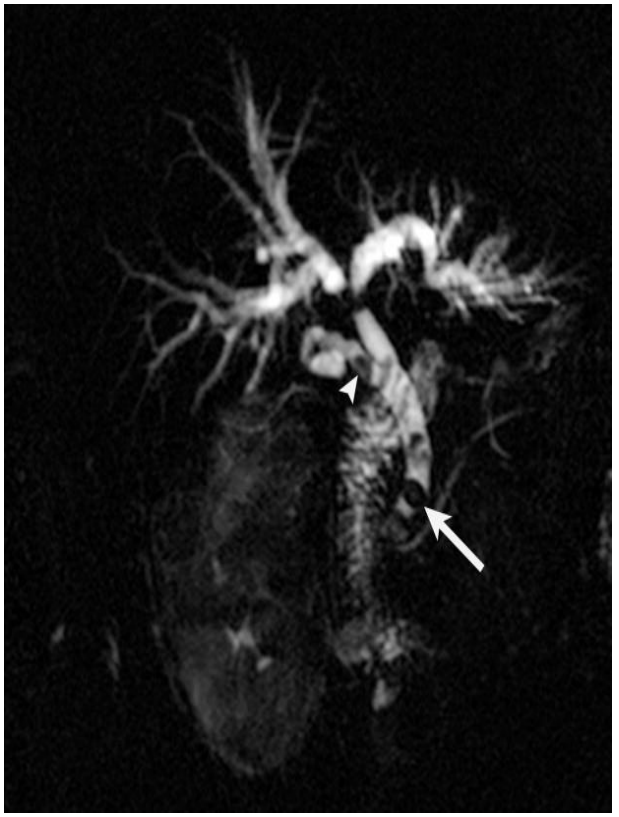


T_2 weighted image

MRI brain hemorrhage

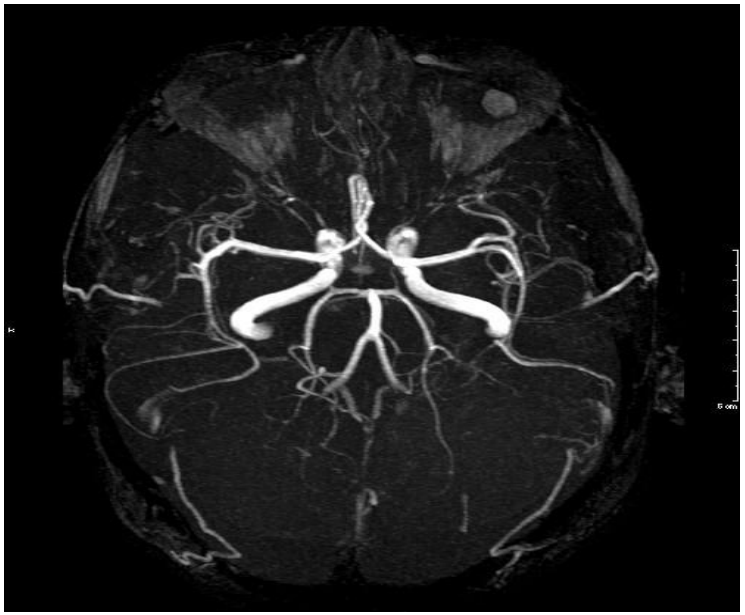


MRI cholangiography



Blood

- Protons of the blood are faster than the other types so that T_1& T_2 can not be discriminated.
- Flash technique is used to see the blood.
- No contrast media is used (advantage than CT especially for patients who have renal failure, allergy for iodine compounds).
- MR angiography (MRA)



MRI Urography

- No contrast media.

MRI Machine

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Before MRI, there is a checklist!

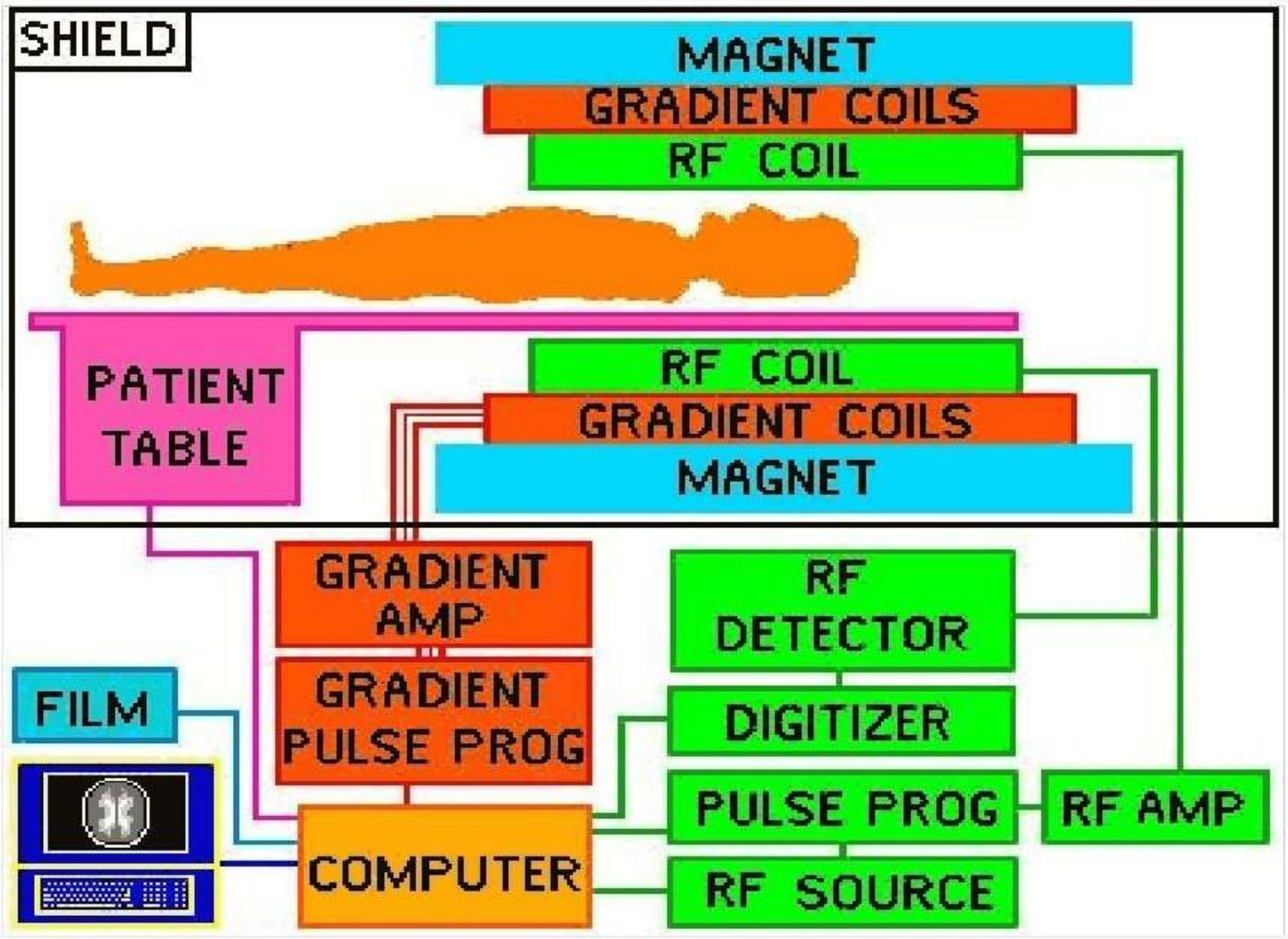
- No mobiles, no credit cards.
- Known potential safety concerns due to large static magnetic field:
  - Internal cardiac pacemakers
  - Steel cerebral aneurysm clips (ferromagnetic)
  - Small steel slivers embedded in eye
  - Life-support equipment with magnetic steel
  - Cochlear implants
  - Stents anywhere in the body
  - jewelry, watches

Further checklist!

- Malfunction: ICDs, neurostimulators, bone growth stimulators (prosthetic heart valves)
- NEED sedation: infants, younger peds, agitated adults (claustrophobia)
- Precautions: magnetic plastic cards, watches, hearing aids, ferromagnetic steel, iron and nickel objects →(LEAVE OUTSIDE)

Components of MRI

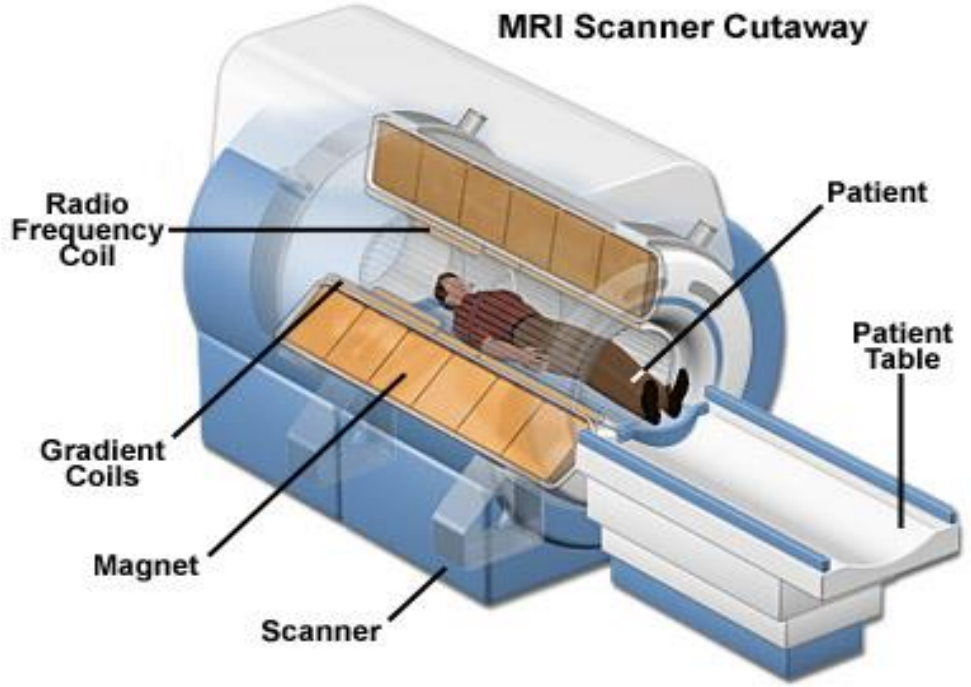
MRI Components Arrangement



Components of MRI Machine

The MRI is comprised of 3 main components:

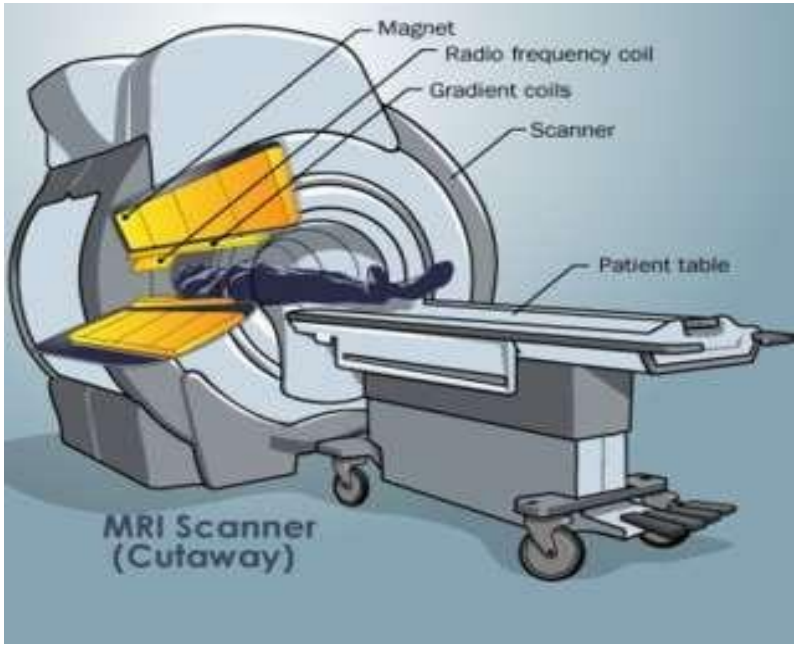
- A superconducting primary magnet
- 3 set of magnetic field gradient coils
- RF transmitter and receiver



The bore

- A tube like structure, which holds the components of the MRI machine. It is similar to the Gantry in CT scan machine.
- The bore holds the following components:

Magnet → Gradient Coil → Shim Coil → RF Coil → Computer



Primary Magnet

- The biggest and most important component of an MRI system, capable of producing a large, stable magnetic field.
- **The magnets used are:**
  - Superconducting,
  - Resistive and
  - Permanent magnet.

- Each has advantages and disadvantages. But
- Most commonly used magnet is Superconducting magnet.

Magnet Types

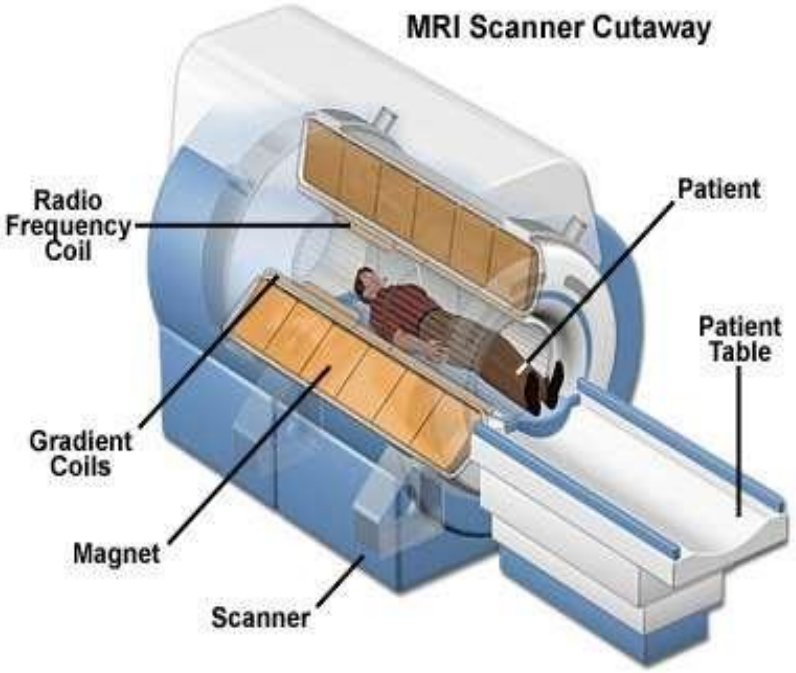
1. **Permanent/Fixed magnet**
2. **Resistive magnet**
3. **Super conducting magnet**

- Permanent magnets and resistive magnets are generally restricted to field strengths below 0.4t (tonne)
- Closed bore super conducting magnets are used for High-resolution imaging systems in clinical MRI.

The super-conducting magnets are large and complex, need the coils to be soaked in liquid helium to reduce their temperature to a value close to absolute zero.

Gradient Coil

- When the MRI system is in a resting state, the magnetic field is quite uniform or homogeneous over the region of the patient's body.
- However, during the imaging process the field is distorted with gradients.
- A gradient is a change in field strength, gradients are produced by a set of gradient coils, which are contained within the magnet assembly.
- The primary function of gradients, is to allow spatial encoding of the MR signal.



➢ Magnetic field gradients for imaging are typically measured in units of **Millitesla per meter (mT/m)**

Gradient Coil Contd…..

- In an MRI system, there are typically three sets of gradient coils. Like the magnets, each coil is made by winding thin strips of copper or aluminum in a specific pattern.
- In the MRI system, they are wrapped around the cylinder that surrounds the patient. These magnets are much lower strength compared to the main magnetic field; they may range in strength from 180 gauss to 270 gauss.
- While the main magnet creates an intense, stable magnetic field around the patient, the gradient magnets create a variable field, which allows different parts of the body to be scanned.

Shim Coil

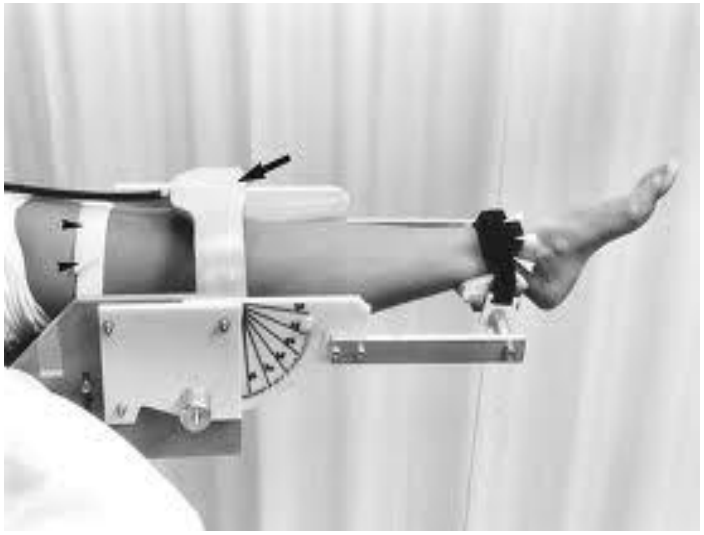
- One of the requirements for good imaging is a homogeneous magnet field,
- in which there is a uniform field strength over the image area.
- Shimming is the process of adjusting the magnetic field to make it more uniform.

Radio Frequency Coil

- The RF coils are located within the magnet assembly. RF receiver coils are relatively close to the patient's body.
- These coils function as the antennae, First, responsible for transmitting the RF radiation that induces the atoms to emit a signal. Next, it receives the emitted signal and amplifies it so it can be manipulated by the computer.
- There are different coil designs for different anatomical regions.
- The three basic types are: body, head, and surface coils.

- The surface coils have 2 conditions:
  1. It has to surround the part of interest.
  2. This part should not be moved during the imaging process even due to breathing.

Knee surface coil



Breast surface coil

Chest surface coil

Head coil

Computer

- The computer interprets the data, and creates images that display the different resonance characteristics of different tissue types. We see this as an image of shades of grey-some body tissues show up darker or lighter.

PREPARATION FOR PROCEDURE

- **Before Scan**
- Patient may be asked to wear a gown during the exam or may be allowed to wear own clothing if it is loose-fitting and has no metal fasteners.

Contrast Dye

Some MRI examinations may require an injection of contrast material into the bloodstream.

Caution: It's possible that contrast dye may cause tissue and organ damage in people with severe kidney disease. If patient have a history of kidney disease, he should give a blood test to determine how well the kidneys are functioning and whether it's safe to proceed with the scan.

- If a contrast material is required in MRI exam, a physician, nurse or technologist will insert an intravenous (IV) catheter, into a vein in hand or arm. A saline solution may be used to inject the contrast material. The solution will drip through the IV to prevent blockage of the IV catheter until the contrast material is injected.
- If a contrast material is used during the examination, it will be injected into the intravenous line (IV) after an initial series of scans. Additional series of images will be taken during or following the injection.

- **Anesthesia:**

- An MRI scan is a painless procedure, so anesthesia is not usually required.
- General anesthesia is often used when young children and babies have an MRI scan. This is because it's very important to stay still during the scan, young children and babies are often unable to do when they're awake.
- If patient have claustrophobia (fear of enclosed spaces) or anxiety, Physician should give a prescription for a mild sedative prior to scheduled examination.
- Jewelry should be removed prior to the MRI scan. Because it can interfere with the magnetic field of the MRI unit, metal and electronic items are not allowed in the exam room.

- **DURING THE SCAN**

- An MRI scanner is a short cylinder that's open at both ends. Patient will lie on a motorized bed that's moved inside the scanner. Patient will enter the scanner either head first or feet first, depending on the part of the body being scanned.
- In some cases, a frame (surface coil) may be placed over the body part being scanned, such as the head or chest. This frame contains receivers that pick up the signals sent out by the body during the scan and it can help to create a better-quality image.
- A computer is used to operate the MRI scanner, which is located in a separate MR scanner control room to keep it away from the magnetic field generated by the scanner.
- The radiographer operates the computer.

- Children will be given appropriately sized earplugs or headphones during the exam. The MRI scanner will make loud tapping noises at certain times during the procedure. These noises are due to vibrations of gradient coils.
- MRI scanners are air-conditioned and well-lit. Music may be played through the headphones to help patient pass the time.
- A single scan may take from a few seconds to three or four minutes. Patient may be asked to hold breath during short scans. Depending on the size of the area being scanned and how many images are taken, the whole procedure will take 15 to 90 minutes. MR system capable of performing rapid, high-resolution imaging is called?
- Patient should move out of scanner after the scan is over.

- **After The Scan**

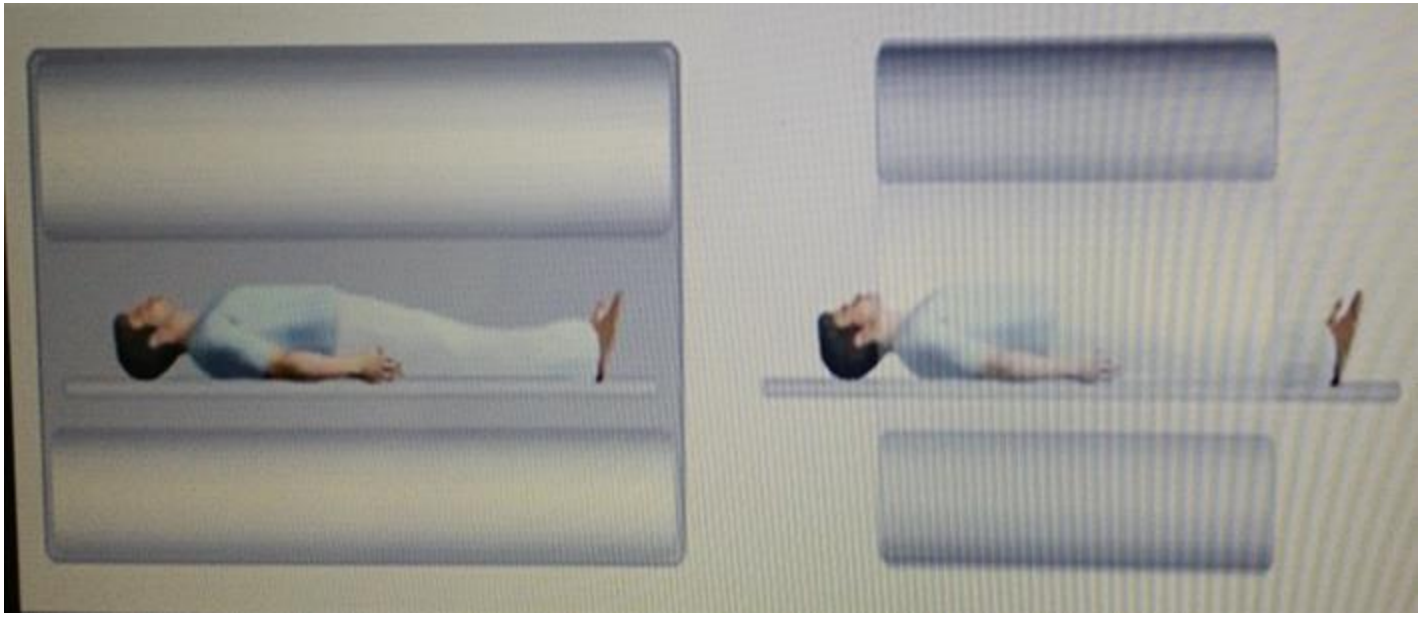
- Patient may be asked to wait while the radiographer checks the quality of the pictures. In some cases, he may be asked to get back into the MRI scanner so that more pictures can be taken. If the pictures are satisfactory, patient can get dressed and go out.

- If patient had sedative before the scan it will not be safe for him to drive or drink alcohol for 24 after having scan.

- MRI scan needs to be studied and reported by a radiologist (a doctor trained in interpreting scans and X-rays) and possibly discussed with other specialists.

Types of MRI Machines

1. **Closed MRI**



2. Open MRI

Disadvantages of open MRI

The magnet is weak so the scanning time is relatively long but the resolution of the images the same as closed one.

3. Extremity MRI

Advantages of Extremity MRI

To investigate the hand or leg (only small parts wrist, elbow, ankle, joints) to reduce the load on the big device.

4. Dynamic MRI

- The bed rotates from upright to recumbent (lie down position), stopping at any angle in between.

Advantages of MRI

- MRI can be used for both; Physiology and Anatomy.
- They are particularly useful for showing soft tissue structures, such as ligaments and cartilage, and organs such as the brain, heart, and eyes.
- MRI can provide information about how the blood moves through certain organs and blood vessels, allowing problems with blood circulation, such as blockages, to be identified.
- MRI is a non ionizing technique, which means no radiations.
- ‘Slice’ image can be taken on many planes.
- The image is a 3D image.

Disadvantages of MRI

Claustrophobia: Patients are in a very enclosed space.

Noise: The scanner is very noisy.

Keeping still: Patients have to keep very still for extended periods of time.

Cost: A scanner is very expensive, therefore scanning is also costly.

Medical contraindications: Pacemakers, metal objects in the body etc

The Uses of MRI

- Physicians use the MR examination to help diagnose or monitor treatment for conditions such as:
  - Tumors and other cancer related abnormalities.
  - Certain types of heart problems.
  - Blockages or enlargements of blood vessels
  - Diseases of the liver, such as cirrhosis, and that of other abdominal organs.
  - Diseases of the small intestine, colon, and rectum
  - Diagnosing: Infection of the brain/spine/CNS
  - Visualising: Injuries; torn ligaments-especially in areas difficult to see like the wrist, ankle or knee
  - Evaluating: Masses in soft tissue; cysts; bone tumours or disc problems

Comparison between MRI and CT

	CT	MRI
Ionizing radiation	Yes	No
Cost	lower	Higher (x3)
Speed	10-30 s (full scan 5-10 min).	Several minutes (full scan 30-60min)
Data modes	Few	Many
3D images	Yes	Yes
Resolution	~7 lp/cm (Line Pair per centimetre)	~3 lp/cm
Work with metal in the body	Yes	No

THANK YOU


Questions