Physics of Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) It is a medical imaging technique and diagnostic tool in radiology based on the Nuclear Magnetic Resonance (NMR).

Main properties

- non-invasive and 3D

-no ionizing radiations

-very good spatial resolution (1mm isotropic for anatomy)

-anatomy, functional and physiological state of the internal organs for both healthy and pathological tissues

The Components of the MR Scanner

1- A magnet which produces a very powerful uniform magnetic field **Bo** (1.5T - 11T, note that the earth magnetic field is around 60 microT)

2- Gradient coils that make the magnetic field linearly vary across the imaging volume. This determines the plane of imaging

3- Radio Frequency (RF) transmission system

The single steps of an MR examination can be described quite simply

• The patient is placed in a magnet,

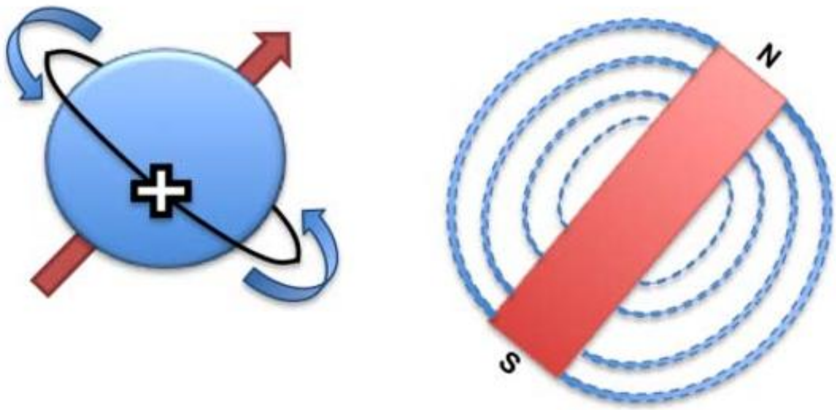
• A radio wave is sent in,

• The radio wave is turned off,

• The patient emits a signal , which is received and used for reconstruction of the picture

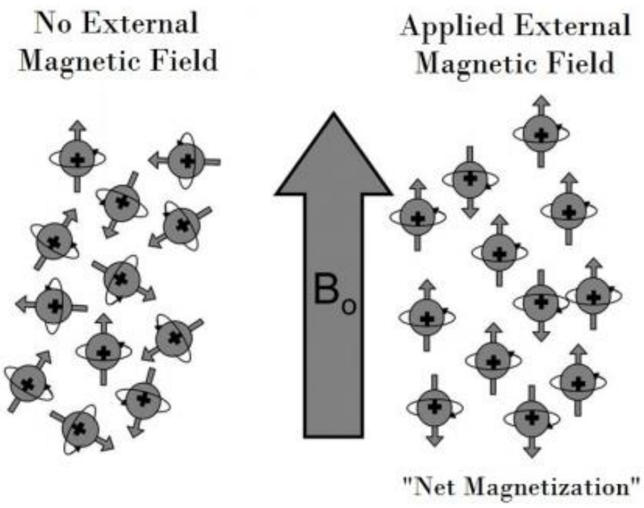
OBTAINING MR SIGNALS (Image)

The primary origin of the MR signal used to generate almost all clinical images comes from hydrogen nuclei (abundant in human body) . Hydrogen nuclei consist of a single proton (**not all nuclei are "MRI active, Only those with an odd number of protons and neutrons**) that carries a positive electrical charge. The proton is constantly spinning and. Recall that a moving electrical charge is called a current and that an electrical current generates a magnetic field. Thus, protons have their own magnetic fields and behave like little bar magnets, but the distribution of these bar magnets are randomly.



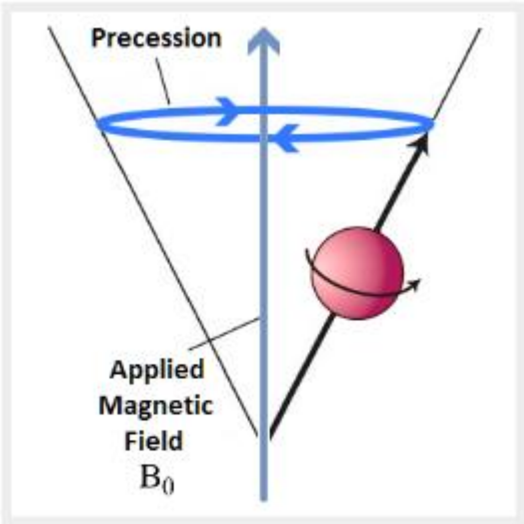
Protons possess a positive charge and are constantly spinning around their own axes. This generates a magnetic field making protons similar to bar magnets.

However, when an external magnetic field (**Bo**) is applied, they (**protons**) align either with (parallel) or against (anti-parallel) the external field.



Alignment of protons due to an external magnetic field

As well as, the above effect of external magnetic field (**Bo**). Protons start to precess around the magnetic field (**Bo**).



The speed of precession, that is, how many times the protons precess per second, is measured as the precession frequency (also named the Larmor frequency, ω_0, in MHz) and determined by the Larmor equation:

$$\omega_0 = \gamma \, B_0$$

where

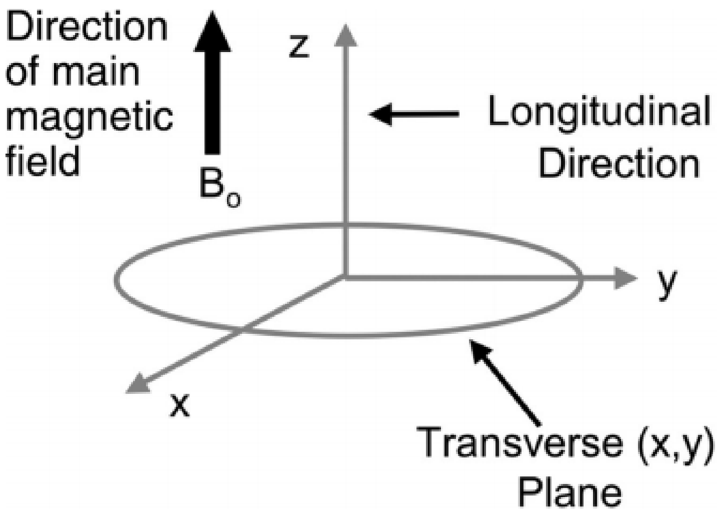
ω_0: Larmor frequency

γ: gyromagnetic ratio. Its value for the proton is 42.6 MHz/T

Longitudinal magnetisation

-In the strong magnetic field more of protons align parallel to the applied magnetic filed this produce a net magnetisation in the direction of the field.

-The direction of the strong magnetic field conventionally defines the z axis which is generally along the longitudinal axis of the patient in a typical MRI machine.



Longitudinal magnetisation and Transverse magnetization

The net magnetisation cannot be measured as it is in the same direction as the external field. Therefore, to measure the magnetization and build an image an angle must be between to **Bo** and the net magnetisation, this what Radio frequency does.

Radio frequency (RF) Pulses and transverse magnetization

The purpose of the RF pulse is to disturb the protons so that they fall out of alignment with B_0. This can only occur when the RF pulse has the same frequency as the precessional frequency of the protons, a phenomenon called resonance; hence the term magnetic resonance imaging.

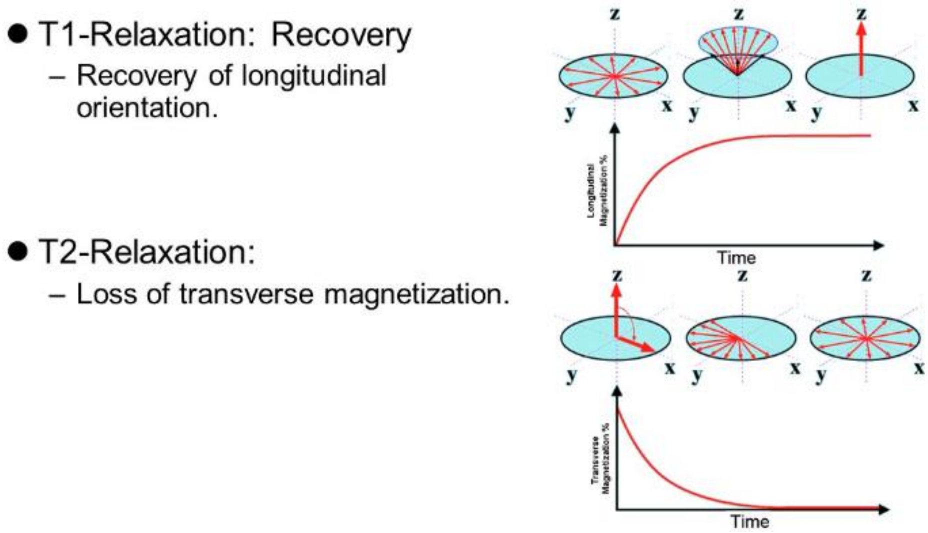
The precession rate of protons at 1 Tesla equal to 42.58 MHz. Therefore, Radio frequency that applied to during the imaging shod be at 42.85 MHz.

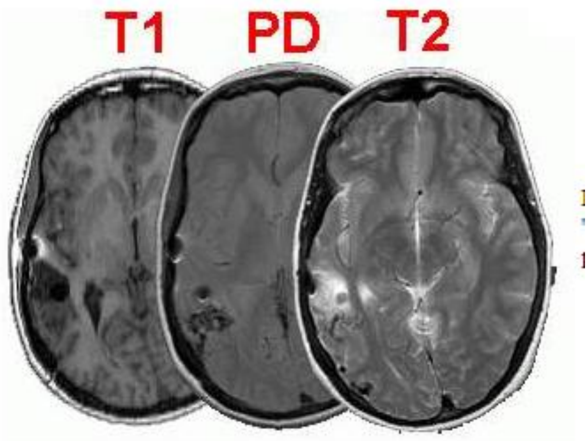
Image weighting

The characteristic that makes MRI particularly useful in clinic applications is the signal contrast between different areas of the tissue and between normal and abnormal tissue. The main processes used to obtain contrast in MR imaging are based on differences in relaxation times T_1 and T_2 and proton density in different tissues.

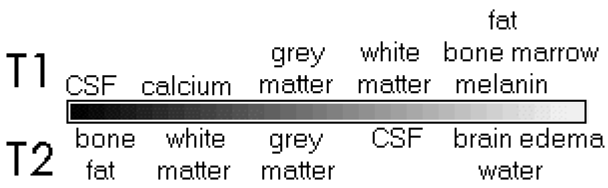
T1 relaxation is the process by which the net magnetization (**M**) grows/returns to its initial maximum value parallel to **Bo**

T2 relaxation is the process by which the transverse components of magnetization decay.





T1, proton density and T2 weighted slices from the same patient. The 'pathological' T2 scan is useful for locating the damage region in the brain. The 'anatomical' T1 scans usually have the best scan resolution, and are useful for localizing anatomical structures. The PD scan shows overall hydrogen density per cubic mm.



Relative brightness levels for different material in T1 and T2 scans.

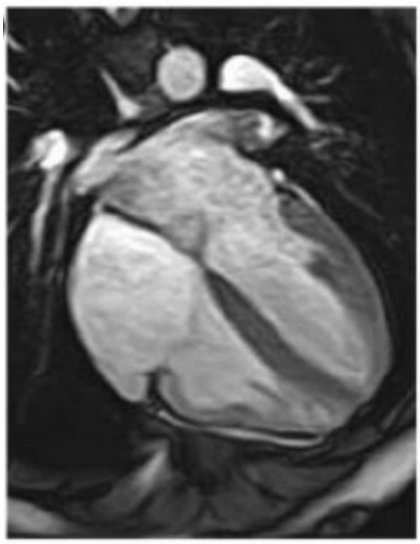
Application of MRI in medicine

1- **Imaging the Brain**

MRI used to image the structure of the brain.

2- **Heart**

Movement of the heart produces unique problems in medical imaging. This problem can be solving using MRI.



Normal heart

3- **Functional magnetic resonance imaging (fMRI)** measures brain activity by detecting changes associated with blood flow.