Theoretical lecture

Lecture One: Historical Introduction of MRI Device

1. Historical Introduction

Magnetic resonance imaging (MRI) was discovered in 1970, by Paul C Lauterbur, Stony Brook, in New York. He jointly used radiofrequency (RF) and spatial magnetic field gradients to generate images that display the magnetic properties of the proton, reflecting clinically relevant information. Basically, it is a nuclear magnetic resonance (NMR) technique, applied for human imaging. The Nobel prize in medicine (2003), was awarded for the above discovery, which was shared by Sir Peter Mansfield, and Paul C Lauterbur. **Figure1** shows the MRI device.

Figure1: Magnetic Resonance Imaging (MRI) device.

Nuclear magnetic resonance (NMR) is the spectroscopic study of the **magnetic properties of the nucleus of the atom (1940).**

Nuclear magnetic resonance was used to obtain information from the distribution of water molecules in the human body, by which the internal anatomy of the human body could be mapped accurately.

MRI can be used to detect:

1. Brain tumors
2. Traumatic brain injury
3. Stroke
4. Dementia
5. Infection
6. The causes of headaches, etc.…

The special features of MRI include:

1. High contrast sensitivity to soft tissue differences.
2. Inherent safety to the patient (non-ionizing radiation).
3. To examine anatomic and physiologic properties of the patient
4. Imaging of blood flow without contrast.

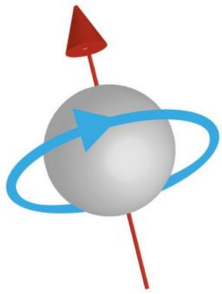
The limitations of MRI include:

1. High equipment cost.
2. Long imaging time (nearly 20-30 mins).
3. Image artifacts.
4. Patient claustrophobia.

Principle work of MRI:

- The modern MRI is only concerned with the nucleus of only one particular element, hydrogen 1H.
- The nucleus of the hydrogen atom contains a single proton and no neutrons, making it the simplest possible nucleus, and it is the most abundant nucleus in the human body, present in water and long-chain lipids.

- All sub-atomic particles have a 'spin'; like tiny spheres spinning on their own axes.
- Since each proton have a single positive charge, it is easy to imagine that this moving charge creates a tiny magnetic field. This is known as **the magnetic moment** of the proton, **μ**.



- Wherever possible similar atomic particles ***pair up*** so that their spins and therefore their magnetic moments will be canceled out. See **Figure 2**.

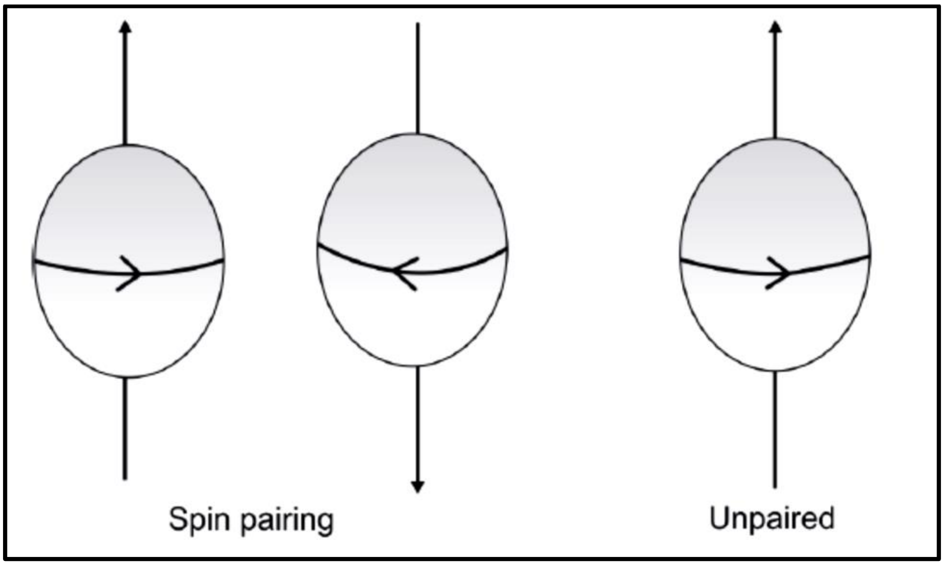


Figure2: Spin pairing in the nucleus, unpaired spins give magnetic moment

- Any nucleus with an unpaired spin (either proton or neutron or both) will have a residual magnetic moment.

- In atoms with large atomic numbers there are a lot of electrons around the nucleus, which tends to shield the effect of the unpaired spins.

- The hydrogen nucleus is a single proton, and its single orbiting electron does not provide much shielding. 1H, therefore, has the largest magnetic moment of all the elements, which is the other important factor making MRI such a sensitive technique. From now on, we will only consider the ***1H nucleus***; this may also be called ***the proton*** or ***a spin***.

- When an external magnetic field is applied, all the protons of the hydrogen atom are arranged in the direction or opposite of the field, and there can be no other arrangement.

- A Large number of these protons' magnetic moments cancel each other out, leaving only a few as in the figure below, as there is no other proton that cancels its magnetic moment, see **Figure 3**.

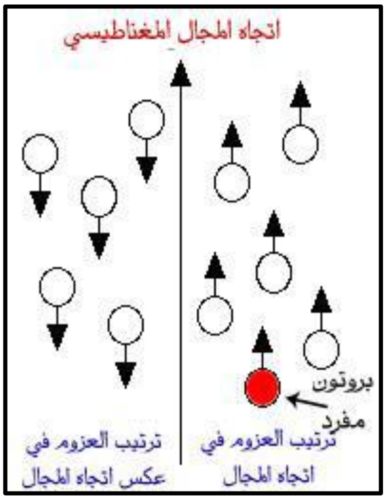


Figure 3: a magnetic moment with the external applied magnetic field

- These individual protons, although few in number, are sufficient to form the required images with high accuracy.

- ***Precession*: when an external magnetic field is applied. The direction of the spin axis tilts and rotates around the external** magnetic field, with a fixed frequency. This precession occurs at an angular frequency (ω_o) that is proportional to magnetic field strength (Bo).

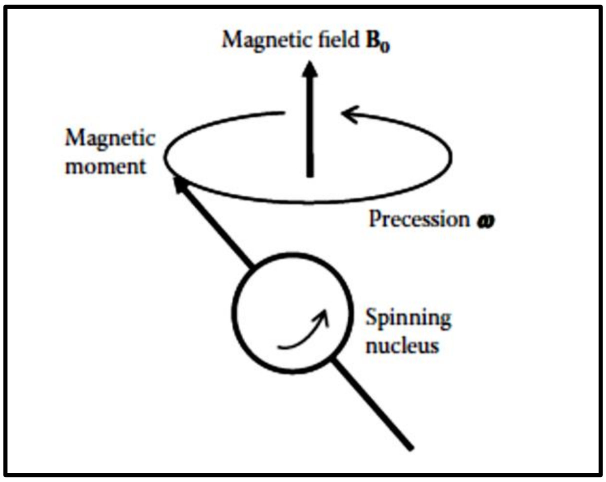


Figure 4: the 1H nucleus processes in an External magnetic field (right).

Larmor Equation gives the relation between magnetic field strength and angular frequency

$$\omega_o = \gamma B_o$$

Where γ is the gyromagnetic ratio (MHz/Tesla), ω_o is the angular frequency (Larmor frequency) in MHz, and B_o is the applied magnetic field.

When the magnetic field (Bo) is 3 T, and the gyromagnetic ratio (42.58 MHz/T), then the resonance frequency (Larmor frequency) is equal to:

ω_o = 42.58 MHz/T*3T= 127.74 MHz

- If a radiofrequency (RF) pulse having a frequency equal to the ***Larmor frequency*** of tissue is applied perpendicular to the magnetic field, then it is absorbed by the proton nuclei and changes the direction of spinning in the opposite direction to which they were previously spinning. This process is called ***Resonance***.

- When the RF pulse is finally turned off, the unmatched hydrogen atoms gradually return to their original position and emit a certain kind of energy. This process is called ***Relaxation*.**
- This energy is then detected by the highly sensitive antenna, which feeds the data into the computer system in the form of waves or signals.
- Finally, the computer system interprets this data and converts the signal into a visible and understandable image that can be read and studied by the doctors and scientists. See figure 5 below:

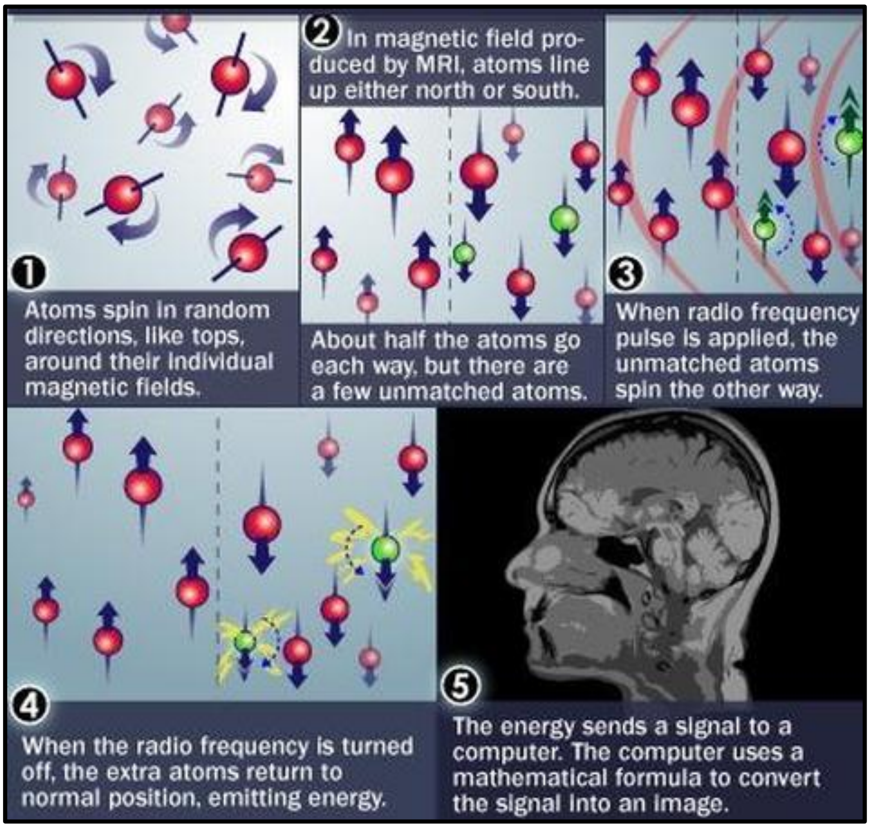


Figure 5: Steps of MRI scanning.