INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 4, Issue 6)
Available online at: www.ijariit.com

The physics of Magnetic Resonance Imaging

Shajahan V S
vs.shajahan@gmail.com
Vocational College, Ibri, Oman

ABSTRACT

MRI is an acronym for Magnetic Resonance Imaging. MRI is used in radiology and it is one of the scanning technologies where magnetism, radio waves and a computer are used to take the total image of the body structures. The chief advantage of the MRI is to give clear images of soft-tissue structure where other imaging techniques fail to give without any affect to the patient. MRI is based on the interaction of magnetic properties of hydrogen with both a large external magnetic field and radio waves, which send signals to the body and then receive signals back. These returning signals are converted into images by a computer attached to the scanner. Imaging of any part of the body can be obtained in any plane. This Article gives a brief idea about the history, construction, working principle of MRI which includes Nuclear spin, Lamoure's frequency,T1 and T2 relaxation and T1 and T2 weighted images .

Keywords— *MRI, Nuclear spin, Larmour's frequency,T1 and T2 relaxation, T1 and T2 weighted images*

1. INTRODUCTION

An MRI is scan which is based on painless radiology technic and avoids x-ray radiation exposure. It is true that there are no side effects of an MRI scan. The origin al name of MRI is NMRI that stands for Nuclear Magnetic Resonance Imaging. Since the word 'Nuclear' got negative association it was dropped from the NMRI and remained as MRI.

MRI is mainly works on the principal of Nuclear Magnetic Resonance. Spectroscopic technic is used to get microscopic chemical and physical data of the molecules. NMR results from specific magnetic properties of certain atomic nuclei and it is mostly used to find out the structure of organic molecules in solution and study molecular physics, crystals as well as non-crystalline materials. MRI is a routinely used advanced medical imaging technique of NMR.

2. HISTORY

There has been lot of talk around the history of MRI due to other innovation in medicine and health. Felix Bloch and Edward Purcell discovered the magnetic resonance phenomenon in 1946 and for that discovery of magnetic phenomenon they were awarded with Nobel Prize in 1952

In 1971, Raymond Damadian disclosed that the nuclear magnetic relaxation of tissues and tumors are different from each other: therefore, the idea motivated the other scientist to study magnetic resonance for the discovery of disease. Richard Ernst suggested that magnetic resonance imaging using phase and frequency encoding, and the Fourier Transform in 1975 which is based on the present technique of MRI. After a couple of years there were other scientist have got different ideas among all Raymond Damadian proved MRI is field-focusing nuclear magnetic resonance. Peter Mansfield developed the echo-planar image (EPI) technique in 1977 which produced the image rate on par with video rate (30ms/image)

There were a lot of scientists contributed to development of this technology moving forward, but the first clinical MRI scanner was built by a team lead by Professor John Mallard at the University of Aberdeen in 1980. In 2003, Paul C. Lauterbur of the University of Illinois and Sir Peter Mansfield of the University of Nottingham were awarded the Nobel Prize in Medicine for their discoveries concerning magnetic resonance imaging. MRI is clearly a young, but growing science

3. CONSTRUCTION

3.1 RF coil

The signals of MR in MRI are shaped through the process of resonance, which is the result of radiofrequency coils. They consist of two electromagnetic coils, the transmitter and receiver, which generate the field and receive the resulting signal. RF –coils may function as receivers, transmitters or both.

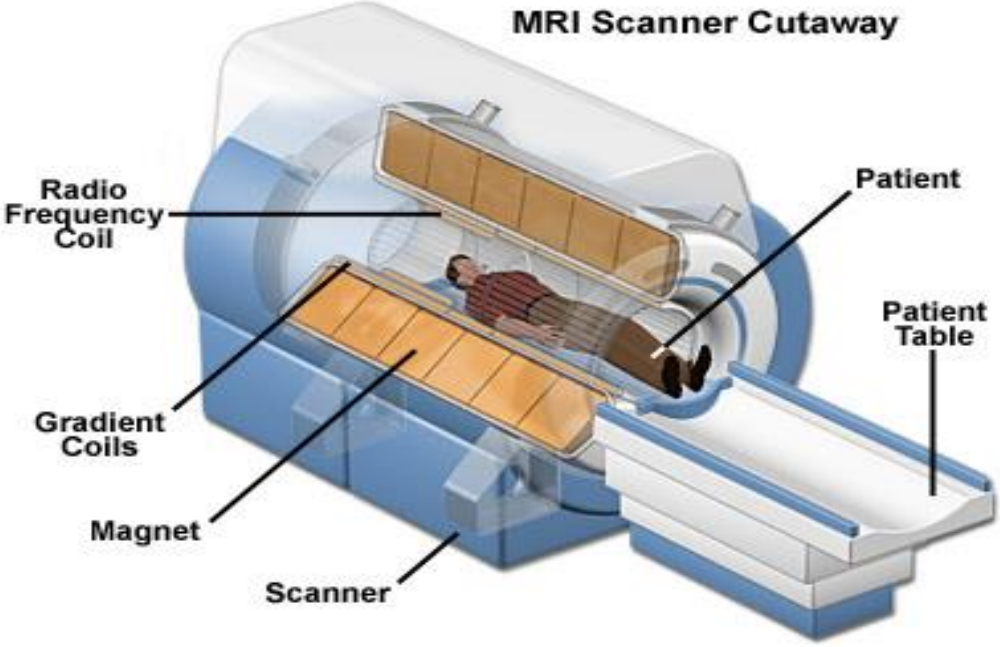


Fig. 1: MRI Machine

When used as transmitters, RF-coils generate an oscillating/rotating magnetic field (denoted **B1**) that is perpendicular to the static main magnetic field (**Bo**). If the oscillation of **B1** closely matches the natural precession of nuclear spins near the Larmor frequency, energy is deposited into the spin system causing a change in its net alignment. The **B1** field is generated by the transmit RF-coil in response to a powerful current generated by the scanner's transmit circuitry. **B1** is typically turned on for only brief periods of time (a few m sec), called "RF-pulses." By adjusting the magnitude or duration of these **B1** pulses, the nuclear spin system can be rotated by variable flip angles, such as 90º or 180º

When used as receivers, RF-coils are responsible for detecting the MR signal. The oscillating net magnetic flux from the excited spin system can be captured by the coil in which an induced electric current is generated. This current is then amplified, digitized, and filtered to extract frequency and phase information.

3.2 Gradient coils

Gradients are loops of wire or thin conductive sheets on a cylindrical shell lying just inside before the MRI scanner. When current passed through this coil secondary magnetic field is created. This gradient field slightly distorts the main magnetic field in a predictable pattern, causing the resonance frequency of protons to vary in as function of position. Therefore gradient coils allow the spatial encoding of MR signal. The functions of X, Y and Z coils are
X –coil: Create a varying magnetic field from left to right.
Y-coil: Create a varying magnetic field from top to bottom.
Z-coil: Create a varying magnetic field from head to toe.

Radiofrequency Coil both transmit the pulse sequence and receive the resulting MR signal. For this reason they are called "**Transceiver".**

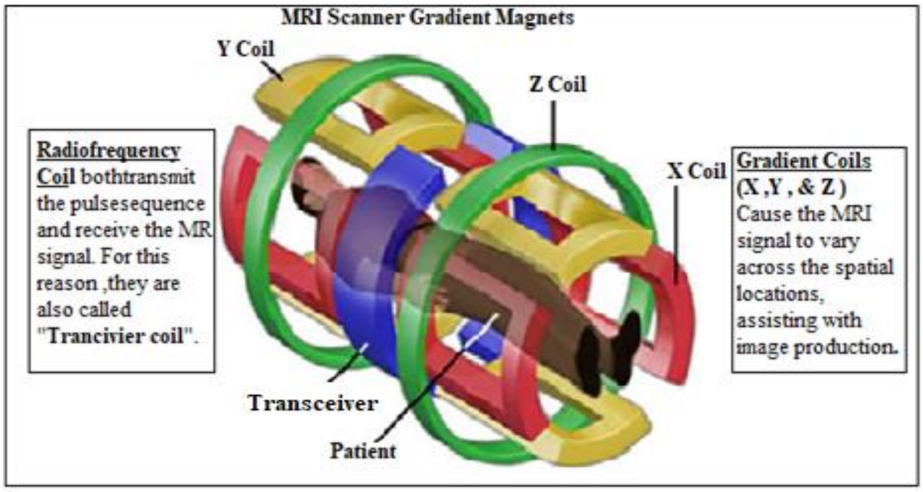


Fig. 2: Radiofrequency coils and gradient coils

3.3 Magnet

Apart from all components of MRI, magnet is the very vital and biggest components. There are mainly three types of magnets are used.

Permanent magnet: It can provide the static magnetic field .They are made from ferromagnetic materials. The main advantage of this is maintaining coast is very less. But there are significant drawbacks to using permanent magnets. They can only achieve the field strength usually less than0.4Tesla and they are of limited precision and stability. Permanent magnets also a threat for safety of the patient , since their magnetic fields cannot be turned off, ferromagnetic objects are virtually impossible to remove from them once they come into direct contact.

Resistive electromagnet: It is a solenoid made by copper wire. An advantage is low initial cost, but field strength and stability are limited. They need electrical power during operation which can make it expensive to operate.

Superconducting magnet: This magnet made by a superconductors, (niobium-titanium or niobium-tin alloy), lose its electrical resistance if cooled by liquid helium to 4 K.
They can create a magnetic field up to 4 T. Even though It is very expensive to make superconductive magnet, the strong magnetic field allows for the highest-quality imaging, and superconducting magnets are the most common type found in MRI scanners today.

3.4 Patient Table

Fig. 3: Patient Table

This component simply slides the patient into the MRI machine. The position at which the patient lies down on the table is determined by the part of the body that is being scanned. Once the part of the body under examination is in the exact center of the magnetic field, which is referred to as the ISO centre, the scanning process is started.

3.5 Antenna/Computer System

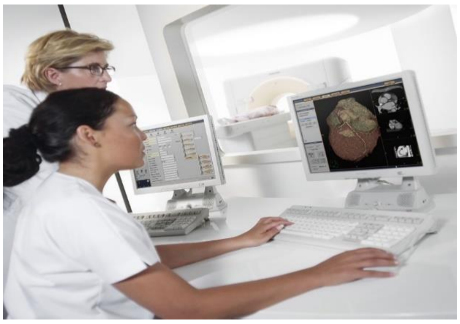


Fig. 4: Computer system setup

The antenna is a very sensitive device that easily detects the RF signals emitted by a patient's body while undergoing examination and feeds this information into the computer system. The computer system is a powerful system, its major function is to receive, record, and analyze the images of the patient's body that have been scanned. It interprets the data sent in by the antenna and then, helps to produce an understandable image of the body part being examined.

4. WORKING AND THEORY

Our body has plenty of hydrogen atoms in the form of water, carbohydrates and Fats etc. Each nucleus of hydrogen behaves like a magnet, so they have a magnetic moment. In the absence of external field these hydrogen gents randomly oriented and spin in any direction, canceling each other out. Therefore the net magnetic moment is zero. When they subjected to an external magnetic field from MRI machine all of these protons lineup. Most of them line up with the main magnetic field, have lower energy and few of them line up opposite to the field, have higher energy.

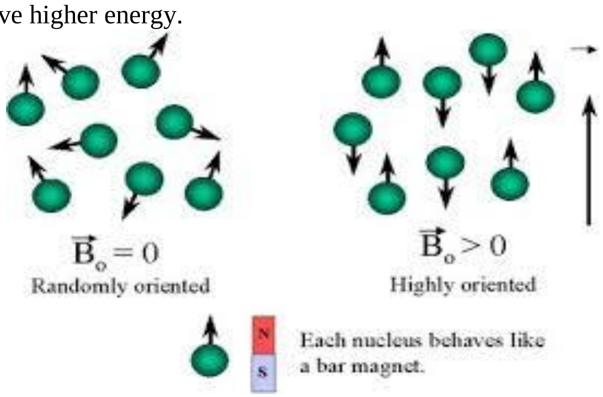
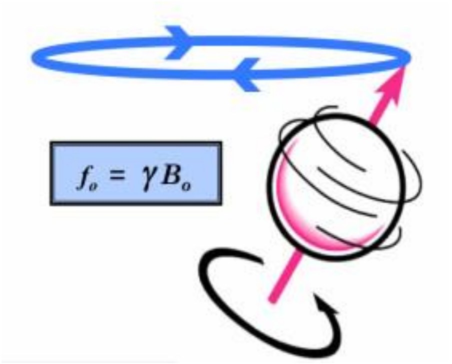


Fig. 5: Working

These protons are presses; the rate of precession can be calculated by **Larmour equation** that is rate of rotation is directly proportional to the strength of magnetic field. **fo = γ Bo** Where is γ is called Gyro Magnetic Ratio .The Larmour's frequency of hydrogen as shown in table. Basically it is 42.58 MHz /T



Magnetic field	Larmour's Frequency
1 Tesla	42.58 MHz /T
2 Tesla	85.18 MHz /T
3 Tesla	127.747 MHz /T

Due to most of the protons in lower energy state which lineup with main magnetic field, the net magnetization will be in the direction of the external field, called the **longitudinal magnetization (Mz)**.

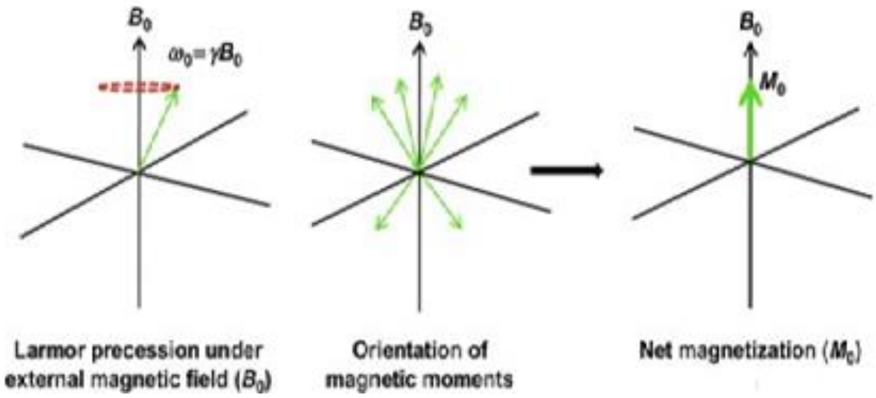


Fig. 6: Longitudinal magnetization

If we transmit a RF signal say, 42.58 MHz/T which is equal to frequency of the protons in homogeneous field (Larmor's frequency (42.58 MHz/T)) called the **resonant frequency** it take in two ways:

(i) The protons which are in lower energy absorb the energy flip in to higher energy state (50% up and 50%down). Therefore the longitudinal magnetization will be zero since as the opposing magnetic field cancel each other.

(ii) It pushes the proton to synchronize and spin together .So the net magnetic moment oriented horizontally or 90^0 to the longitudinal magnetization. This is called **transverse magnetization (Mxy).** Net magnetization can be detected coil and antenna.

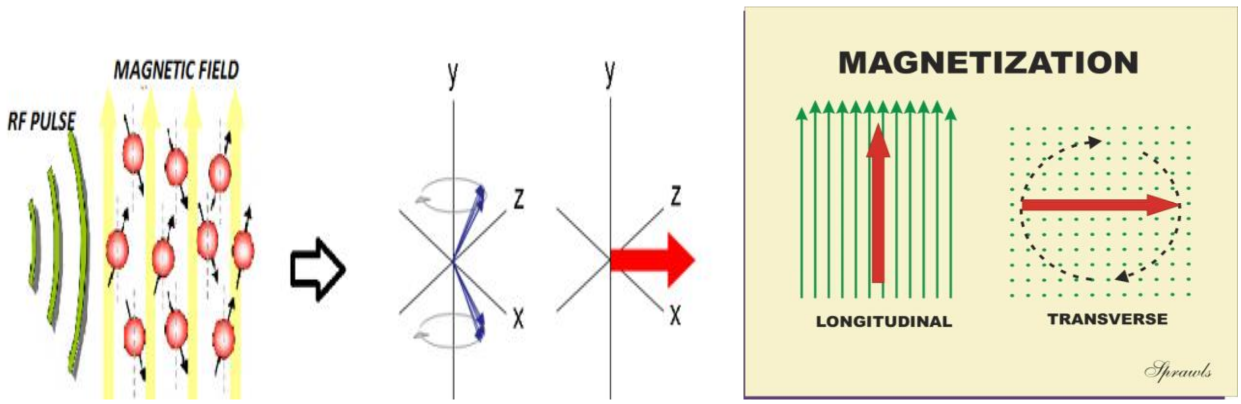


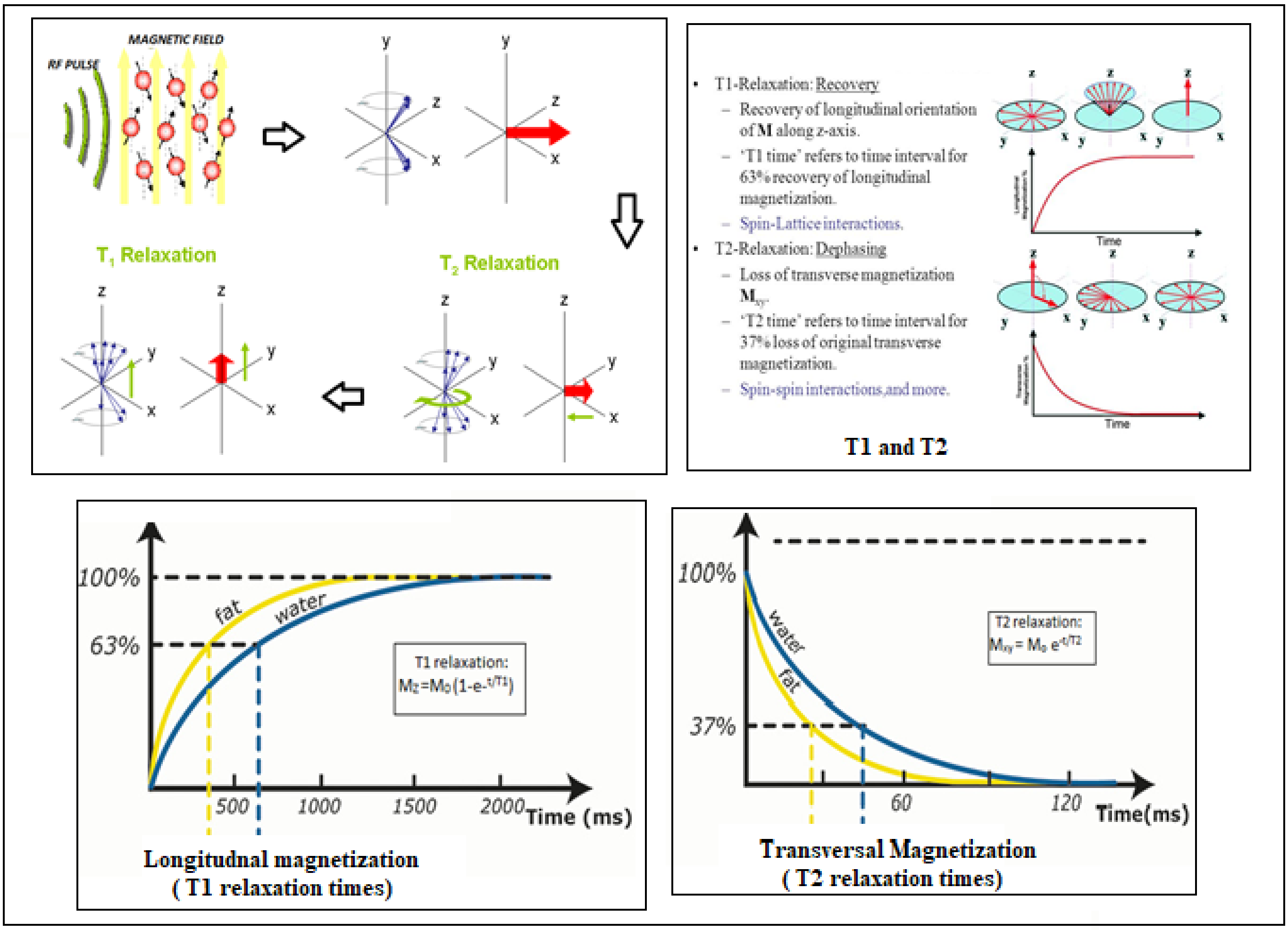
Fig. 7: Magnetization

When we remove the RF signal the protons will relax back into their baseline position. The protons will spin, being positively charged they repel each other and they move apart .Due to this they lose their transverse magnetization (Mxy) . This process is called **T2 relaxation**. Since it is the interaction between protons and spins themselves, **this is also called spin –spin relaxation**. No net energy transfer in this relaxation.T2 contrast describe the time taken for the transverse magnetization to decay e-1 or 37% of its initial value.

The protons in high energy state go to the lower energy state by losing their energy to the surrounding tissue in the form of heat. So that most of the proton line up in base line, it restore longitudinal magnetization (Mz).This is called **T1 relaxation or spin –Lattice relaxation** because in this process the energy is transferred from Spin to the surrounding tissue or lattice. T1 is a time constant that is used to describe how fast the process of T1 relaxation takes. Specifically, T1 is the time taken for longitudinal magnetization to regrow from 0 to (1−e−1), or approximately 63% of its final value.

Different molecules (water molecules, lipid fats etc.) Shows different characteristics in their T1 and T2 relaxation. For example water molecules, move rapidly and do not move in to lower energy state quickly .So it will take long time for T1 relaxation. Similarly for large macro molecule (lipids and fats) and get into lower energy state quickly. So it will take shorter time for T1 relaxation.

In case of T2 , Free water (eg, cerebrospinal fluid), comprising rapidly moving small molecules that are relatively far apart, will have less spin–spin interaction and therefore longer T2 values compared with water-based tissues that have a large macromolecular content (eg, grey matter), giving them more time to interact with each other.



By varying RF pulse applied and collected, different type of image is created. The time between the successive pulse sequence is applied to the same slice is called repletion time TR. The time between the delivery of RF pulse and receipt of the echo is called Echo time (TE).

The images produced by short TE and TR times are called T1 weighted images. The images produced by longer TE and TR times are called T2 weighted images, the contrast and brightness of both T1 weighted images and T2 weighted images are predominately determined by the properties of tissue.

For example in a short TE and TR times, the Fat quickly realigns its longitudinal magnetization with B0, and it, therefore, appears bright on a T1 weighted image. Conversely, water has much slower longitudinal magnetization realignment after an RF pulse and therefore, has less transverse magnetization after an RF pulse. Thus, water has low signal and appears dark. So generally we can say, a tissue with short T1 produces all intense MR signal and is displayed as bright white in a T1 weighted image. A tissue with long T1 produces a – low intensity signal and appears dark in MR image. Similarly a tissue with a long T2 produces a high-intensity signal and is bright in the image. One with short T2 produces a low-intensity signal and is dark in the image.

We can enhances and improves the quality of the MRI images (or pictures) by injecting the Gadolinium contrast media (sometimes called a MRI contrast media, agents or 'dyes') are chemical substances used in magnetic resonance imaging (MRI) scans.

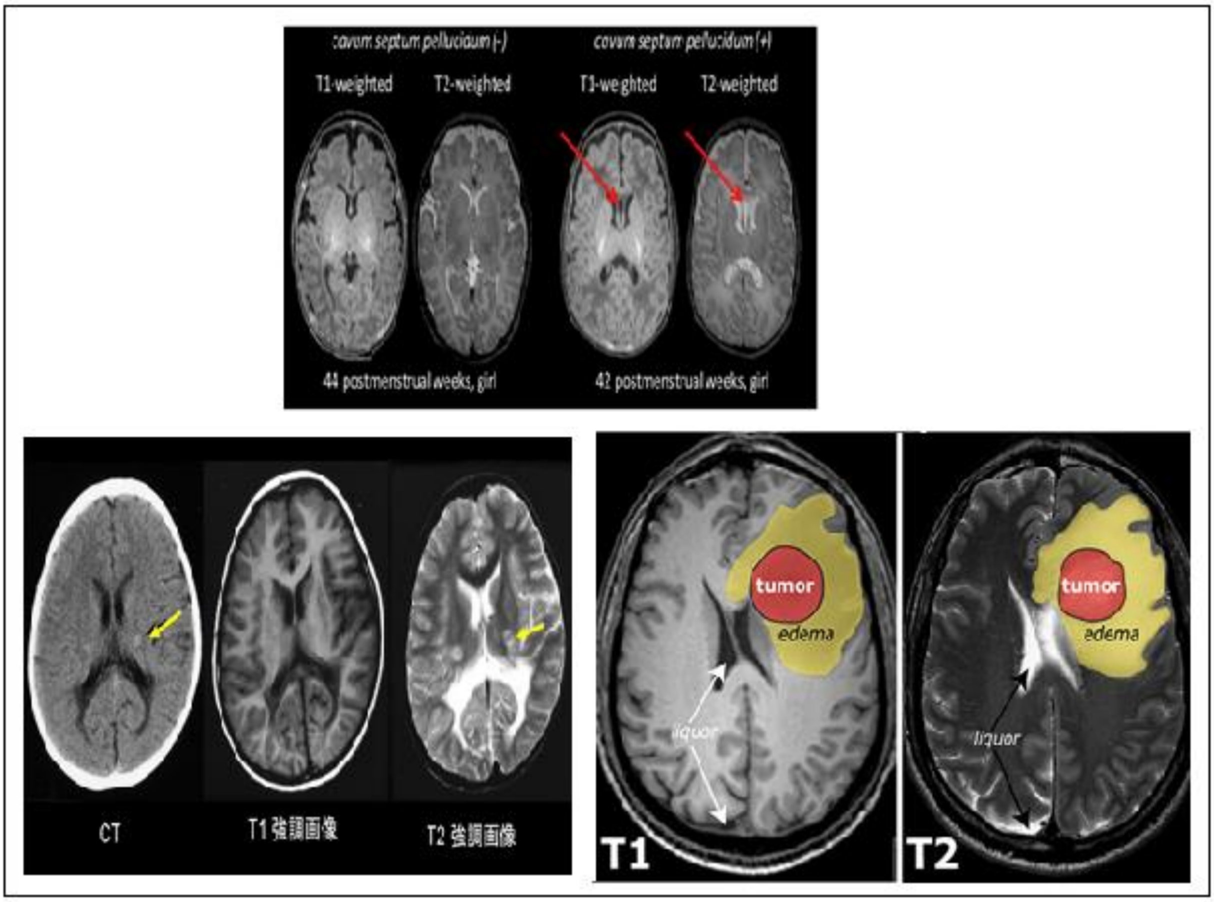


Fig. 8: T1 and T2 weighted images

5. APPLICATION

- MRI is very accurate and the best method to detect any kind of disease throughout the body where other methods fail to diagnose the patients diseases.
- If there is bleeding or welling or any trauma in the head can be seen easily through MRI.
- Abnormalities such as brain aneurysms, tumors of the brain, stroke and inflammation of the spine can be detected easily.
- Surgeons of neurology use the MRI when there are problems like brain anatomy, integrity of the spinal cord after trauma, and vertebrae or intervertebral discs of the spine.
- MRI is very important because it can find any kind of damage related to the heart structure and aorta
- It can also give the exact information about glands, organs in the abdomen, structure of the joints, soft tissues, and bones of the total body etc. Sometimes MRI is used after the surgery if there is any problem related to operation and healing.

6. LIMITATIONS

- The poor people cannot afford on MRI as they are more expensive than CT scan
- There is too much noisy while doing MRI scan
- MRI is sometimes harmful for the patient those who have metal implants in their body. Safety measure must be taken under the supervision of senior doctors and trained radiologists to avoid injuries from the MRI.

7. CONCLUSION

This article has outlined the basic physics involved in MRI and the basic knowledge required for interpretation of MRI images. The MRI machine continues to have great impacts in the human life and with scientists continuing to improve this important device, it seems that we may not have seen the full potential of the MRI scanners just yet. There are many excellent books and review and research papers are available on MRI working principles, its health effects and safety.

8. REFERENCES

[1] The Basics of NMR: Joseph P. Hornak, Ph.D.
[2] A Basic Guide to NMR: James N. Shoolery
[3] Nuclear magnetic resonance -Application to Organic chemistry: Johan B Robert
[4] MRI Basic principle and Application: Mark A brown and Richard C Semelka
[5] Short Introduction to MRI physics for Neuroimaging: Michael Chappell ,Thomas Okell and Mark Jenkinson
[6] Nuclear magnetic resonance, Second Edition P.J. Hore
[7] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1121941
[8] https://en.wikipedia.org/wiki/Felix_Bloch_(diplomatic_officer)
[9] https://en.wikipedia.org/wiki/History_of_magnetic_resonance_imaging
[10] https://www.medicinenet.com/mri_scan/toledo-oh_city.htm

[11] https://radiopaedia.org/articles/mri-sequences-overview
[12] https://en.wikipedia.org/wiki/Physics_of_magnetic_resonance_imaging-

BIOGRAPHY

Shajahan V S
Physics lecturer
Vocational College, Ibri, Oman

Master of Science in Physics from Bharathidasan university
Bachelor of Education in Physical Science from Mahatma Gandhi University

