Al-Mustaqbal University
College of Health and Medical Technologies
Radiological Techniques Department

Magnetic Resonance Imaging

First Semester

Lecture 3,4 : Concepts of MRI

By

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Scientific Content:

The way magnetic resonance imaging (MRI) is generated is complicated and is much harder to understand than plain radiography, CT and ultrasound. It has strong underpinnings in physics which must be understood before any real sense of "how it works" is gained. What follows is a very abbreviated or "broad strokes" description of the process.

A magnetic resonance system (the actual machine) consists of the following components:

1. **A large magnet** to generate the magnetic field.
2. **Shim coils** to make the magnetic field as homogeneous as possible.
3. **A radiofrequency (RF) coil to transmit** a radio signal into the body part being imaged.
4. **A receiver coil** to detect the returning radio signals.
5. **Gradient coils** to provide spatial localization of the signals.
6. **A computer to reconstruct the radio signals into the final image**.

Concept of MRI image

An image has contrast if there are areas of high signal (white on the image), as well as areas of low signal (dark on the image). Some areas have an intermediate signal (shades of grey in-between white and black). A tissue gives an intermediate signal (grey). (Fig.1).

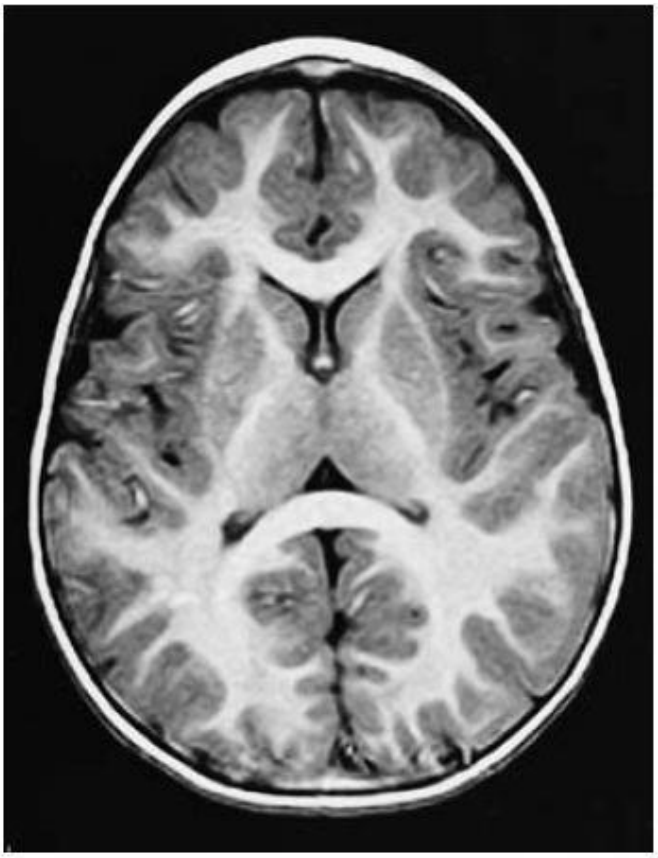


Fig.(1): Axial IR T1 weighted image using a TI of 700 ms. Note the exquisite contrast between grey and white matter.

The image contrast is controlled by two groups of parameters:

A. Extrinsic contrast parameters

B. Intrinsic contrast mechanism

A. **Extrinsic contrast parameters** : which are controlled by the system operator ;These include the following.

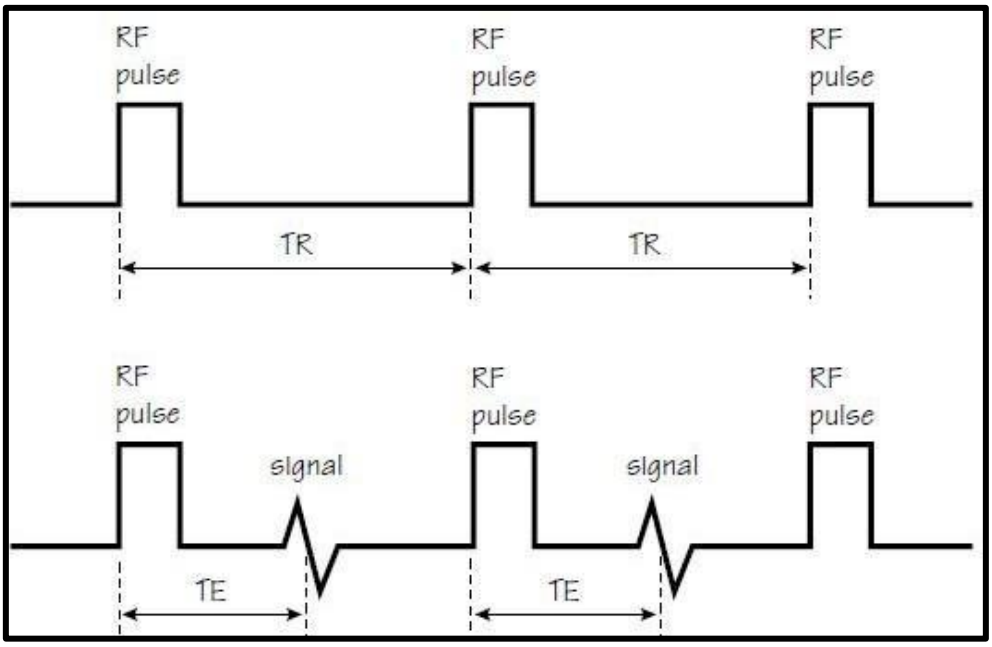


Fig.(2): A basic pulse sequence.

1- Repetition time (TR). This is the time from the application of one RF pulse to the application of the next. It is measured in milliseconds (ms). The TR affects the length of a relaxation period after the application of one RF excitation pulse to the beginning of the next (Fig. 2).

2- Echo time (TE). This is the time between an RF excitation pulse and the collection of the signal. The TE affects the length of the relaxation period after the removal of an RF excitation pulse and the peak of the signal received in the receiver coil. It is also measured in ms (Fig .2).

3- Flip angle. This is the angle through which the NMV is moved as a result of a RF excitation pulse.

4- Turbo-factor or echo train length (ETL/TF) .

5- Time from inversion (TI).

6- 'b' value: is a factor that reflects the strength and timing of the gradients used to generate diffusion-weighted images .

B. Intrinsic contrast mechanism:

Which do not come under the operator's control; These include:

1. T1 recovery
2. T2 decay
3. Proton density
4. Flow
5. Apparent diffusion coefficient (ADC): is a measure of the magnitude of diffusion (of water molecules) within tissue.

The MRI Simplified

MRI uses a powerful magnetic field that makes the hydrogen protons in water molecules, which comprise between 70% and 80% of the average human brain, line up. This ubiquitous biological molecule has two protons, which by virtue of their positive charge act as small magnets on a subatomic scale. Then once they are all lined up from the magnetic field, they are then knocked out of line by radio waves. When the radio waves are stopped, the protons relax back into line, releasing resonance signals that are transmitted to a computer.

To have a better understanding or image of this, think of the hydrogen proton as if it were a gyroscope or even the planet earth, spinning on its axis, with a northsouth pole. In this respect it behaves like a small bar magnet. Now under normal conditions, these hydrogen proton "bar magnets" spin in the body with their axes randomly aligned since nothing is pulling them magnetically in the same direction. An example could be a group of children on a playground running around with no sense of order.

When the body is placed in a strong magnetic field, such as an MRI scanner, the protons' axes all line up. This uniform alignment creates a magnetic vector oriented along the axis of the MRI scanner. Now think of those same children with no order and how each one will line up if someone yells "cookie." How loud you yell "cookie" depends on your strength and this is the same with different machines. Each scanners come in different field strengths, usually between 0.5 and 1.5 tesla (T).

The strength of the magnetic field can be altered electronically from head to toe using a series of gradient electric coils, and, by altering the local magnetic field by these small increments, different slices of the body will resonate as different frequencies are applied.

When additional energy, in the form of a radio wave, is added to the magnetic field, the magnetic vector is deflected. The radio frequency (RF) wave that causes the hydrogen nuclei to resonate is dependent on the element sought (hydrogen) and the strength of the magnetic field.

When the RF source is switched off the magnetic vector returns to its resting state, and this causes a signal, or radio wave to be emitted. It's this signal which is used to create the MR images. Receiver coils are used around the body part in question to act as aerials to improve the detection of the emitted signal. The intensity of the received signal is then plotted on a grey scale and cross sectional images are built up.

Multiple transmitted RF pulses can be used in sequence to emphasise particular tissues or abnormalities. A different emphasis occurs because different tissues relax at different rates when the transmitted RF pulse is switched off. The time taken for the protons to fully relax is measured in two ways. The first is the time taken for the magnetic vector to return to its

resting state and the second is the time needed for the axial spin to return to its resting state. The first is called T1 relaxation, the second is called T2 relaxation.

A MR examination is thus made up of a series of pulse sequences. Different tissues (such as fat and water) have different relaxation times and can be identified separately. By using a "fat suppression" pulse sequence, for example, the signal from fat will be removed, leaving only the signal from any abnormalities lying within it.

Spatial encoding of the MRI signal is accomplished through the use of gradients (smaller magnetic fields) which perturb the main magnetic field, and cause hydrogen protons in different locations to precess (move) at slightly different rates. The portion of the gradient coils and the associated current that is perpendicular to the main magnetic field cause a force (Lorentz force) on the coils. The gradients are turned on and off very quickly in this process causing them to vibrate causing the majority of the noise associated with the MRI environment. This still occurs even though they are embedded in an epoxy.

Parameter Weighting

Terms such as "T1-weighted" and "T2-weighted" are among the most overused and least understood concepts in MR imaging. In the broadest sense, these terms are used to communicate to other physicians the type of MR pulse sequence employed to generate a series of images.

Most non-radiologists are often taught to look at the "color" of cerebrospinal fluid (CSF) or other fluids to determine the type of "weighting" — dark CSF means "T1-weighting" and bright CSF means "T2-weighting". Although this

simple scheme worked fine in the past, now consider the brain image from the commonly used T2-FLAIR (fluid-attenuated inversion recovery) sequence. This sequence is known to have strong sensitivity to T2 changes, but the CSF signal has been suppressed by an inverting pulse and rendered black. This can lead to confusion for some since parts of "weighting" image has similar coloring to a "FLAIR" image.

A fundamental misconception about "weighting", is that contrast in the image is dominated by one specific tissue parameter to the exclusion of all others. Another common misconception is that T1-weighted or T2-weighted images are parameter "maps" whose pixel intensities are proportional to tissue T1 or T2 values.

It's alright to use terms like "T1-weighted" and "T2-weighted" as long as you realize they are imprecise, are not parameter "maps", and that nearly all images have mixed contributions from all the different tissue parameters.

T1 weighting

In a T1 weighted image, differences in the T1 relaxation times of tissues must be demonstrated.

-To achieve (T1 weighted image):

- For T1 weighting differences between the T1 times of tissues is exaggerated and to achieve this the TR must be short.
- To remove T2 effects the TE must also be short (Fig.3)

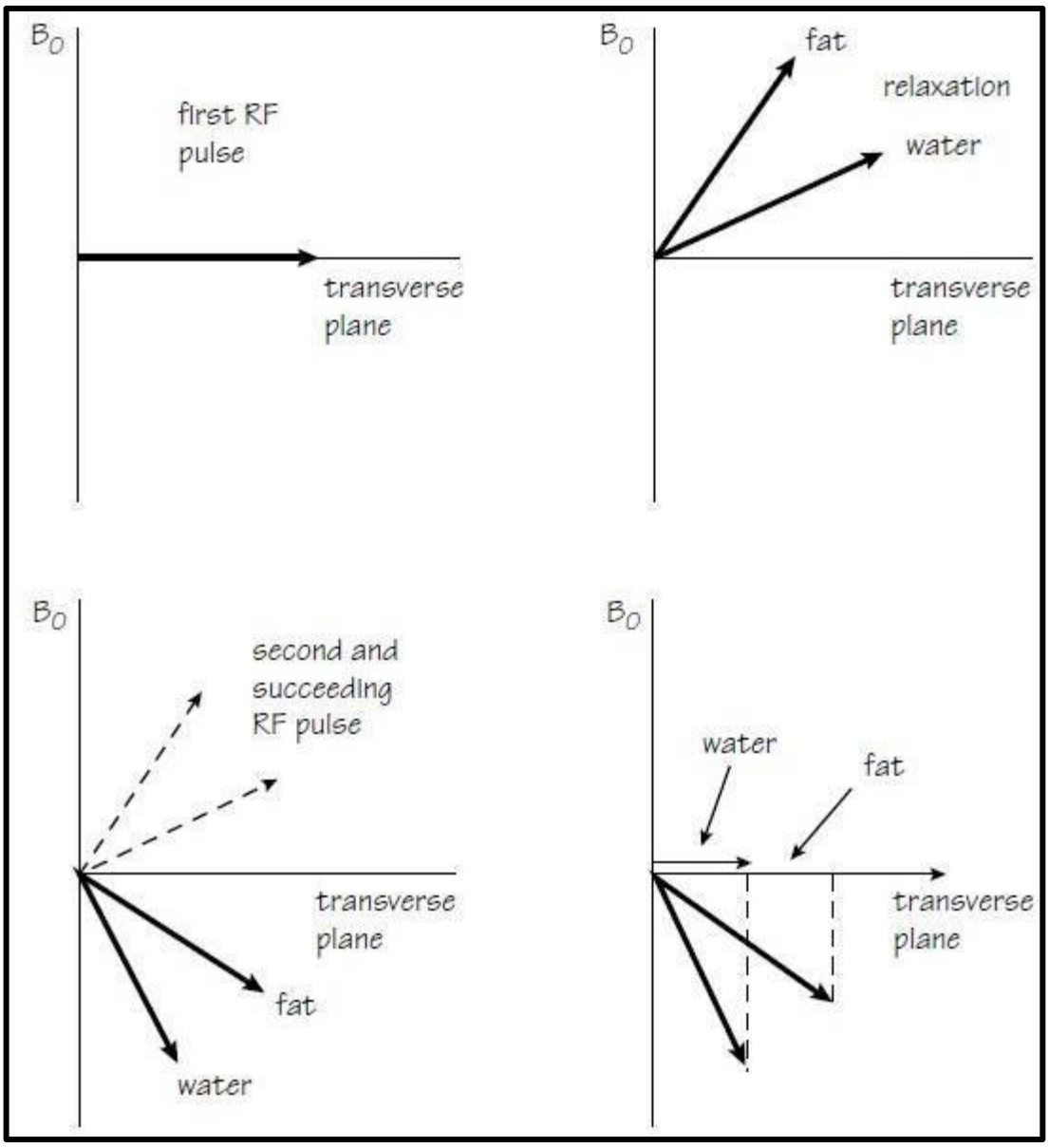


Fig.(3) : Short TR

Signal brightness could be seen in the T1:

- In T1 weighted images, tissues with short T1 relaxation times such as fat, are bright (high signal), because they recover most of their longitudinal magnetization during the TR.
- Tissues with long T1 relaxation times such as water, are dark (low signal) because they do not recover much of their longitudinal magnetization. T1 weighted images best demonstrate anatomy but also show pathology if used after contrast enhancement (to identify solid from cystic lesion).

High signal	fat haemangioma intra-osseous lipoma radiation change degeneration fatty deposition methaemoglobin cysts with proteinaceous fluid paramagnetic contrast agents slow flowing blood
Low signal	cortical bone avascular necrosis infarction infection tumours sclerosis cysts calcification
No signal	air fast flowing blood tendons cortical bone scar tissue calcification

Table (1) : Signal intensities seen in T1 weighted images.

T2 weighting

In a T2 weighted image the differences in the T2 relaxation times of tissues must be demonstrated.

-To achieve (T2 weighted image):

1- For T2 weighting the differences between the T2 times of tissues is exaggerated, therefore the TE must be long.
2- T1 effects are diminished by selecting a long TR (Fig.4).

Signal brightness could be seen in the T2:

- Tissues with a short T2 decay time such as fat are dark (low signal) because they lose most of their coherent transverse magnetization during the TE period.
- Tissues with a long T2 decay time such as water are bright (high signal), because they retain most of their transverse coherence during the TE period.
- T2 weighted images best demonstrate pathology as most pathology has an increased water content and is therefore bright on T2 weighted images.

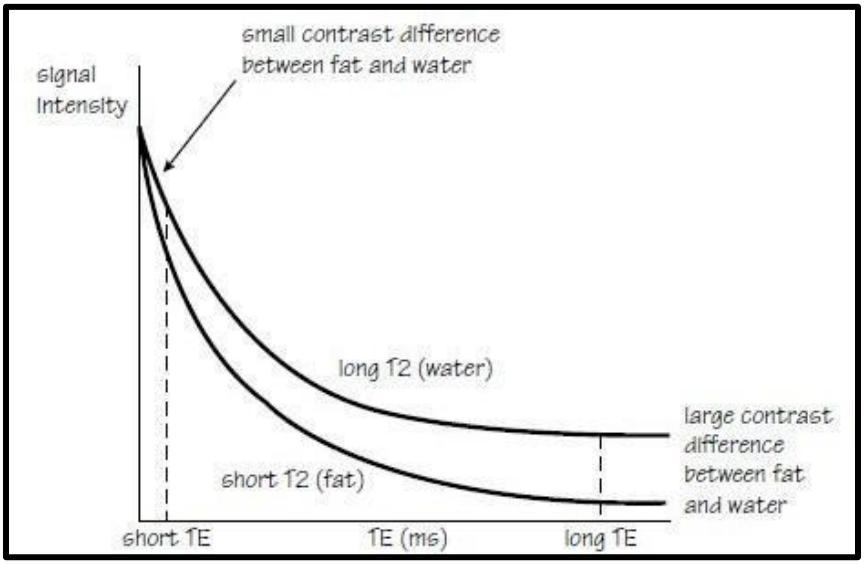


Fig.(4): T2 differences between fat and water

Typical parameters T2 W images

TR 2000 ms .

TE 70 ms

High signal	CSF synovial fluid haemangioma infection inflammation oedema some tumours haemorrhage slow-flowing blood cysts
Low signal	cortical bone bone islands de-oxyhaemoglobin haemosiderin calcification T2 paramagnetic agents
No signal	air fast flowing blood tendons cortical bone scar tissue calcification

Table (2): Signal intensities seen in T2 weighted images

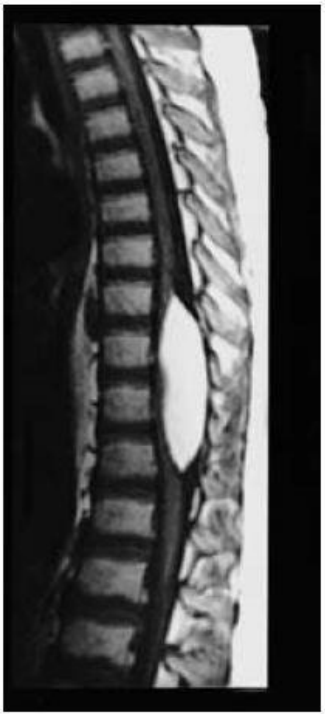


Fig.(5A): Sagittal T1 weighted image of spine. Intraspinal lipoma is bright as it contains fat.

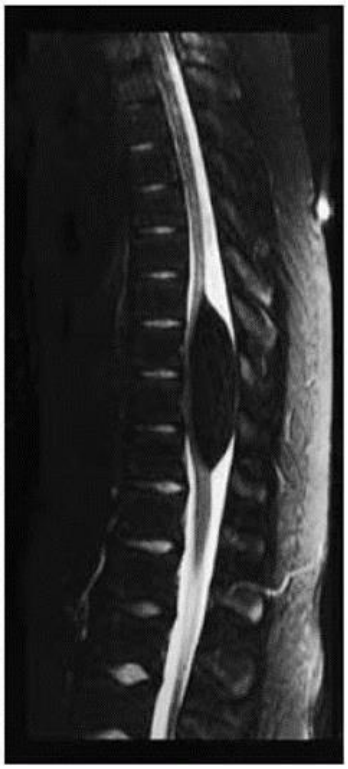


Fig. (5.B): The intraspinal lipoma is now dark. Sagittal T2 weighted image through the spine in the same patient seen in

Proton density (PD) weighting

In a PD weighted image differences in the proton densities (number of hydrogen protons in the tissue) must be demonstrated.

To achieve this:

- both T1 and T2 effects are diminished. T1 effects are reduced by selecting a long TR and T2 effects are diminished by selecting a short TE.

Signal brightness could be seen in the PD:

- Tissues with a high proton density are bright (high signal) because the high number of protons result in a large component of transverse magnetization.
- Cortical bone and air are always dark on MR images regardless of the weighting as they have a low proton density and therefore return little signal.
- Proton density weighted images show anatomy and some pathology (Fig. 6 and 7).

Typical values

TR 2000ms+ TE 10–30ms

Fig. 6 Proton density contrast.

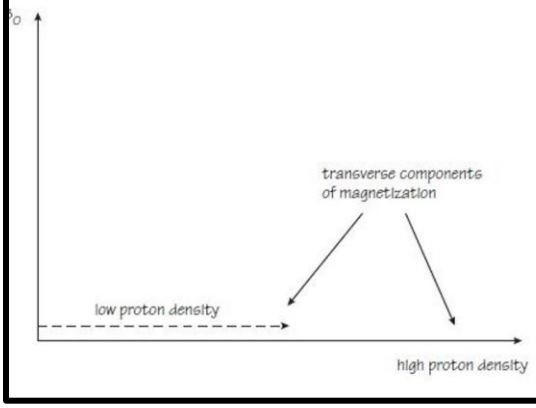
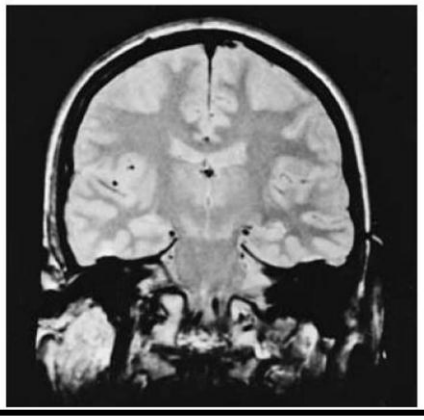


Fig.7 Coronal FSE PD weighted image of the brain.



Pretest: : الاختبار

Q1: Why the radiology technicians need to know the MRI terms?

Q2: Mention the differentiation between MRI Terms of T1, T2?

Q3: Mention why we use the flip angle in MRI protocols?

Q4: Compare between by drawing the T1 and T2 relaxation time?