الجامعة التقنية الوسطى

كلية التقنيات الصحية والطبية/ بغداد

قسم تقنيات الأشعة المادة: التصوير بالرنين المغناطيسي

المرحلة:الرابعة

Title: **العنوان:**

MRI Terms 1

Name of the instructor: **اسم المحاضر:**

م.م.علا سالم صادق

Target population: **الفئة المستهدفة:**

طلبة قسم تقنيات الأشعة/ المرحلة الرابعة

Introduction: المقدمة:

MRI technicians need to know MRI terms definitions for several reasons, including:

Understanding medical terminology: MRI technicians need to have a basic understanding of medical terminology to communicate effectively with physicians and other healthcare professionals Mastering MRI procedures: MRI technicians need to understand and master MRI procedures, including the terminology used in MRI imaging, to perform their job effectively.

Ensuring MRI safety: MRI technicians need to have sound knowledge of the physical principles of the MRI scanner and understand the associated safety risks to avoid adverse events from occurring.

Encountering MRI terminology: MRI technicians are likely to encounter MRI terminology in the course of their work, and they need to be familiar with the terminology to perform their job effectively.

Pretest: **الاختبار القبلي:**

Q/ Why the Radiological Technologist need to know the MRI terms?

Scientific Content: **المحتوى العلمي:**

1- **Alignment: - When nuclei are placed in an external magnetic field their magnetic moments line up with the magnetic field flux lines. (fig.1)**

2- **Ampere's law: - Determines the magnitude and direction of the magnetic field due to a current, if you point your right-hand thumb along the direction of the current, then the magnetic field points along the direction of the curled figures. (fig.2)**

3- **Anti-parallel alignment: - Describes the alignment of the magnetic moments in the opposite direction of main magnetic field Bo.**

4- **Axial: - A plane, slice, or section made by cutting the body or part of it at right angles to the long axis of the body. (fig.3)**

5- **B or Bo: - A conventional symbol for the constant magnetic field produced by the large magnet in the MR scanner.**

6- **Bipolar: - Describes a magnet with two poles, north and south. (fig.4)**

7- **Black blood imaging: acquisitions in which blood vessels are black.**

8- **Blood oxygen level dependent (BOLD): a functional MRI technique that uses the differences in magnetic susceptibility between oxyhemoglobin and deoxyhemoglobin to image areas of activated cerebral cortex. (fig.5)**

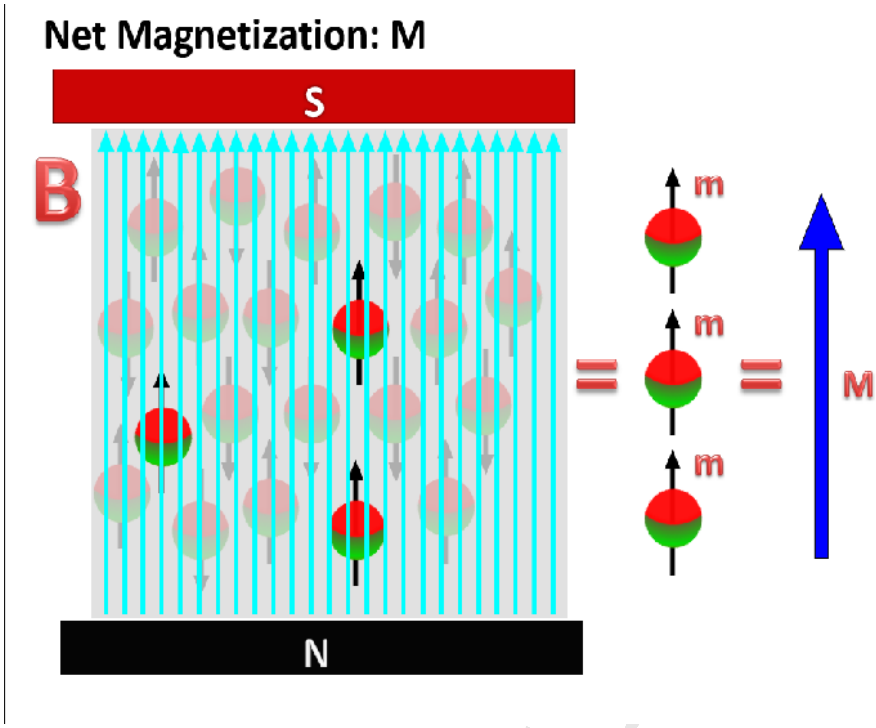

Fig.1: Alignment of protons with the external magnetic field.

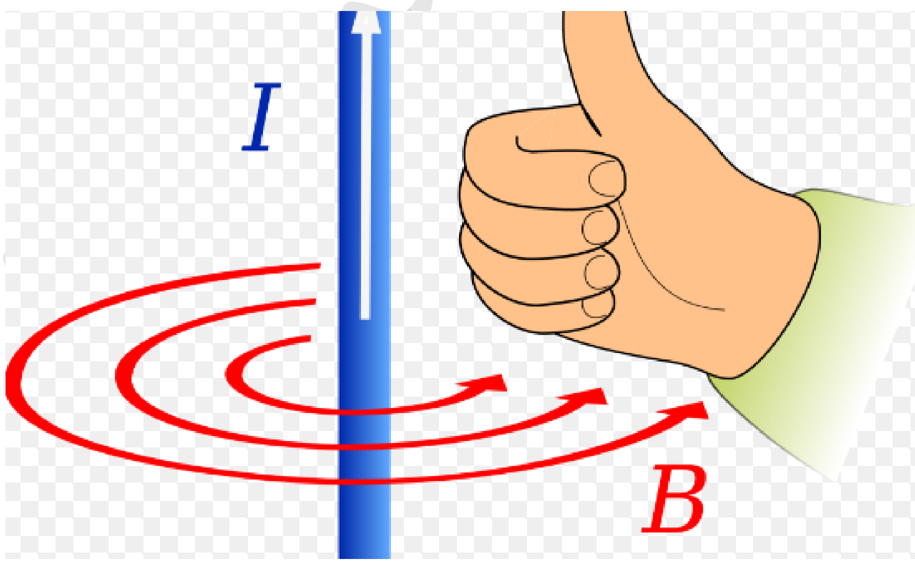

Fig.2: Ampere's law.

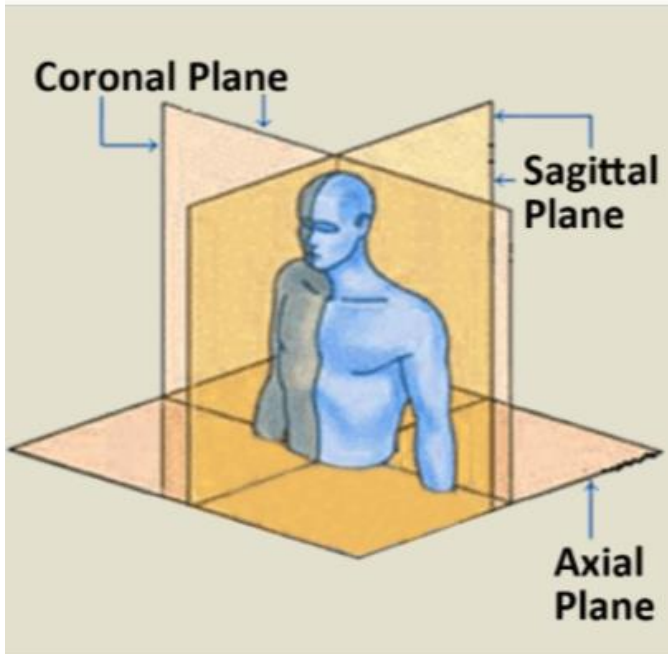

Fig.3: Axial, sagittal, and coronal plane.

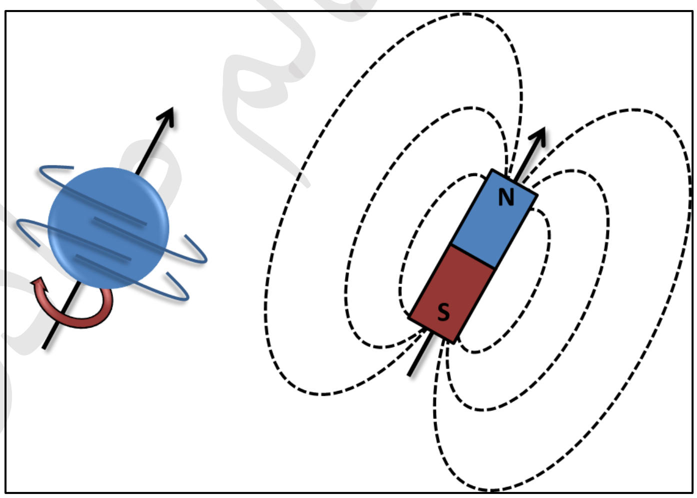

Fig.4: Bipolar (a magnet with two poles)

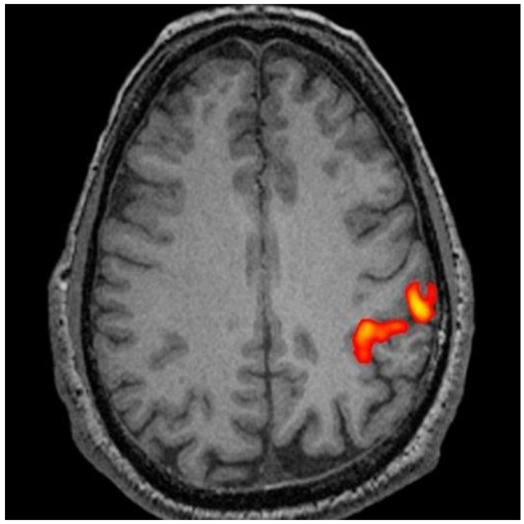

Fig.5: BOLD imaging

9- Bright blood imaging: acquisitions in which blood vessels are bright.

10- Contrast reversal: an image phenomenon where the darks become bright, and the brights become dark. This is usually most prevalent in sequences utilizing an extended TR.

11- Claustrophobia: - A psychological reaction to being confined in a relatively small area.

12- Coronal: - A plane, slice, or section made by cutting across the body from side to side and therefore parallel to the coronal suture of the skull.

13- Cryogen bath: area around the coils of wire in which cryogens are placed.

14- Cryogens substances: used to supercool the coils of wire in a superconducting magnet.

15- Diffusion-weighted image: Imaging techniques designed to weight the measured MRI signal by the amount of diffusion (random thermal motion) of water molecules in the selected voxels.

16- Electromagnet: - A type of magnet that utilizes coils of wire, typically wound on an iron core, so that as current flows through the coil it becomes magnetized.

17- Equilibrium: - A state of balance that exists between two opposing forces or divergent forms of influence.

18- Excitation: - Delivering (inducing, transferring) energy into the "spinning" nuclei via radio-frequency pulses, which puts the nuclei into a higher energy state. By producing a net transverse magnetization, an MRI system can observe a response from the excited system.

19- Echo spacing: spacing between each echo in FSE.

20- Echo train: series of 180° rephasing pulse and echoes in a fast spin echo pulse sequence.

21- Echo train length (ETL): the number of 180° RF pulses and or turbo factor resultant echoes in FSE. (fig.6)

22-Frequency: - The number of cycles or repetitions of any periodic wave or process per unit time. In electromagnetic radiation, it is usually expressed in units of hertz (Hz), where 1 Hz=1 cycle per second.

23- Free Induction Decay (FID): loss of signal due to relaxation; if transverse magnetization of the spins is produced, e.g., by a 90É RF pulse, a transient MR signal at the Larmor frequency results that decays toward zero with a characteristic time constant of T2*. This decaying signal is the FID. (fig.7)

24- Fringe field: stray magnetic field outside the bore of the magnet.

25- Frequency encoding: the process of locating an MR signal in one dimension by applying a magnetic field gradient along that dimension during the period when the signal is being received.

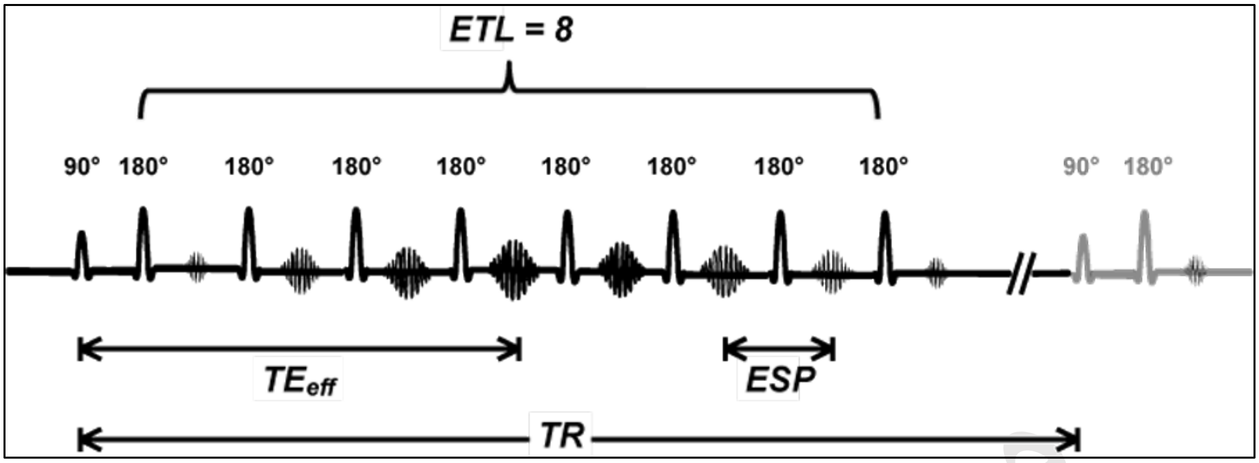

Fig 6: Echo train, echo spacing, and echo train length in FSE.

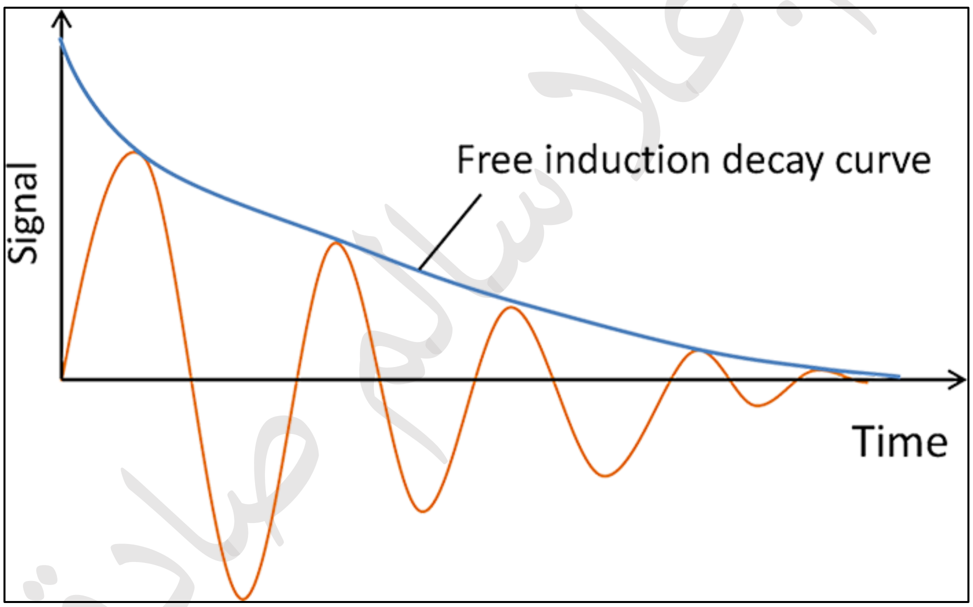

Fig 7: Free induction decay curve

26- Gyromagnetic ratio: - A constant for any given nucleus that relates the nuclear MR frequency and the strength of external magnetic field. It represents the ratio of the magnetic moment (field strength) to the angular momentum (frequency) of a particle. The value of the gyromagnetic ratio for hydrogen is 4.258Hz/Gauss (42.58 MHz/Tesla).

27- Gadolinium (Gd): gadolinium is a non-toxic paramagnetic contrast enhancement agent utilized in MR imaging. When injected during the scan, gadolinium will tend to change signal intensities by shortening T1 in its surroundings.

28- Gradient coils: three paired orthogonal current-carrying coils located within the magnet which are designed to produce desired gradient magnetic fields which collectively and sequentially are superimposed on the main magnetic field (Bo) so that selective spatial excitation of the imaging volume can occur. Gradients are also used to apply reversal pulses in some fast-imaging techniques.

Posttest: الاختبار البعدي:

Q/ Define BOLD MRI?

References: المصادر:

- **MRI A to Z: Gray Liney.**
- **MRI at a Glance: Catherine Westbrook.**

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قسم تقنيات الأشعة المادة: التصوير بالرنين المغناطيسي

المرحلة:الرابعة

Title: **العنوان:**

MRI terms 2

Name of the instructor: **اسم المحاضر:**

م.م.علا سالم صادق

Target population: **الفئة المستهدفة:**

طلبة قسم تقنيات الأشعة/ المرحلة الرابعة

Introduction: **المقدمة:**

MRI technicians need to know MRI terms to communicate effectively with healthcare professionals, understand and master MRI procedures, ensure MRI safety, and perform their job effectively. MRI terms can be found in MRI reports, glossaries, and educational resources. It is important for MRI technicians to keep up-to-date with the latest MRI technology and terminology to provide the best possible care for their patients and parameters.

29- Hertz: - The standard unit of frequency equal to 1 cycle per second. The larger unit megahertz (MHz=1000,000 Hz).

30- Homogeneity: - Uniformity of the main magnetic field.

31- Hydrogen density: - The concentration of Hydrogen atoms in water molecules or in some groups of fat molecules within tissue. Initial MR signal amplitudes are directly related to H+ density in the tissue being imaged.

32- Inhomogeneity: - Lack of homogeneity or uniformity in the main magnetic field.

33- Image data acquisition time: the time required to gather a complete set of image data.

34- Image reconstruction: the mathematical process of converting the composite signals obtained during the data acquisition phase into an image.

35- Larmor equation: - An equation that states that the frequency of precession of the nuclear magnetic moment is directly proportional to the product of magnetic field strength (Bo) and the gyromagnetic ratio. W=gBo.

36- Longitudinal magnetization: the component of the net magnetization vector in the direction of the static magnetic field. After RF excitation, this vector returns to its equilibrium value at a rate characterized by the time constant T1.

37- Longitudinal relaxation time: the time constant, T1, which determines the rate at which excited protons return to equilibrium within the lattice. A measure of the time taken for spinning protons to re-align with the external magnetic field. The magnetization will grow after excitation from zero to a value of about 63% of its final value in a time of T1. (fig 8)

38- Magnetic resonance: - The absorption or emission of energy by atomic nuclei in an external magnetic field after the application of RF excitation pulses using frequencies which satisfy the conditions of the Larmor equation.

39- Net magnetization: - A vector which represents the sum of all of the contributions of the magnetic moments within the magnetic field; the magnitude and direction of the magnetization resulting from this collection of atomic nuclei.

40- Oblique: - A plane or section not perpendicular to the xyz coordinate system, such as the long and short axis views of the heart. (fig 9)

41- Orthogonal: - A plane or section perpendicular to the xyz coordinate system.

42- Permanent magnet: - Magnets that retain their magnetism.

43- Precession: - The secondary spin of magnetic moments around Bo. (fig 10)

44- Proton density: - The number of protons in a unit volume of tissue.

45- Paramagnetic substance: a substance with weak magnetic properties due to its unpaired electrons.

46- Pixel: acronym for a picture element, the smallest discrete two-dimensional part of a digital image display. (fig 11)

47- Relaxation time: after excitation the spins will tend to return to their equilibrium distribution in which there is no transverse magnetization and the longitudinal magnetization is at its maximum value and oriented in the direction of the static magnetic field. After excitation the transverse magnetization decays toward zero with a characteristic time constant T2, and the longitudinal magnetization returns toward equilibrium with a characteristic time constant T1. (fig 12)

48- Repetition time (TR): the amount of time that exists between successive pulse sequences applied to the same slice. It is delineated by initiating the first RF pulse of the sequence then repeating the same RF pulse at a time t. Variations in the value of TR have an important effect on the control of image contrast characteristics. Short values of TR (< 1000 ms) are common in images exhibiting T1 contrast, and long values of TR (> 1500 ms) are common in images exhibiting T2 contrast.

49- Readout gradient: the frequency encoding gradient. (fig 13)

50- Shim coils: coils positioned near the main magnetic field that carry a relatively small current that is used to provide localized auxiliary magnetic fields in order to improve field homogeneity.

51- Sampling rate: rate at which samples are taken during readout.

52- Shimming: process whereby the evenness of the magnetic field is optimized. (fig 14)

53- Voxel volume element; the element of the three-dimensional space corresponding to a pixel, for a given slice thickness.

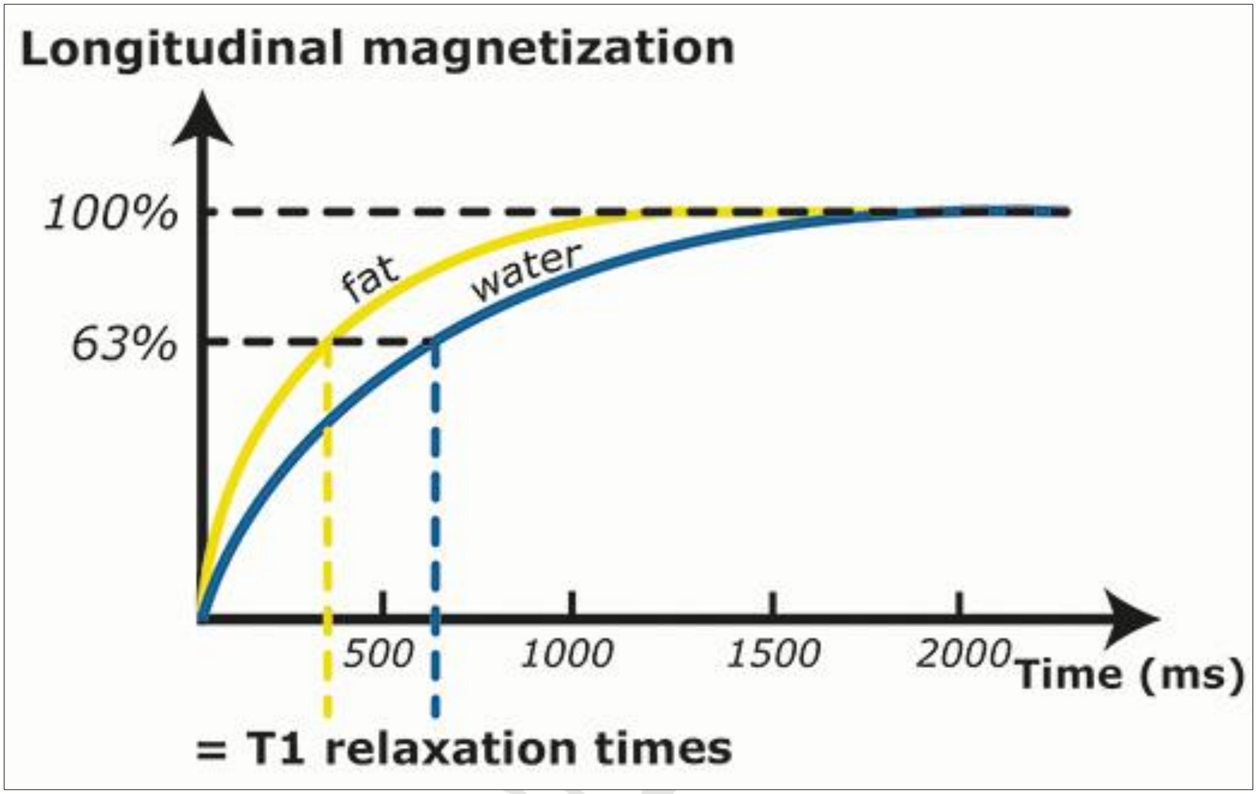

Fig 8: T1 relaxation time

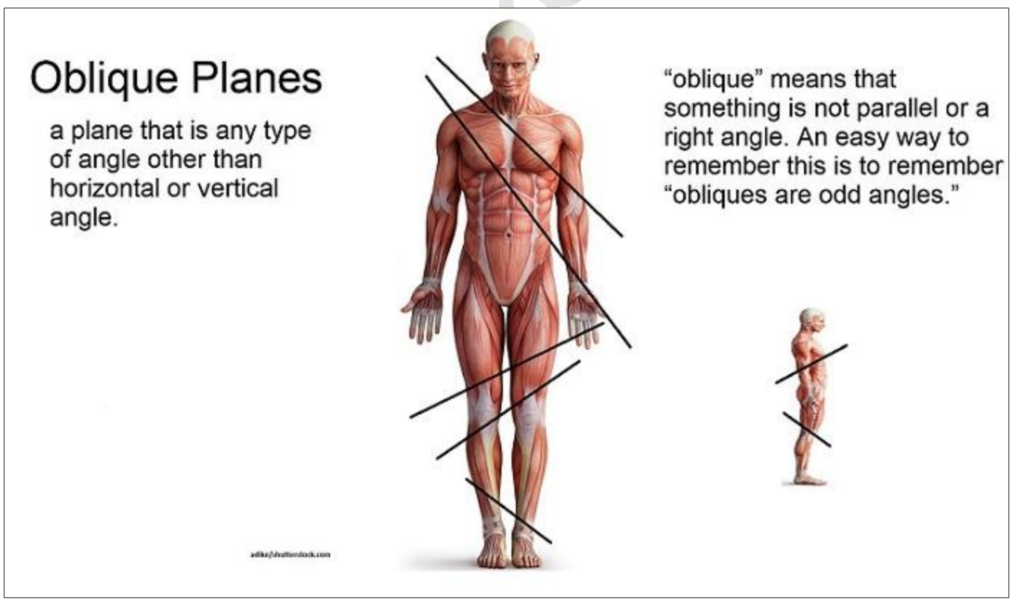

Fig 9: oblique plane

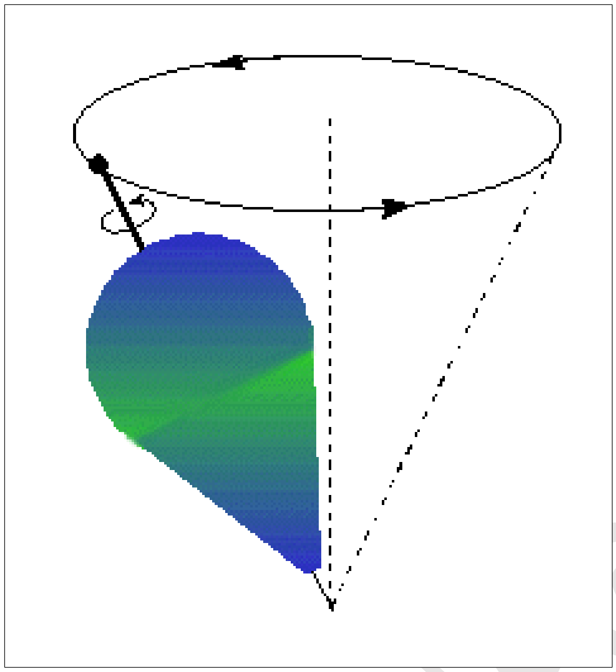

Fig 10: Precession

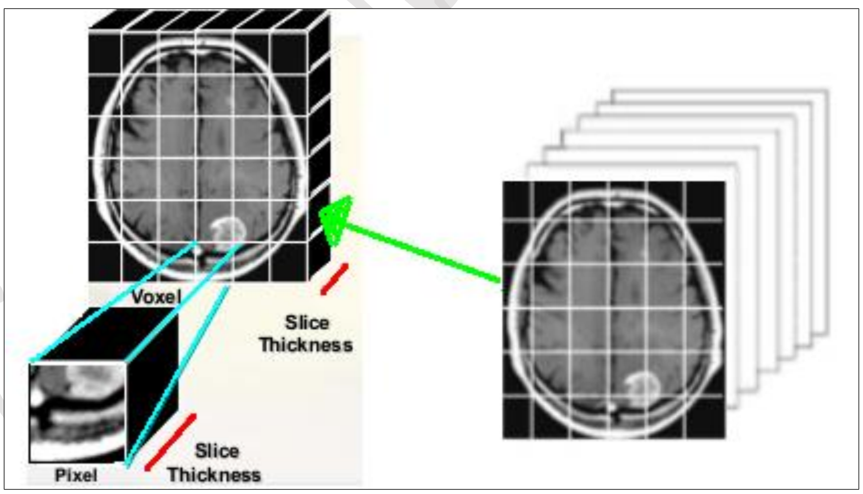

Fig 11: Pixel and voxel

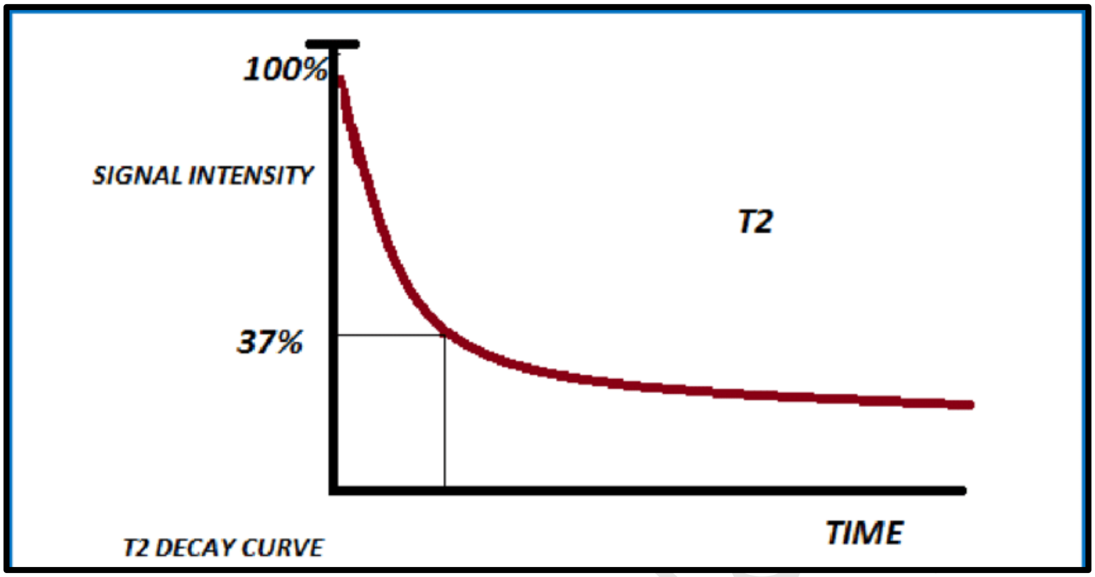

Fig 12: T2 decay curve

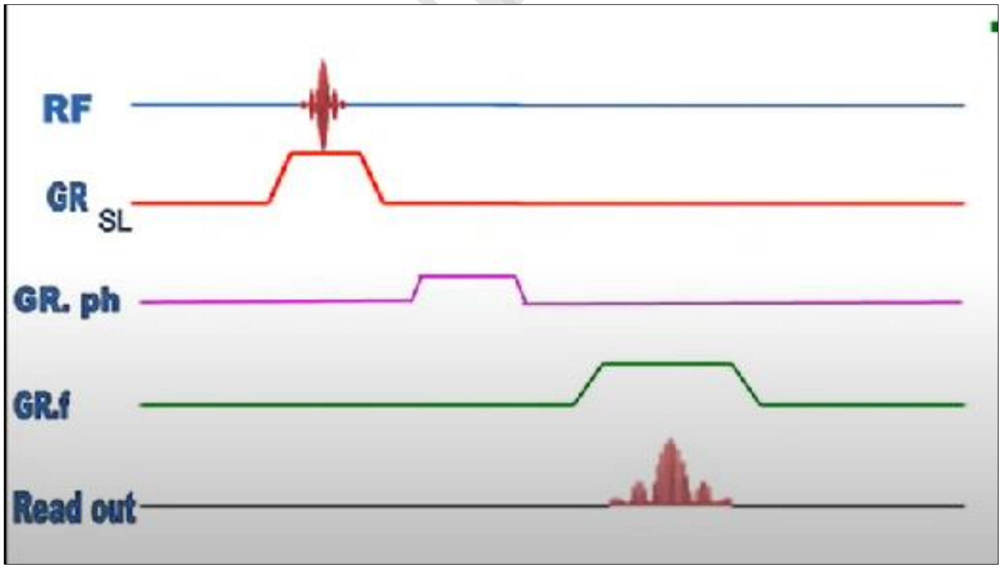

Fig 13: MRI sequence

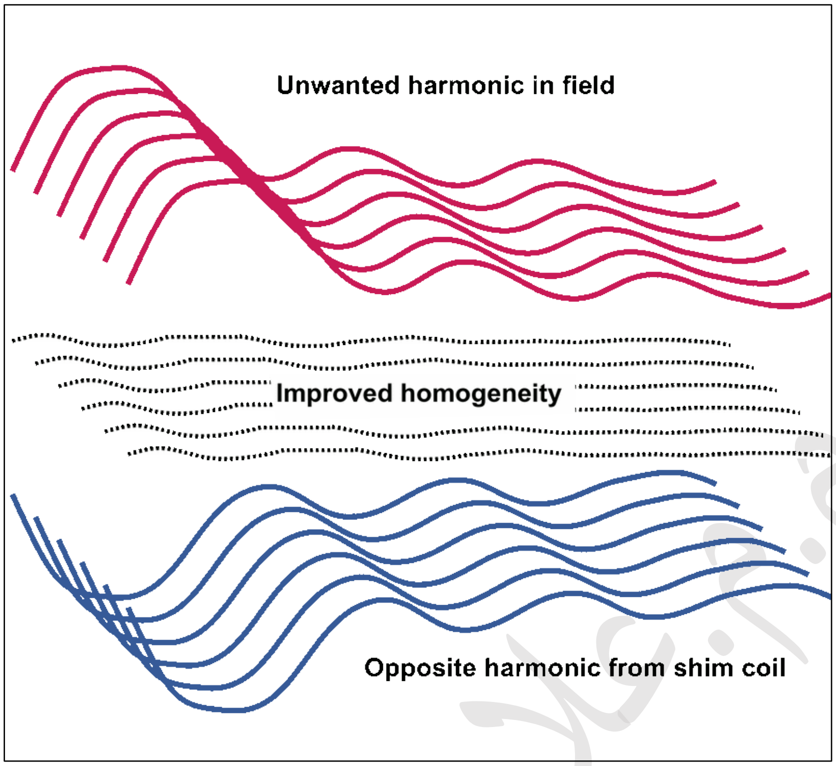

Fig 14: Shimming by shim coil

References: المصادر:

- **MRI A to Z: Gary Liney**
- **MRI at a Glance: Catherine Westbrook**

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كلية التقنيات الصحية والطبية/ بغداد

قسم تقنيات الأشعة المادة: التصوير بالرنين المغناطيسي

المرحلة:الرابعة

Title: العنوان:

Concepts of MRI (3+4)

Name of the instructor: اسم المحاضر:

م.م.علا سالم صادق

Target population: الفئة المستهدفة:

طلبة قسم تقنيات الأشعة/ المرحلة الرابعة

Introduction: المقدمة:

MRI technicians' students need to understand MRI concepts for several reasons, including:

- Performing MRI exams: MRI technicians need to have a thorough understanding of the physical principles of MRI and the general concepts of image contrast.

MRI technicians need to understand MRI concepts to perform MRI exams effectively, ensure MRI safety, interpret MRI results accurately, and keep up-to date with MRI technology.

MRI concepts can be learned to the student through MRI technology theoretical and practical lectures, continuing education courses. It is important for MRI technician students to stay up-to-date with the latest MRI technology and concepts to provide the best possible care for their patients in the future.

Pretest: الاختبار القبلي:

Q/What are the most important hardware within MRI system?

Scientific Content: المحتوى العلمي:

- **MRI components**

Scanners of MRI come in many varieties. The most important hardware within MRI system are as follows (fig 1):

1.A large magnet to generate the magnetic field. The static magnetic field in MRI system can be created by:

A- Permanent magnets, or B- Electromagnets.

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.

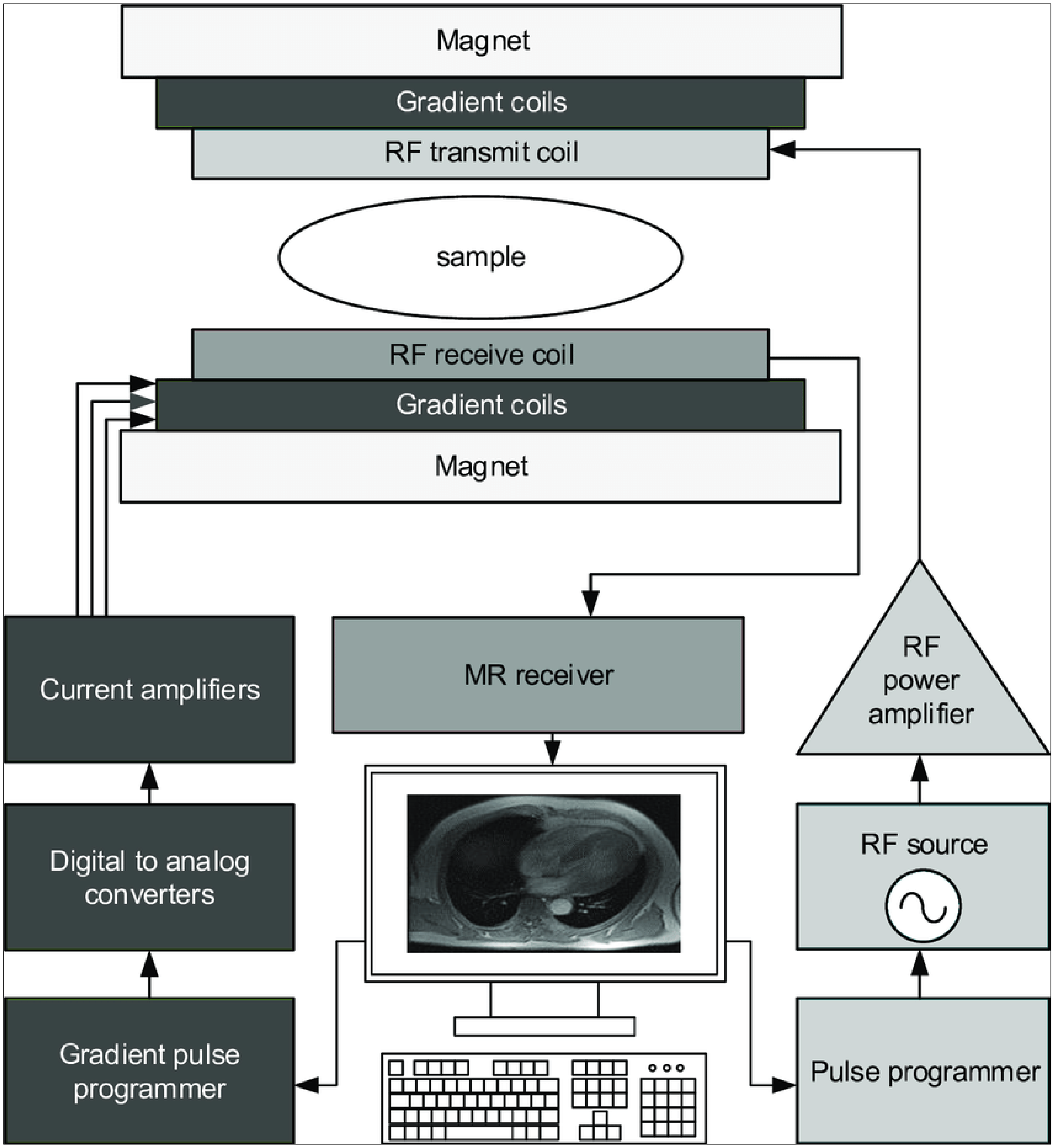


Fig.1: Block diagram of a typical magnetic resonance imaging scanner.

- **<u>Concepts of MRI image</u>: - 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).**

- Terminology

- **Intensity: When describing most MRI sequences, we refer to the shade of grey of tissues or fluid with the word intensity, leading to the following absolute terms:**
  A- high signal intensity = white
  B- intermediate signal intensity = grey
  C- low signal intensity = black

- Often, we refer to the appearance by relative terms:

A-hyperintense = brighter than the thing we are comparing to it.
B-isointense = same brightness as the thing we are comparing to it.
C-hypointense = darker than the thing we are comparing to it.

- **Parameters that affect image contrast: The image contrast is controlled by two groups of parameters:**

  A. Extrinsic contrast parameters: which are controlled by the system operator; These include the following: -
  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.
  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 signals 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). The time between inversion 180 degree and excitatory 90-degree pulses is called as 'time to

invert or TI'. It is used in certain pulse sequences to manipulate the contrast between different tissues in the image.

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

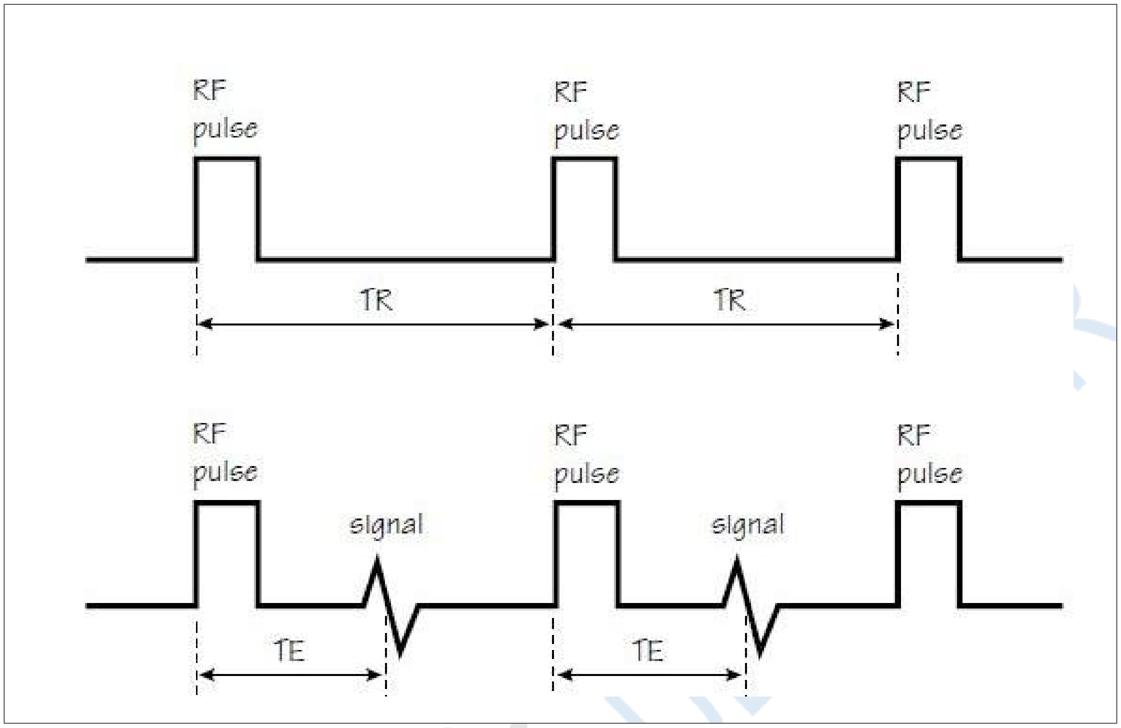


Fig 2: A basic pulse sequence

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.**

- **Technical factors influencing the image contrast and quality:**

In MRI, a protocol is defined as a set of rules which include a variety of different parameters that we select at the imaging consol. Protocols are judged by how well they show anatomy and pathology, and this is based on producing images that demonstrate the following four characteristics: -

1- High signal-to-noise ratio (SNR).
2- Good contrast-to-noise ratio (CNR).
3- High spatial resolution.
4- Short scan time.

In an ideal world, all four of these characteristics are achieved in every image. However, due to a variety of constraints, this is not usually possible. Optimizing parameters in favor of one of the aforementioned characteristics usually means compromising another. The skill lies in making informed decisions about which is most important for each patient and pathology, and using knowledge of underpinning physics to appropriately balance protocol parameters.

*Signal-to-noise ratio (SNR): The SNR is defined as the ratio of the amplitude of signal received to the average amplitude of the background noise.

Signal is cumulative and predictable. It occurs at, or near, time TE and at specific frequencies at, the Larmor frequency. It depends on many factors and can be altered. Noise, on the other hand, is not predictable and it occurs at all frequencies and is also random in time and space. In the context of MRI, the main source of noise is from thermal motion in the patient but it is also generated by background electrical noise of the system. Noise is constant for every patient and depends on the build of the patient, the area under examination, and the inherent noise of the system. The purpose of optimizing SNR is to make the contribution from signal larger than that from noise. As signal is predictable and noise is not, this usually means using measures that increase signal relative to noise, rather than reducing noise relative to signal.

Therefore, any factor that affects signal amplitude affects the SNR. These are as follows:

1-Magnetic field strength of the system

2- Proton density of the area under examination

3- Coil type and position

4-TR, TE, and flip angle

5-Number of signal averages (NSA)

6-Receive bandwidth

7-Voxel volume

1-Magnetic field strength: The magnetic field strength plays an important part in determining SNR. As field strength increases, the NMV increases and there is more available magnetization to image the patient. SNR therefore increases. Although the magnetic field strength cannot be altered, when imaging with low-field systems, SNR may be compromised, and it might be necessary to alter protocol parameters that boost the SNR.

2-Proton density of the area under examination: The number of protons in the area under examination determines the amplitude of received signal. Areas of low proton density (such as the lungs) have low signal and therefore low SNR, whereas areas with a high proton density (such as the pelvis) have high signal and therefore high SNR.

3-Type of coil: The type of coil affects the amount of received signal and therefore the SNR. Larger coils receive more noise in proportion to signal than smaller coils because noise is received from the entire receiving volume of the coil. Quadrature coils increase SNR because several coils are used to receive signal. Phased array coils increase SNR as the data from several coils are added together. Surface coils placed close to the area under examination also increase SNR. The use of the appropriate receiver coil plays an extremely important role in optimizing SNR. The position of the coil is also very important for maximizing SNR. To induce maximum signal, the coil must be positioned in the transverse plane perpendicular to B0. Angling the coil, as sometimes happens when using surface coils, results in a reduction of SNR. (fig 3)

4-TR, TE, and flip angle:

-The TR controls the amount of longitudinal magnetization that recovers before the next RF excitation pulse is applied. A long TR allows full recovery of longitudinal magnetization so that more is available to be flipped into the transverse plane in the next TR. A short TR does not allow full recovery of longitudinal magnetization so less is available to be flipped. Look at Figure (4) where the TR increases from 140 to 700 ms (at 1.5 T). The SNR improves as the TR increases.

-The flip angle controls the amount of transverse magnetization created by the RF excitation pulse, which induces a signal in the receiver coil (Figure 5). If the TR is long, maximum signal amplitude is created with flip angles of 90° because full recovery of longitudinal magnetization occurs with a long TR, and this is fully converted into transverse magnetization by a 90° flip angle. Look at

Figures (6) in which the flip angle changes from 10° to 90°. SNR significantly decreases in the lower flip angle image.

- The TE controls the amount of coherent transverse magnetization that decays before an echo is collected. A long TE allows considerable decay of coherent transverse magnetization before the echo is collected, while a short TE does not. Look at Figure (7) where the TE increases from 11 to 80 ms (at 1.5T). SNR decreases as the TE increases because there is less transverse magnetization available to rephase and produce an echo.

5- Number of excitation or number of signal average (NEX/NSA): Every individual signal which contributes to form a MR image, can be received once or collected several times using repeated excitations. Hence, the average signal value is used to generate the image. When the number of excitations is increased, the error (the noise) doubt and the measurements are more precise. In practice, the number of excitations ranges from 1 to 6. The number of excitations (Nex) implies the number of times a particular line in sampled in K space. K space refers to the raw data of an image. By increasing the number of excitations, the SNR is improved and vice versa. (fig 8)

6-Receive bandwidth: (BW) A general term referring to a range of frequencies (frequencies contained in a signal or passed by a signal processing system). This is the range of frequencies that are acquired by the readout gradient. If the bandwidth is reduced to half, SNR is increased by 40% and the sampling time increased also.

7-voxel volume: The building unit of a digital image is a pixel. The brightness of the pixel represents the strength of the MRI signal generated by a unit volume of patient tissue (voxel). (fig 9). Large voxels contain more spins or nuclei than small voxels and therefore have more nuclei to contribute toward signal. Large voxels consequently have a higher SNR than small voxels (Figure 10). SNR is therefore proportional to the voxel volume, and any parameter that alters the size of the voxel changes the SNR.

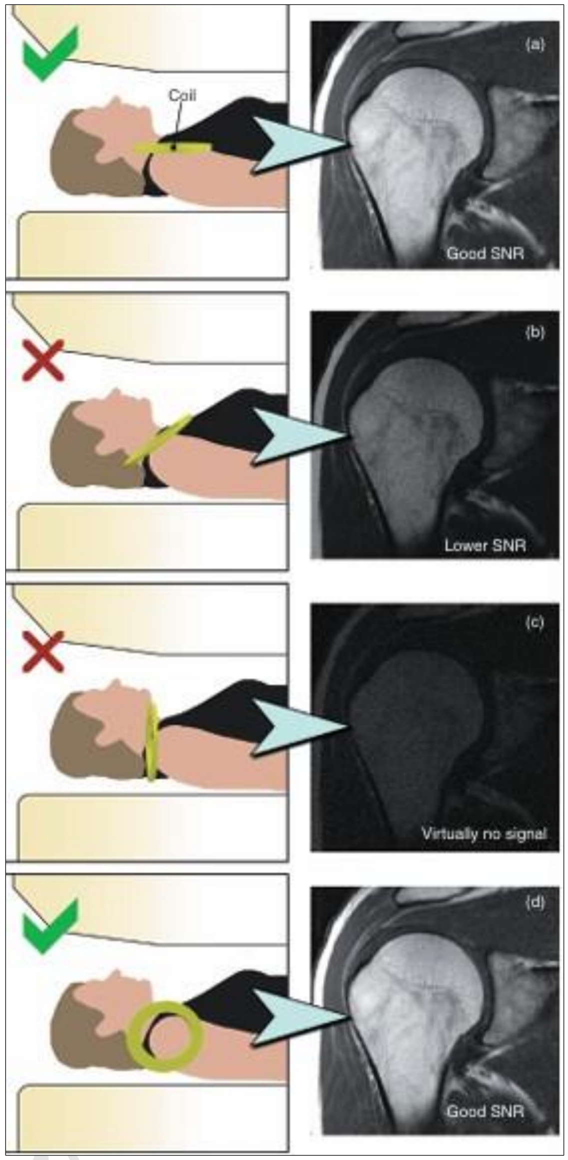


Fig.3: Coil position vs SNR

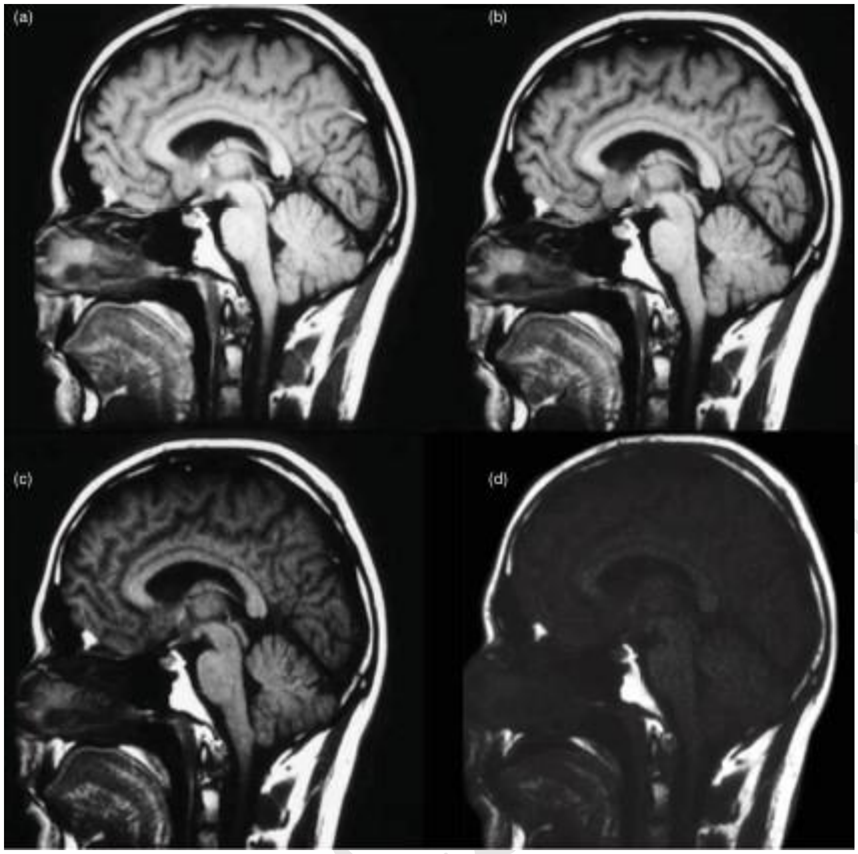


Fig.4: (a) TR 700 ms, (b) TR 500 ms, (c) TR 300 ms, (d) TR 140 ms.

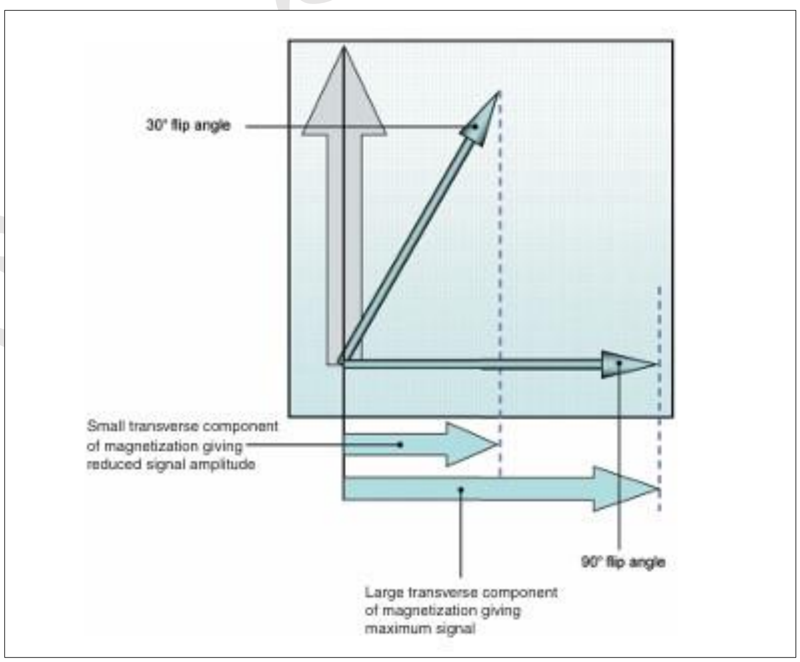
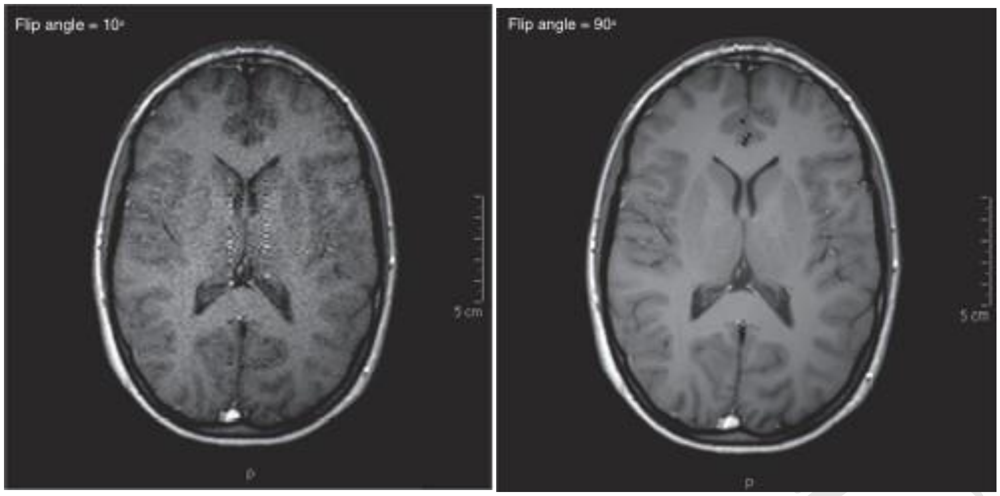


Fig.5: Flip angle vs SNR.



(A) **(B)**

Fig.6: Axial gradient-echo image of the brain using a flip angle of 10° at 3 T(a) & 90° at 3 T (b).

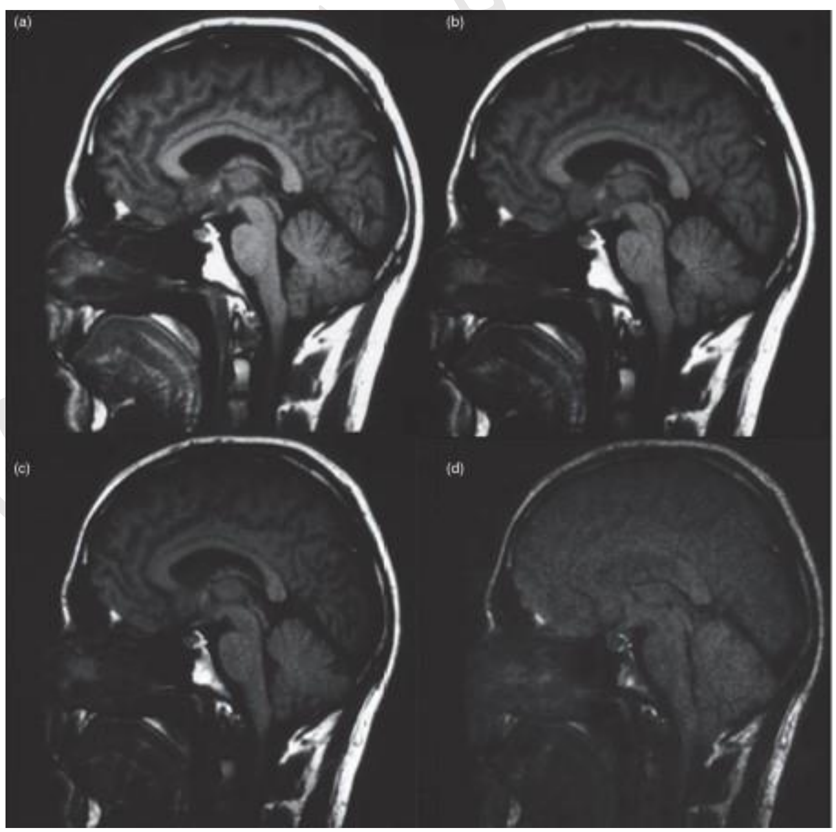


Figure 7: (a) TE 11 ms, (b) TE 20 ms, (c) TE 40 ms, (d) TE 80 ms

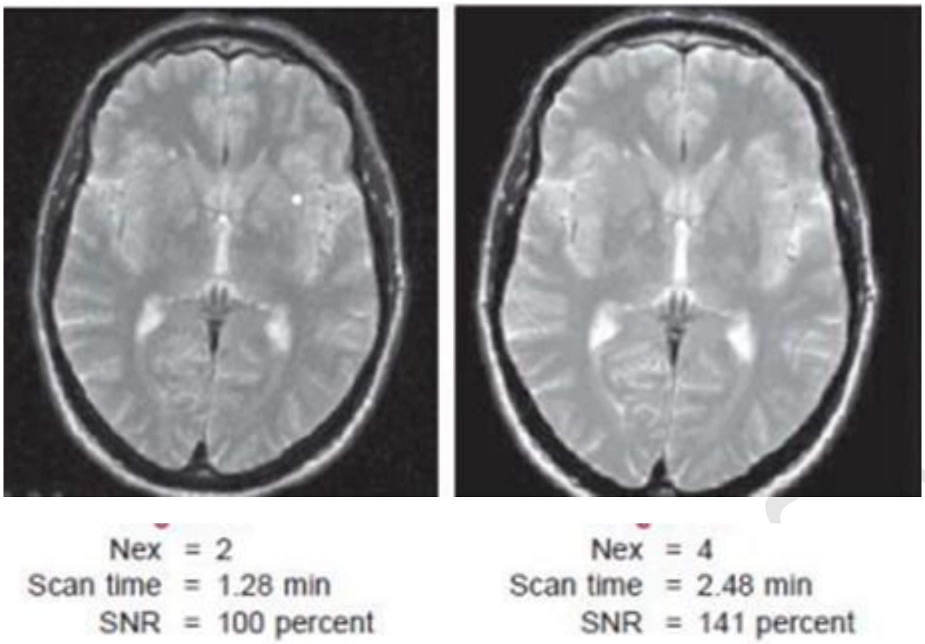


Fig 8: SNR vs NSA

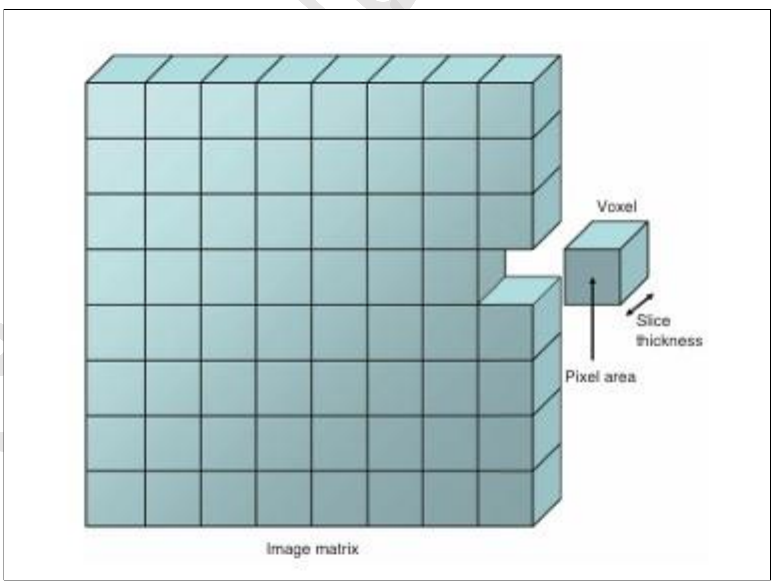


Fig 9: The voxel. The large blue square is the FOV.

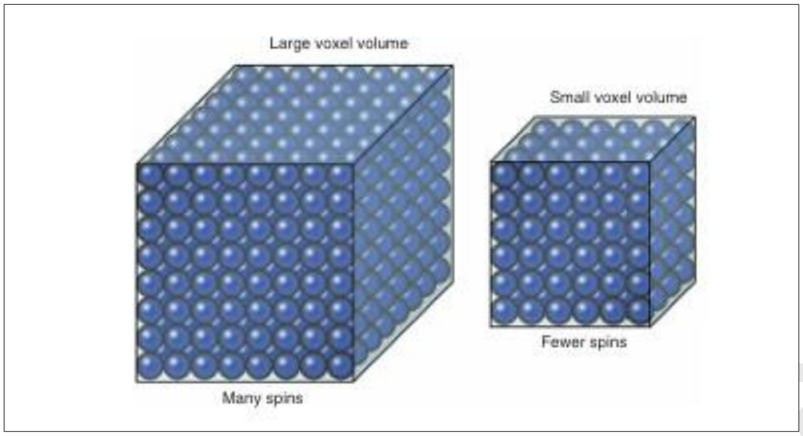


Fig 10: Voxel volume and SNR

- **Contrast to noise ratio (CNR): CNR is defined as the difference in the SNR between two adjacent areas. It is controlled by the same factors that affect SNR. CNR is probably the most critical factor affecting image quality, as it directly determines the eye's ability to distinguish areas of high signal from areas of low signal.**

- **Spatial resolution: Spatial resolution is the ability to distinguish between two points as separate and distinct, and is controlled by the voxel size. Small voxels result in high spatial resolution, as small structures are easily differentiated. Large voxels, on the other hand, result in low spatial resolution, as small structures are not resolved so well.**

- **Scan time: The scan time is the time to complete data acquisition or the time to fill k-space. Scan time optimization is important, as long scan times give the patient more chance to move during the acquisition. Any movement of the patient is likely to degrade images.**

Posttest: **الاختبار البعدي:**

Q/ Mention the factors that affect CNR in MRI image?

References: المصادر:

- **MRI A to Z: Gray Liney.**
- **Step by step MRI: Jagan Mohan Reddy & V Prasad.**
- **MRI in practice: Catherine Westbrook & John Talbot.**

الجامعة التقنية الوسطى
كلية التقنيات الصحية والطبية/ بغداد
قسم: تقنيات الأشعة المادة:التصوير بالرنين المغناطيسي
المرحلة:الرابعة

Title: **العنوان:**

Principles of MRI 5&6

Name of the instructor: **اسم المحاضر:**

م.م.علا سالم صادق

Target population: **الفئة المستهدفة:**

طلبة قسم تقنيات الأشعة/ المرحلة الرابعة

Introduction: **المقدمة:**

Four basic steps are involved in getting an MR image— 1. Placing the patient in the magnet 2. Sending Radiofrequency (RF) pulse by coil 3. Receiving signals from the patient by coil 4. Transformation of signals into image by complex processing in the computers. Present MR imaging is based on proton imaging. Proton is a positively charged particle in the nucleus of every atom. Since hydrogen ion (H+) has only one particle, i.e. proton, it is equivalent to a proton. Most of the signal on clinical MR images comes from water molecules that are mostly composed of hydrogen.

Pretest: **الاختبار القبلي:**

Q/What are the reasons for taking hydrogen as a source to form the MR signal?

Scientific Content: المحتوى العلمي:

- **Atomic structures: - All things are made of atoms. Atoms are organized into molecules, which are two or more atoms arranged together. The most abundant atom in the human body is hydrogen, but there are other elements such as oxygen, carbon, and nitrogen. Hydrogen is most commonly found in molecules of water (where two hydrogen atoms are arranged with one oxygen atom; H_2O) and fat (where hydrogen atoms are arranged with carbon and oxygen atoms; the number of each depends on the type of fat). The atom consists of a central nucleus and orbiting electrons, electrons are particles that spin around the nucleus. (Figure 1). The nucleus is very small, one millionth of a billionth of the total volume of an atom, but it contains all the atom's mass. This mass comes mainly from particles called nucleons, which are subdivided into protons and neutrons. Protons have a positive electrical charge, neutrons have no net charge, and electrons are negatively charged.**

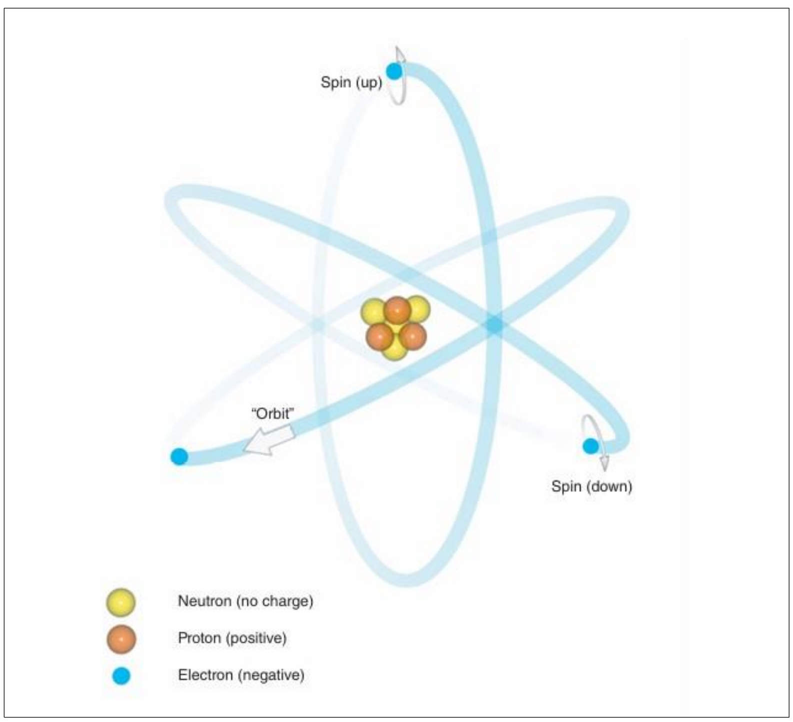


Fig.1: The atom

- **Protons 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. Normally the protons in human body (outside the magnetic field) move randomly in any direction. When external magnetic field is applied, i.e. patient is placed in the magnet, these randomly moving protons align (i.e. their magnetic moment align) and spin in the direction of external magnetic field. Some of them align parallel and others anti-parallel to the external magnetic field. When a proton aligns along external magnetic field, not only it rotates around itself (called spin) but also its axis of rotation moves forming a 'cone'. This movement of the axis of rotation of a proton is called as precession (Fig. 2).**

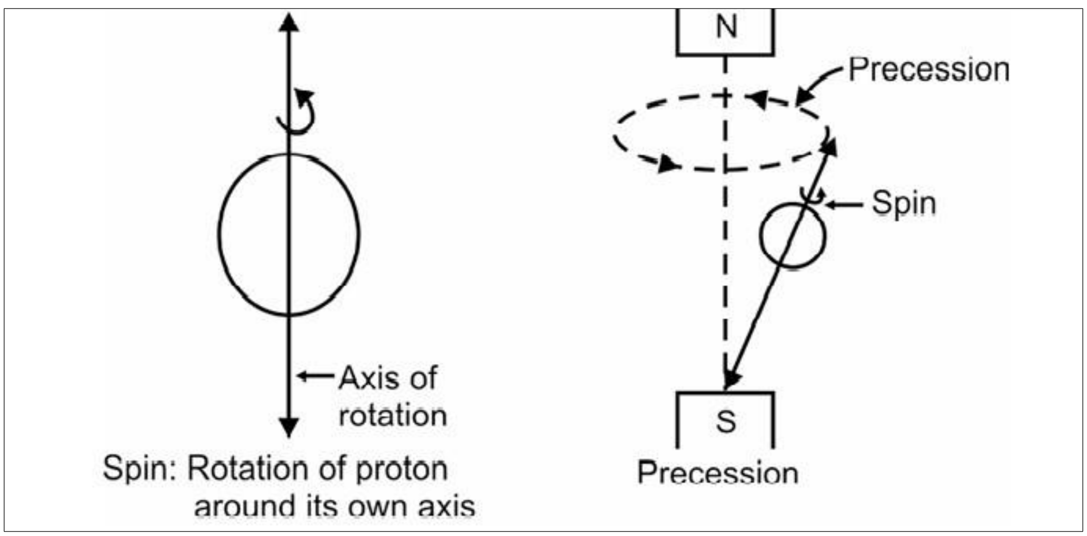


Fig.2: Spin versus precession

The number of precessions of a proton per second is called precession frequency. It is measured in Hertz. Precession frequency is directly proportional to strength of external magnetic field. Stronger the external magnetic field, higher is the precession frequency.

This relationship is expressed by Larmor's equation— Wo = γ Bo

Where wo = Precession frequency in Hz Bo = Strength of external magnetic field in Tesla γ = Gyromagnetic ratio, which is specific to particular nucleus.

- **Longitudinal Magnetization: - Let us go one step further and understand what happens when protons align under the influence of external magnetic field. For the orientation in space consider X, Y, and Z axes system. External magnetic field is directed along the Z-axis. Conventionally, the Z-axis is the long axis of the patient as well as bore of the magnet. Protons align parallel and antiparallel to external magnetic field, i.e. along positive and negative sides of the Z-axis. Forces of protons on negative and positive sides cancel each other. However, there are always more protons spinning on the positive side or parallel to Z-axis than negative side. So, after canceling each other's forces there are a few protons on positive side that retain their forces. Forces of these protons add up together to form a magnetic vector along the Z-axis. This is called as longitudinal magnetization (Fig. 3). Longitudinal magnetization thus formed along the external magnetic field cannot be measured directly. For the measurement it has to be transverse.**

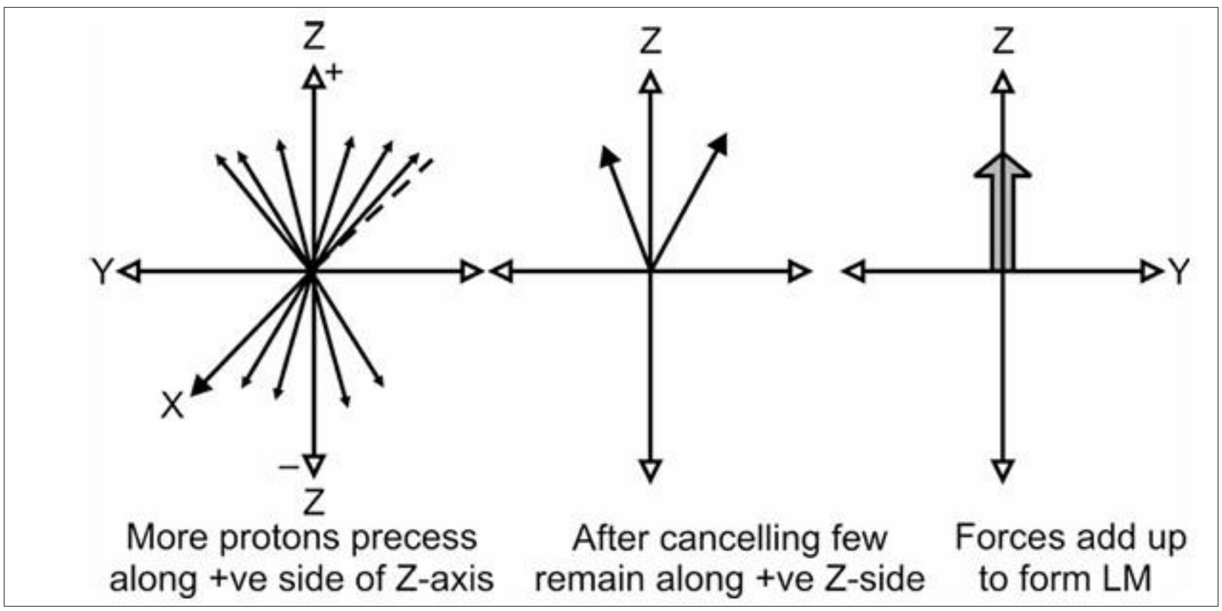


Fig. 3: Longitudinal magnetization

- **Transverse Magnetization: when patient is placed in the magnet, longitudinal magnetization is formed along the Z-axis. The next step is to send radiofrequency (RF) pulse. The precessing protons pick up some energy from the radiofrequency pulse. Some of these protons go to higher energy level and start precessing antiparallel (along negative side of the Z-axis). The imbalance results in tilting of the magnetization into the transverse (X-Y) plane. This is called as transverse magnetization (Fig. 4). In short, RF pulse causes titling of the magnetization into transverse plane. The precession frequency of protons should be same as RF pulse frequency for the exchange of energy to occur between protons and RF pulse. When RF pulse and protons have the same frequency protons can pick up some energy from the RF pulse. This phenomenon is called as "resonance"- the R of MRI. RF pulse not only causes protons to go to higher energy level but also makes them precess in step, in phase or synchronously.**

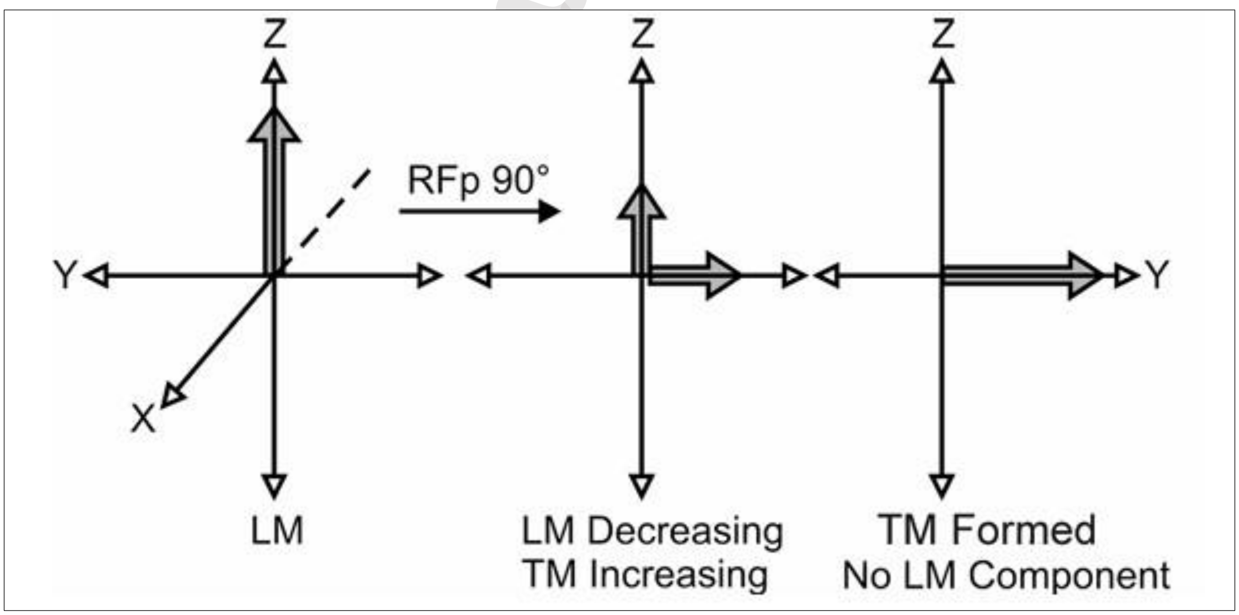


Fig. 4: Transverse magnetization. Magnetization vector is flipped in transverse plane by the 90-degree RF pulse.

- **MR Signal: -** Transverse magnetization vector has a precession frequency. It constantly rotates at Larmor frequency in the transverse plane and induces electric current while doing so. The receiver RF coil receives this current as MR signal (Fig. 5). The strength of the signal is proportional to the magnitude of the transverse magnetization. MR signals are transformed into MR image by computers using mathematical methods such as Fourier Transformation.

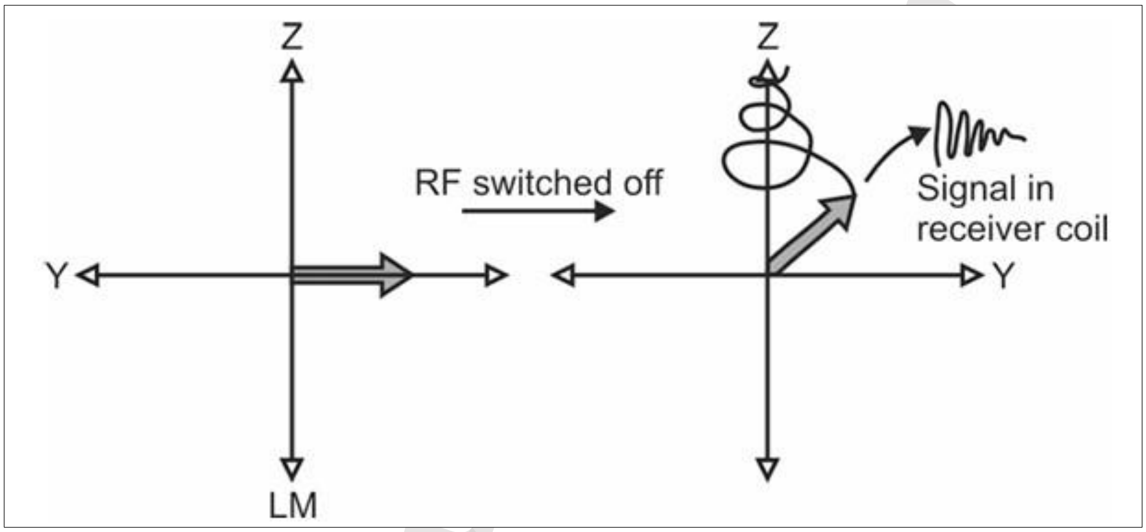


Fig. 5: MR signal.

- **Localization of the Signal: -** Three more magnetic fields are superimposed on the main magnetic field along X, Y, and Z axes to localize from where in the body signals are coming. These magnetic fields have different strength in varying location hence these fields are called "gradient fields" or simply "gradients". The gradient fields are produced by coils called as gradient coils.

  The three gradients are—

  1. Slice selection gradient
  2. Phase encoding gradient
  3. Frequency encoding (read out) gradient.

-Slice Selection Gradient: - Slice selection gradient has gradually increased magnetic field strength from one end to another. It determines the slice position. Slice thickness is determined by the bandwidth of RF pulse. Bandwidth is the range of frequencies. Wider the bandwidth thicker is the slice.

-Phase Encoding and Frequency Encoding Gradients These gradients are used to localize the point in a slice from where signal is coming. They are applied perpendicular to each other and perpendicular to the slice selection gradient (Fig. 6).

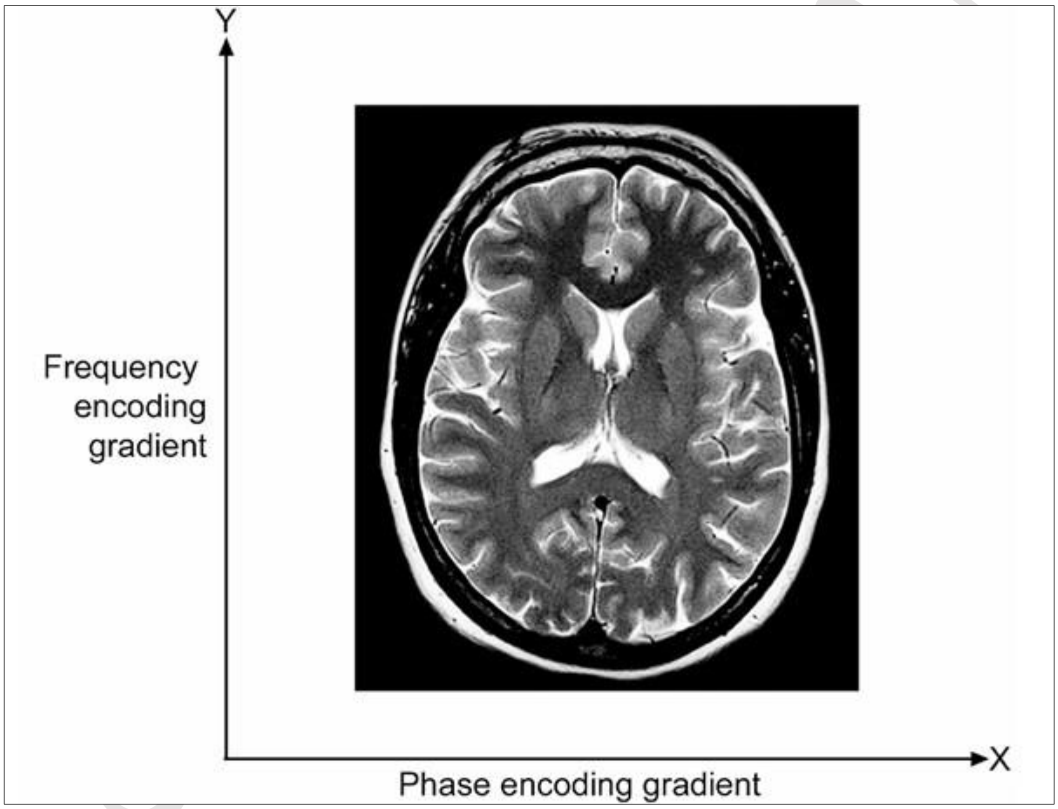


Fig. 6: Frequency and phase encoding gradients

1. **Z-axis—Slice selection gradient**
2. **2. Y-axis—Frequency encoding gradient**
3. **X-axis—Phase encoding gradient.**

In a usual sequence, slice selection gradient is turned on at the time of RF pulse. Phase encoding gradient is turned on for a short time after slice selection gradient.

Frequency encoding or readout gradient is on in the end at the time of signal reception. Information from all three axes is sent to computers to get the particular point in that slice from which the signal is coming.

- **Revision: Basic four steps of MR imaging include:**
  1. **Patient is placed in the magnet— All randomly moving protons in patent's body align and precess along the external magnetic field. Longitudinal magnetization is formed along the Z-axis.**
  2. **RF pulse is sent— Precessing protons pick up energy from RF pulse to go to higher energy level and precess in phase with each other. This results in reduction in longitudinal magnetization and formation of transverse magnetization in X-Y plane.**
  3. **MR signal is received— The transverse magnetization vector precesses in transverse plane and generates current. This current is received as signal by the RF coil.**
  4. **Image formation— MR signal received by the coil is transformed into image by complex mathematical process such as Fourier Transformation by computers.**

- **T1, T2 Relaxations and Image Weighting: Relaxation means recovery of protons back towards equilibrium after been disturbed by RF excitation. Relaxation times of protons such as T1 and T2, and number of protons in tissues (proton density) are the main determinant of the contrast in an MR image.**
- **What happens when RF pulse is switched off? When RF pulse is switched off, LM starts increasing along Z-axis and TM starts reducing in the transverse plane. The process of recovery of LM is called Longitudinal Relaxation while reduction in the magnitude of TM is called as Transverse Relaxation.**
- **Longitudinal Relaxation: When RF pulse is switched off, spinning protons start losing their energy. The low energy protons tend to align along the Z-axis. As more and more protons align along the positive side of the Z-axis there is gradual increase in the magnitude (recovery) of the LM (Fig. 7). The energy released by the protons is transferred to the surrounding (the crystalline lattice of molecules) hence the longitudinal**

relaxation is also called as 'spin-lattice' relaxation. The time taken by LM to recover to its original value after RF pulse is switched off is called longitudinal relaxation time or T1 which is the time when LM reaches back to 63% of its original value.

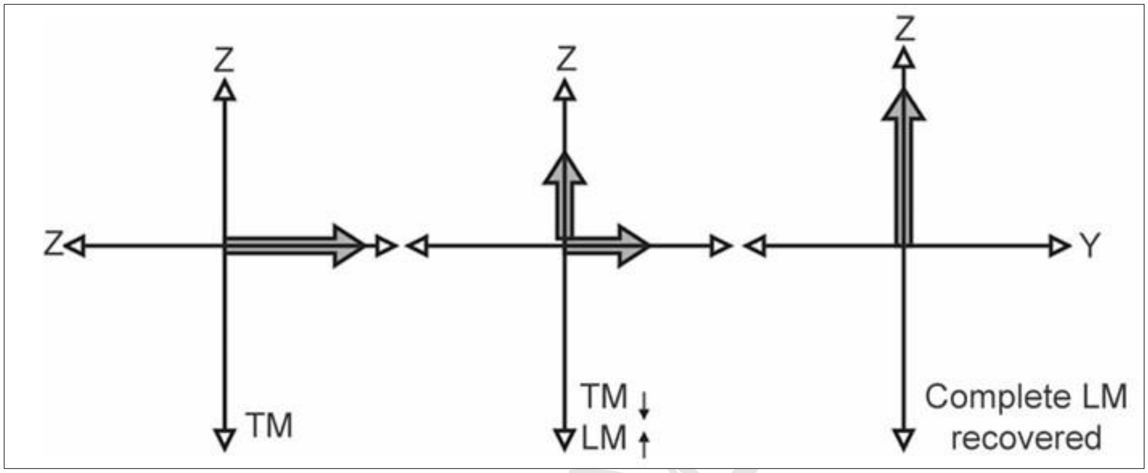


Fig. 7: Longitudinal relaxation (T1)

- **Transverse Relaxation: The transverse magnetization represents composition of magnetic forces of protons precessing at similar frequency. More the number of protons precessing at the same frequency (in-phase) stronger will be the TM. So, right after the 90-deg RF pulse the net magnetization vector (now called transverse magnetization) is rotating in the X-Y plane around the Z-axis at the Larmor frequency. Therefore, the vectors all points in the same direction because they are in-phase. However, they don't stay like this. The transverse magnetization starts decreasing in magnitude immediately as protons start going out of phase. This process of de-phasing and reduction in the amount of transverse magnetization is called transverse relaxation. The time taken by TM to reduce to its original value is transverse relaxation time or T2 which is the time taken by the TM to reduce to 37% of its maximum value. T2 is called spin-spin relaxation because it describes interactions between protons in their molecules (fig.8).**

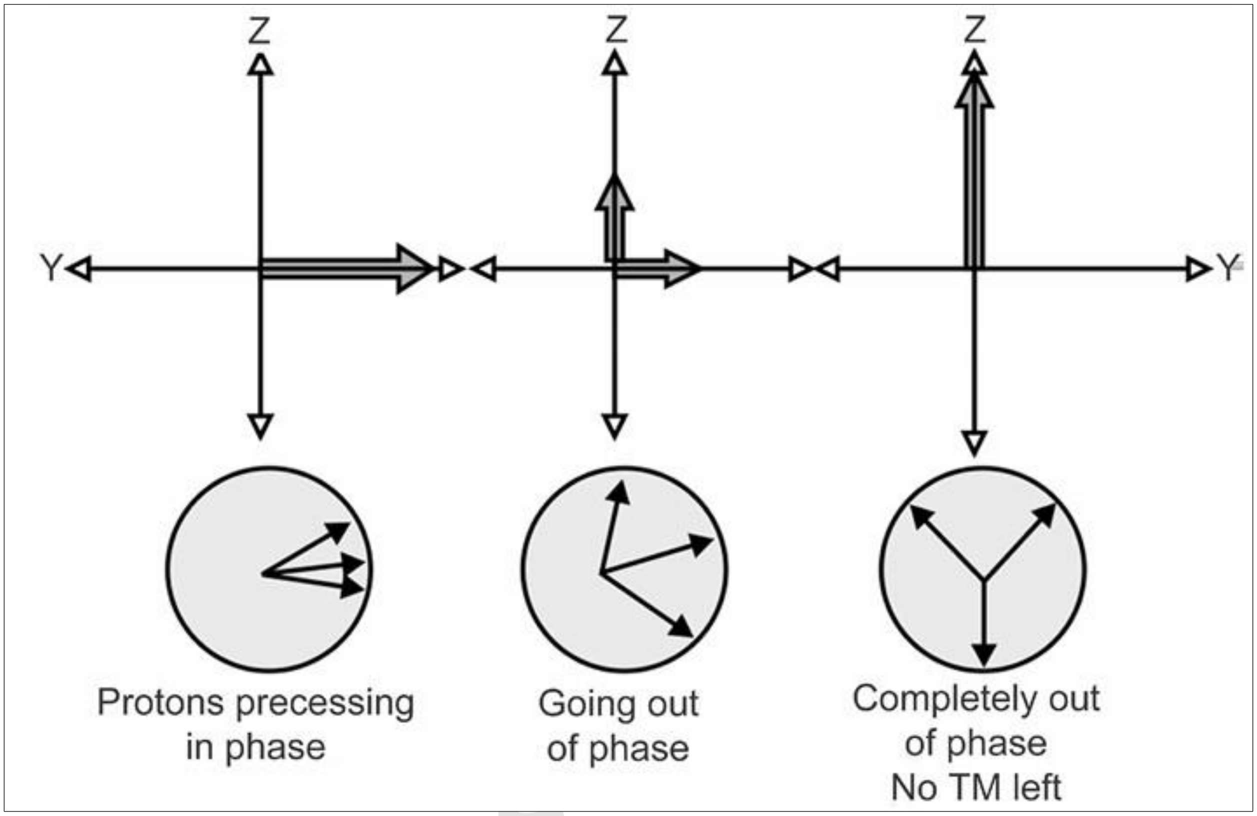


Fig. 8: Transverse relaxation

- **T2* (T2 star): In addition to the magnetic field inhomogeneity intrinsic to the tissues causing spin-spin relaxation, inhomogeneity of the external magnetic field (B0) also causes decay of the TM. Decay of the TM caused by combination of spin-spin relaxation and inhomogeneity of external magnetic field is called T2* relaxation. Dephasing effects of external magnetic field inhomogeneity are eliminated by 180° RF pulses used in spin-echo sequence. Hence there is 'true' T2 relaxation in a spin-echo sequence. The T2* relaxation is seen in gradient-echo sequence as there is no 180° RF pulse in gradient-echo sequence. T2* is shorter than T2 (Fig. 9).**

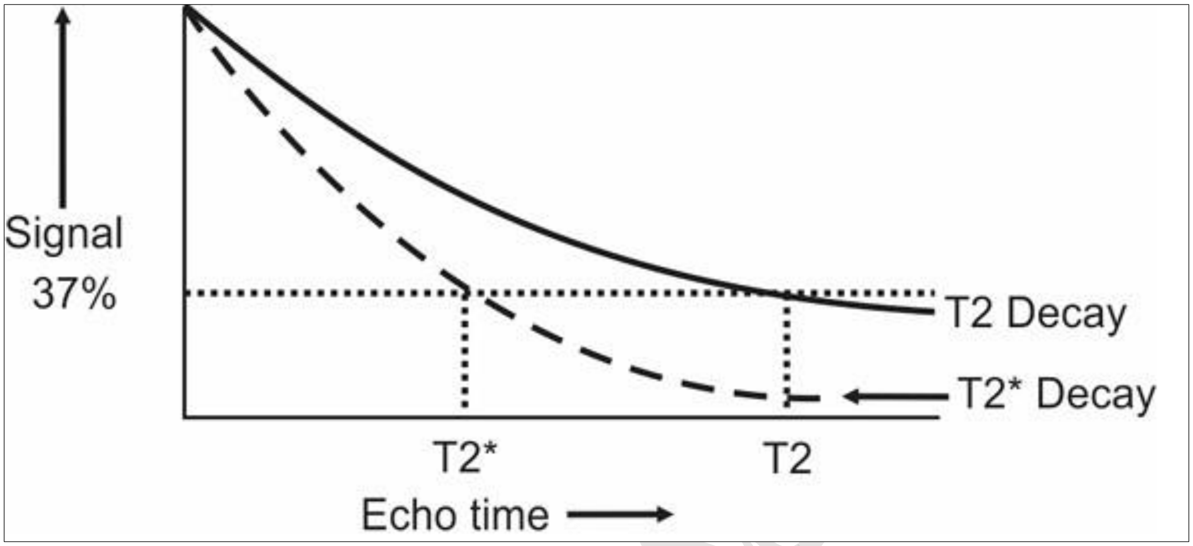


Fig. 9: T2* curve

- **TR and TE: -**
  - **TR (Time to Repeat) is the time interval between start of one RF pulse and start of the next RF pulse. For a spin-echo sequence time interval between beginnings of 90-degree pulses is the TR.**
  - **TE (Time to Echo) is the time interval between start of RF pulse and reception of the signal (echo). (fig.10)**

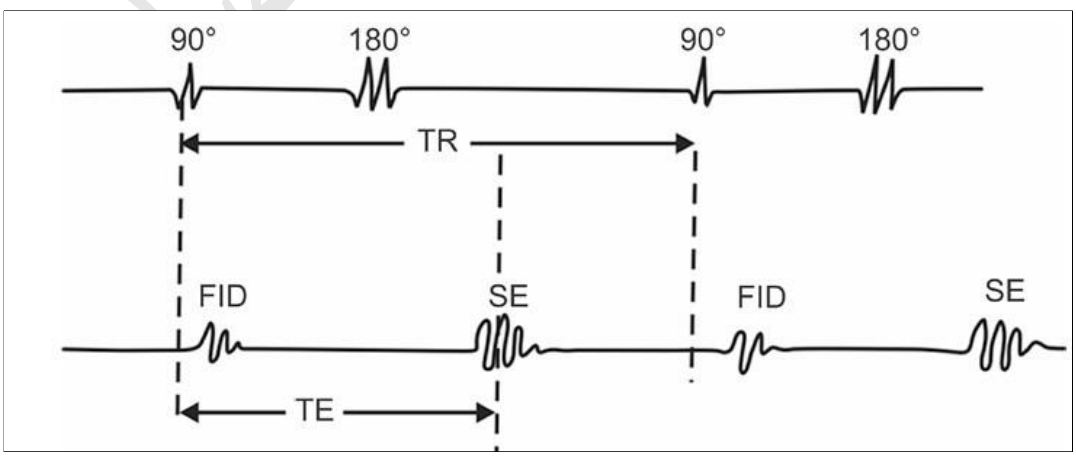
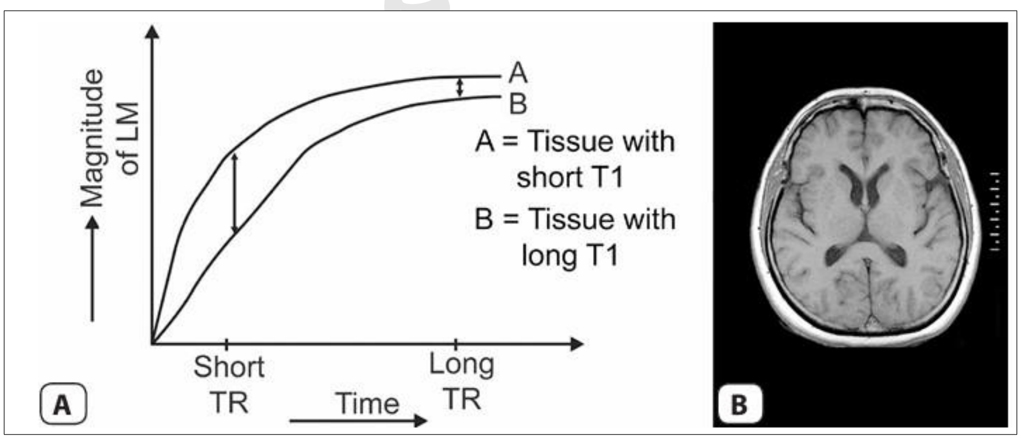


Fig. 10: Spin Echo (SE) sequence.

- **TI: TI is Time of Inversion. It is the time between inverting 180-degree pulse and 90-degree pulse in Inversion Recovery (IR) sequence. TI determines the image contrast in IR sequences.**

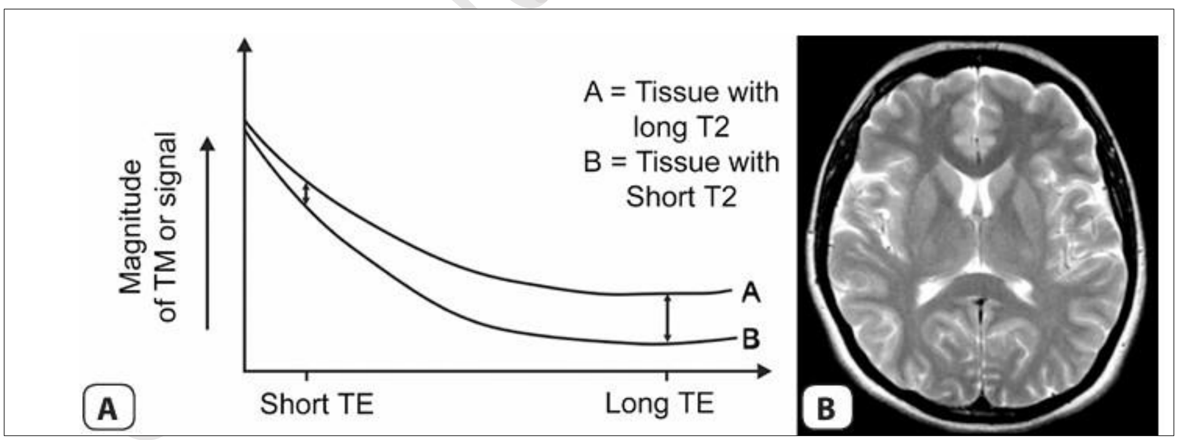
- **T1 Weighted Image: The magnitude of LM indirectly determines the strength of MR signal. Tilting of stronger LM by 90-degree RF pulse will result into greater magnitude of TM and stronger MR signal. The tissues with short T1 regain their maximum LM in short-time after RF pulse is switched off. When the next RF pulse is sent, TM will be stronger and resultant signal will also be stronger. Therefore, material with short T1 have bright signal on T1 weighted images.**

- **How does one make images T1 weighted? This is done by keeping the TR short (Fig. 11). If TR is long the tissues with long T1 will also regain maximum LM giving stronger signal with next RF pulse. This will result in no significant difference between signal intensity of tissues with different T1. With short TR only the tissues with short T1 will show high signal intensity. On T1-W images, differences in signal intensity of tissues are due to their different T1.**



Figs 11.A and B: T1-weighted image. (A) At short TR the difference between LM of tissue A (with short T1) and of tissue B (long T1) is more as compared to long TR. This results in more difference in signal intensity (contrast) between A and B at short TR. The contrast on the short TR image is because of T1 differences of tissues. Hence it is T1-weighted image. (B) T1-weighted axial image of brain: CSF is dark, white matter is brighter than gray matter and scalp fat is bright because of short T1.

- **T2 Weighted Image: Immediately after its formation TM has greatest magnitude and produces strongest signal. Thereafter it starts decreasing in magnitude because of dephasing, gradually reducing the intensity of received signal. Different tissues, depending on their T2, have variable time for which TM will remain strong enough to induce useful signal in the receiver coil. Tissues or material with longer T2, such as water, will retain their signal for longer time. Tissues with short T2 will lose their signal earlier after RF pulse is turned off.**
- **How does one make images T2 weighted? The images are made T2-wighted by keeping the TE longer. At short TE, tissues with long as well as short T2 have strong signal. Therefore, on the images acquired at short echo time, there will not be significant signal intensity difference between tissues with short and long T2. At longer TE, only those tissues with long T2 will have sufficiently strong signal and the signal difference between tissues with short and long T2 will be pronounced (Fig.12). So, the image with long TE is T2-weighted since the signal difference amongst tissues (contrast) is determined by T2 of tissues. Tissues with long T2 are bright on T2-weighted images. TR is kept long for T2-weigthed images to eliminate T1 effects.**



Figs 12.A and B: T2-weighted image. (A) Tissue B has short T2 that results into early loss of magnitude of TM and reduction in signal. At short TE, there is no significant difference between magnitude of TM of A and B. At long TE, signal difference between A and B is more because tissue B will lose most of its signal while tissue A will still have good signal. Since the image contrast is because of differences in T2 of tissues, it is T2-weighted image. (B) T2-weighted axial image of brain: CSF is bright; white matter is darker than gray matter.

- **Proton Density (PD) Image: Contrast in the PD image is determined by the density of protons in the tissue. T1 effect is reduced by keeping long TR and T2 effect is reduced by keeping TE short. Hence long TR and short TE give PD-weighted image (Fig. 13). The signal intensity difference amongst tissues is function of the number of protons they have.**

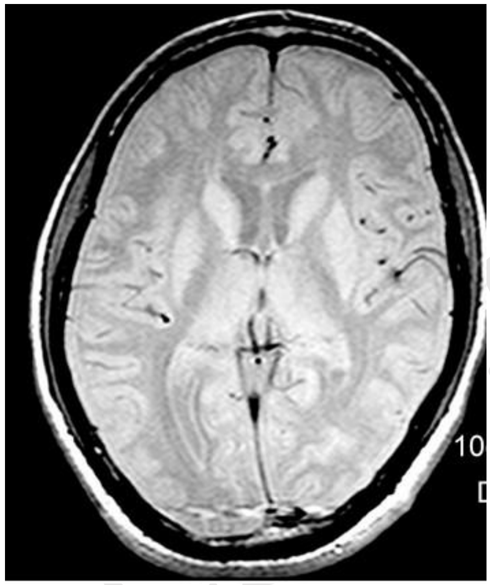


Fig. 13: Proton-density image. Long TR used for PD image eliminates T1 effects and short TE eliminates T2 effects.

Posttest: الاختبار البعدي:

Q / How does one make images PD weighted?

References: المصادر:

- MRI In Practice: Catherine Westbrook & John Talbot.

- MRI Made Easy: Govind B Chavhan.

الجامعة التقنية الوسطى

كلية التقنيات الصحية والطبية/ بغداد

قسم تقنيات الأشعة المادة: التصوير بالرنين المغناطيسي

المرحلة:الرابعة

Title: **العنوان:**

Pulse sequences and image contrast 7&8

Name of the instructor: **اسم المحاضر:**

م.م.علا سالم صادق

Target population: **الفئة المستهدفة:**

طلبة قسم تقنيات الأشعة/ المرحلة الرابعة

Introduction: **المقدمة:**

There are many different pulse sequences available, and each is designed for a specific purpose. The image weigh ting, contrast and quality is determined by the type of pulse sequence we use.

Pretest: **الاختبار القبلي:**

Q/What is the pulse sequence?

Scientific Content: المحتوى العلمي:

A pulse sequence is interplay of various parameters leading to a complex cascade of events with RF pulses and gradients to form a MR image (Fig. 1). So, pulse sequence is a time chart of interplay of—

1. Patient's net longitudinal magnetization.
2. Transmission of RF pulses (90, 180 degree or any degree).
3. X, Y and Z gradient activation for localization and acquisition of signal (echo).
4. K-Space filling with acquired signals or echoes.

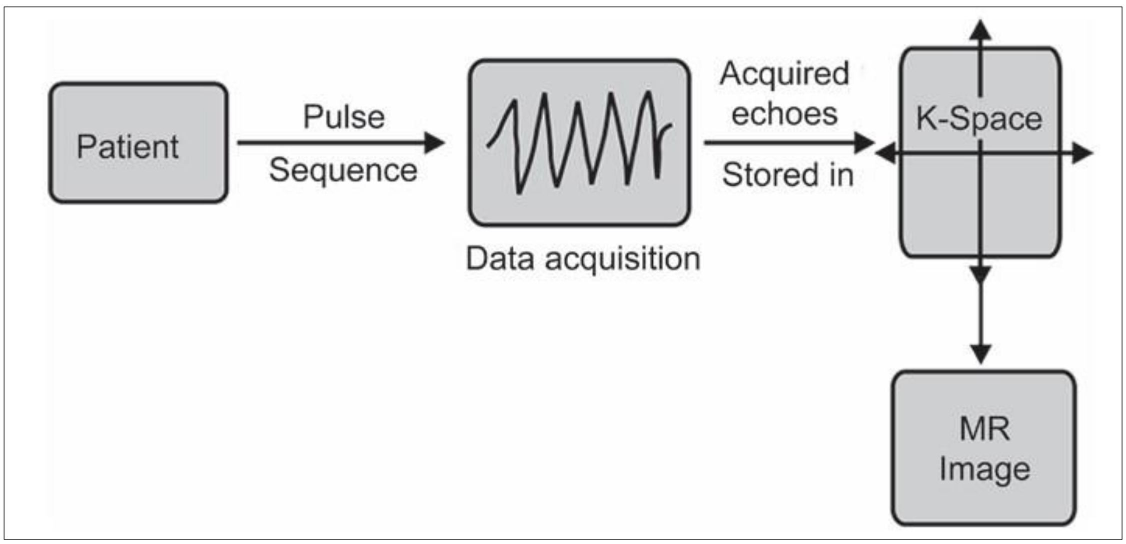


Fig. 1: Steps in image acquisition

Classification: Pulse sequences can be broadly divided into two categories- spin echo and gradient echo sequences. Inversion recovery and echo planar imaging (EPI) can be applied theoretically to both spin-echo and gradient echo sequences. However, in practice inversion recovery is applied to spin-echo sequences and EPI is used with gradient echo sequences. For practical purposes, let's consider following four types of sequences:

1. Spin-echo sequence (SE).
2. Gradient Echo sequence (GRE).
3. Inversion Recovery sequences (IR).
4. Echo Planar Imaging (EPI).

1-Spin Echo (SE) Pulse Sequence It consists of 90- and 180-degree RF pulses. The excitatory 90-degree pulse flips net magnetization vector along Z-axis into the transverse (X-Y) plane. The transverse magnetization (TM) precessing at Larmor frequency induces a small signal called free induction decay (FID) in the receiver coil. FID is weak and insufficient for image formation. Also, the amount of TM magnetization reduces as protons start dephasing. Hence a rephasing 180-degree pulse is sent to bring protons back into the phase. This rephasing increases magnitude of TM and a stronger signal (spin echo) is induced in the receiver coil. This gives the sequence its name. The time between two 90-degree pulses is called as TR (Time to Repeat). The time between 90-degree pulse and reception of echo (signal) is TE (Time to Echo). (fig 2)

For the localization of the signal, slice selection gradient is turned on when RF is sent. Phase encoding gradient is turned on between excitation (90 degree) pulse and signal measurement. Phase encoding gradient has different strength for each TR. Frequency encoding (read out gradient) is turned on during signal measurement.

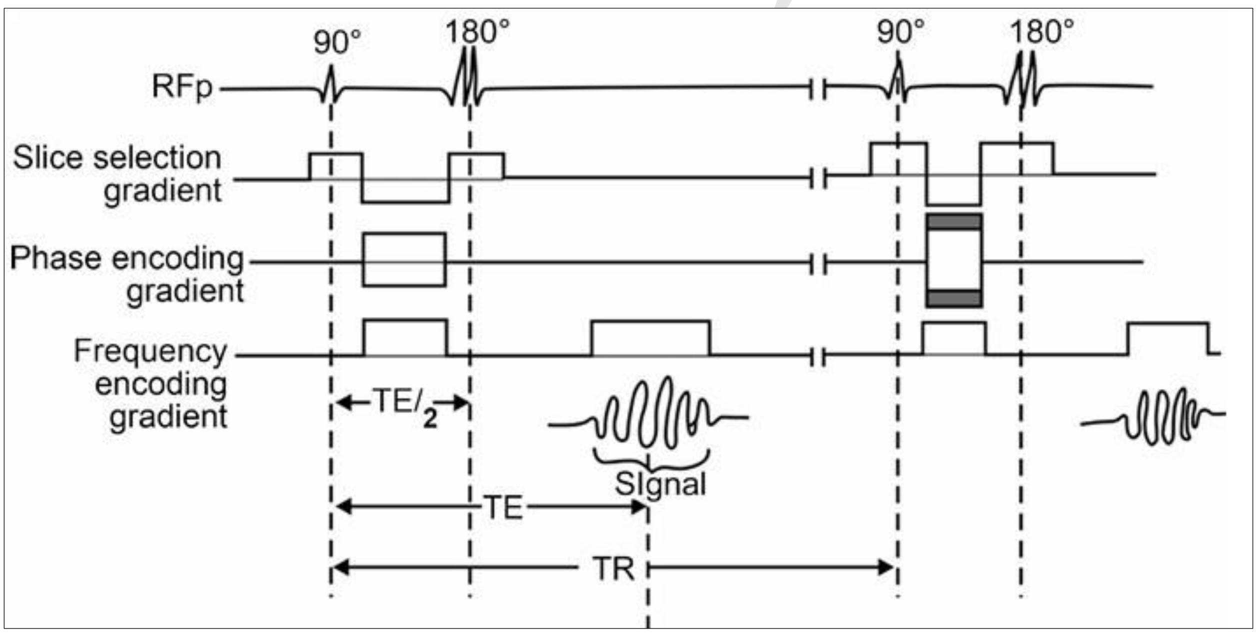


Fig. 2: Spin-echo (SE) sequence

SE sequence forms the basis for understanding all other sequences. It is used in almost all examinations. T1-weighted images are useful for demonstrating anatomy. Since the diseased tissues are generally more edematous and or vascular, they appear bright on T2-weighted images. Therefore, T2-weighted images demonstrate pathology well.

Modifications of SE Sequences: In conventional SE sequence, one line of K-Space is filled per TR. SE sequence can be modified to have more than one echo (line of K-Space) per TR. This is done by sending more than one 180 pulses after the excitatory 90-degree pulse. Each 180-degree pulse obtains one echo. Three routinely used modifications in the SE sequence and these include the following:

A- DUAL SPIN-ECHO Sequence: Two 180-degree pulses are sent after each 90-degree pulse to obtain two echoes per TR. The PD + T2 double echo sequence (Fig. 3) is an example of this modified SE sequence. This sequence is run with long TR. After the first 180-degree pulse, since TE is short, image will be proton density weighted (long TR, short TE). After second 180-degree pulse, TE will be long giving a T2-W image (long TR, long TE). Both these echoes contribute separate K-Space lines in two different K-Spaces.

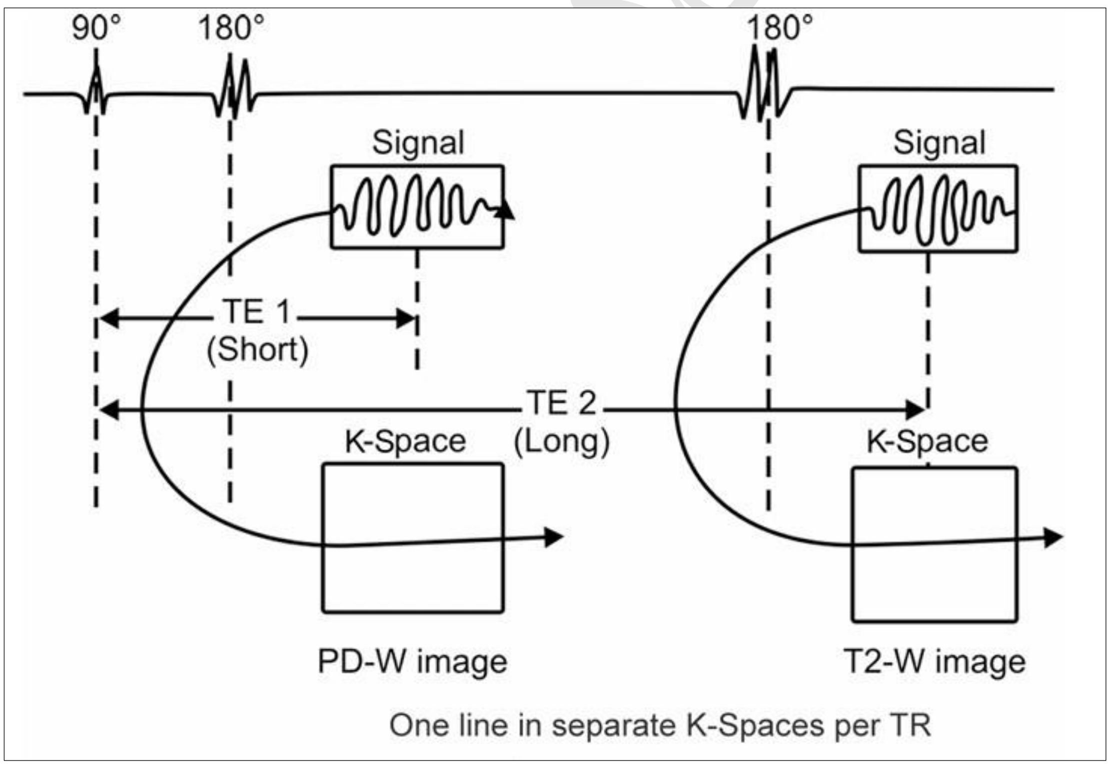


Fig. 3: Double Echo sequence

B- FAST (TURBO) SPIN-ECHO Sequence: In fast SE sequence, multiple 180-degree rephasing pulses are sent after each 90-degree pulse. It is also called as multi spin-echo or Turbo spin echo sequence (Fig. 4). In this sequence, multiple echoes are obtained per TR, one echo with each 180-degree pulse. All echoes are used to fill a single K-Space. Since K-Space is filled much faster with multiple echoes in a single TR the scanning speed increases considerably.

Turbo factor: turbo factor is the number of 180-degree pulses sent after each 90-degree pulse. It is also called as echo train length. The amplitude of signal (echo) generated from the multiple refocusing 180-degree pulses varies since the TE goes on increasing. The TE at which the center of the K-Space is filled is called as 'TE effective'. The amplitude of the signal is maximum at the TE effective. Short turbo factor decreases effective TE and increases T1 weighting. However, it increases scan time. Long turbo factor increases effective TE, increases T2 weighting and reduces scan time.

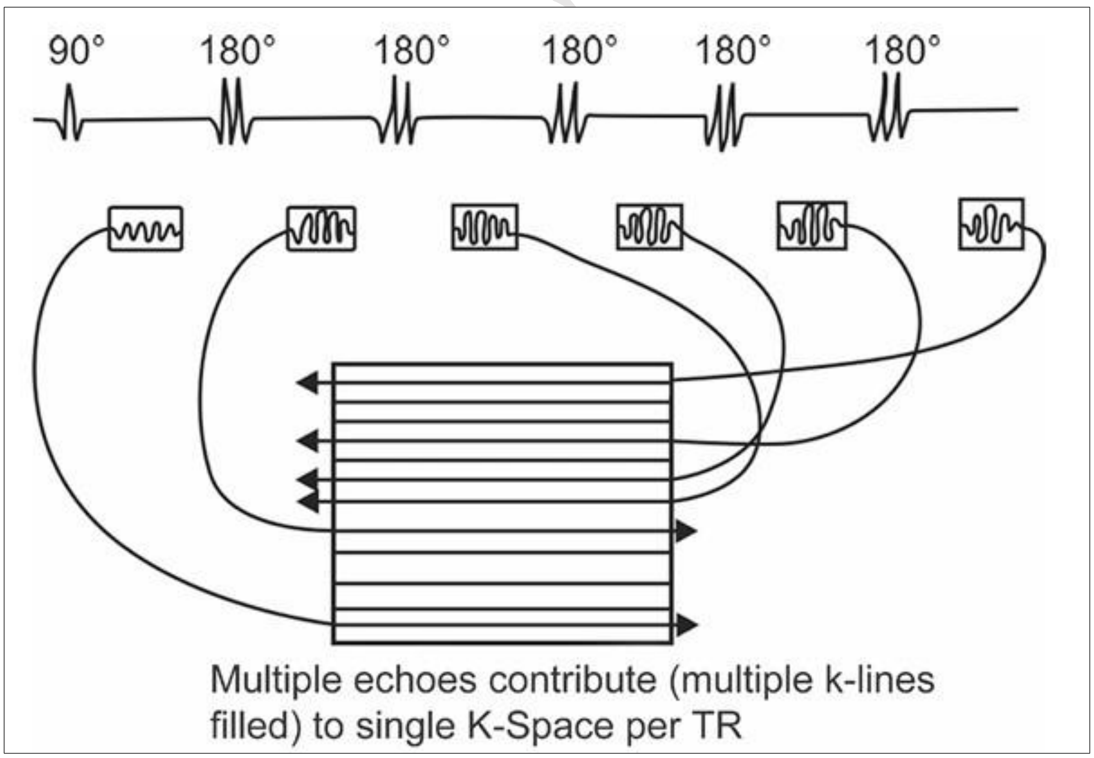


Fig. 4: Fast/Turbo spin echo sequence

c- SINGLE-SHOT FAST SPIN-ECHO Sequence: This is a fast SE sequence in which all the echoes required to form an image are acquired in a single TR. Hence it is called 'single-shot' sequence. In this sequence, not only all K-Space lines are acquired in a single excitation but also just over a half of the K-Space is filled reducing the scan time further by half (Fig. 5). The other half of the K-Space is mathematically calculated with half-Fourier transformation.

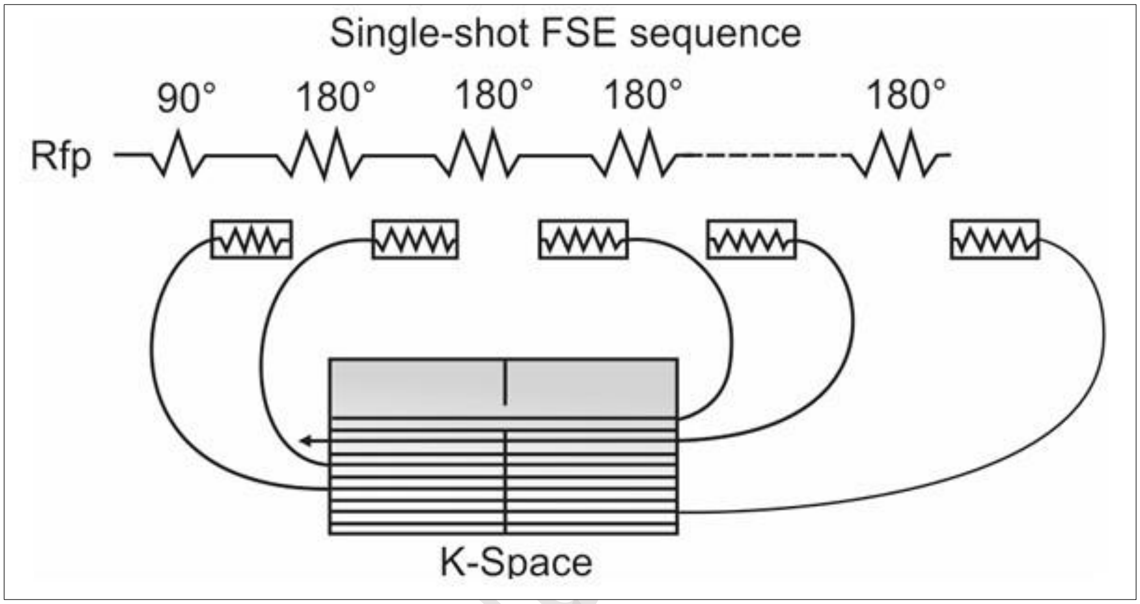


Fig. 5: Single-shot fast spin-echo sequence

2- Gradient Echo (GRE) Sequence: The main differences between SE and GRE sequences are the following: -

- There is no 180-degree pulse in GRE. Rephasing of TM in GRE is done by gradients; particularly by reversal of the frequency encoding gradient. Since rephasing by gradient gives signal, this sequence is called as Gradient echo sequence.

- The flip angle in GRE is smaller, usually less than 90- degree. Since f lip angle is smaller there will be early recovery of longitudinal magnetization (LM) such that TR can be reduced, hence the scanning time.

- Transverse relaxation can be caused by combination of two mechanisms—

A. Irreversible dephasing of TM resulting from nuclear magnetic interactions with proton.

B. Dephasing caused by magnetic field inhomogeneity. In SE sequence, the dephasing caused by magnetic field inhomogeneity is eliminated by 180-degree pulse. Hence there is 'true' transverse relaxation in SE sequence. In GRE sequence, dephasing effects of magnetic field inhomogeneity are not compensated, as there is no 180-degree pulse. T2 relaxation in GRE is called as T2* (T2 star) relaxation.

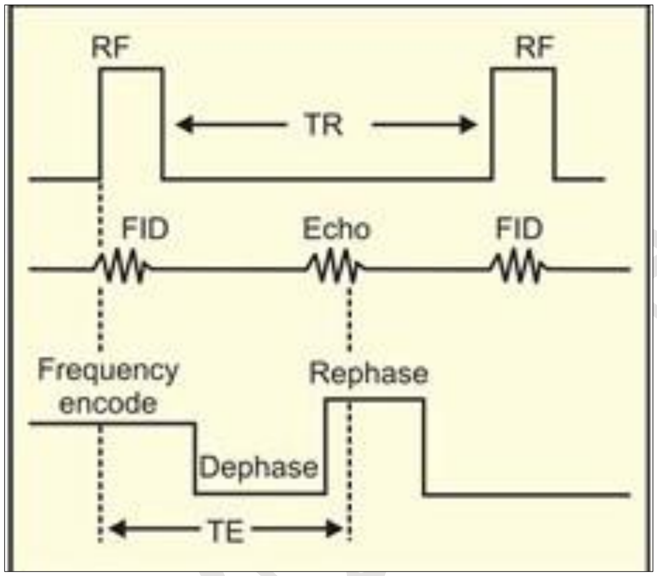


Fig. 6: Schematic illustration of gradient echo pulse sequence

Types of GRE Sequences: GRE sequences can be divided into two types depending on what is done with the residual transverse magnetization (TM) after reception of the signal in each TR. If the residual TM is destroyed by RF pulse or gradient such that it will not interfere with next TR, the sequences are called spoiled or incoherent GRE sequences. In the second type of the GRE sequences, the residual TM is not destroyed. In fact, it is refocused such that after a few TRs steady magnitude of LM and TM is reached. These sequences are called steady-state or coherent GRE sequences.

A- Steady State (SS) or Coherent GRE sequences: In this state, the selected TR will be shorter than the T1 and T2 times of the tissues. In this state, there will be coexistence of both longitudinal and transverse magnetization. Most gradient echo sequences use the steady state. Generally, flip angles of 30° to 45° with TR of 20 to 50 ms favours the steady state. In this sequence, the tissue with long T2 values appear with high signal intensity. SS sequences have very short TR and TE making them fast sequences that can be acquired with breath-hold. They can be

used to study rapid physiologic processes (e.g. events during a cardiac cycle) because of their speed.

Note: - Steady State Free Precession (SSFP) which is a type of SS Coherent GRE sequence. It is used to attain more T2 weighting.

B- Incoherent (Spoiled) Gradient Echo pulse sequence: These pulse sequences begin with a variable flip angle excitation pulse and use frequency encoding gradient rephasing to give a gradient echo. These sequences spoil (or) dephase the residual transverse magnetization so that its effect on image contrast is minimal. It Increased T1 weighting.

3- Inversion Recovery (IR) Sequence: - IR sequence consists of an inverting 180-degree pulse before the usual spin-echo or gradient echo sequence. In practice, it is commonly used with SE sequences. The inverting 180-degree pulse flips LM from positive side of Z-axis to negative side of Z-axis. This saturates all the tissues. LM then gradually recovers and builds back along positive side of Z-axis. This LM recovery is different for different tissues depending on their T1 values. Protons in fat recover faster than the protons in water. After a certain time, the usual sequence of 90–180-degree pulses are applied. Tissues will have different degree of LM recovery depending on their T1 values. This is reflected in increased T1 contrast in the images. The time between inversion 180 degree and excitatory 90-degree pulses is called as ‘time to invert or TI’. TI is the main determinant of contrast in IR sequences.

- Why is the inverting 180-degree pulse used? What is achieved? The inversion 180-degree pulse flips LM along negative side of the Z-axis. This saturates fat and water completely at the beginning. When 90-degree excitatory pulse is applied after LM has relaxed through the transverse plane, contrast in the image depends on the amount of longitudinal recovery of the tissues with different T1. An IR image is more heavily T1-weighted with large contrast difference between fat and water. Apart from getting heavily T1-weighted images to demonstrate anatomy, IR sequence also used to suppress particular tissue using different TI.

- Tissue Suppression: At the halfway stage during recovery after 180-degree inversion pulse, the magnetization will be at zero level with no LM available to flip into the transverse plane. At this stage, if the excitatory 90-degree pulse is applied, TM will not be formed and no signal will be received. If the TI corresponds with the time a particular tissue takes to recover till halfway stage there will not be any signal from that tissue. IR sequences are thus used to suppress certain tissues by using different TI. The TI required to null the signal from a tissue is 0.69 times T1 relaxation time of that tissue.

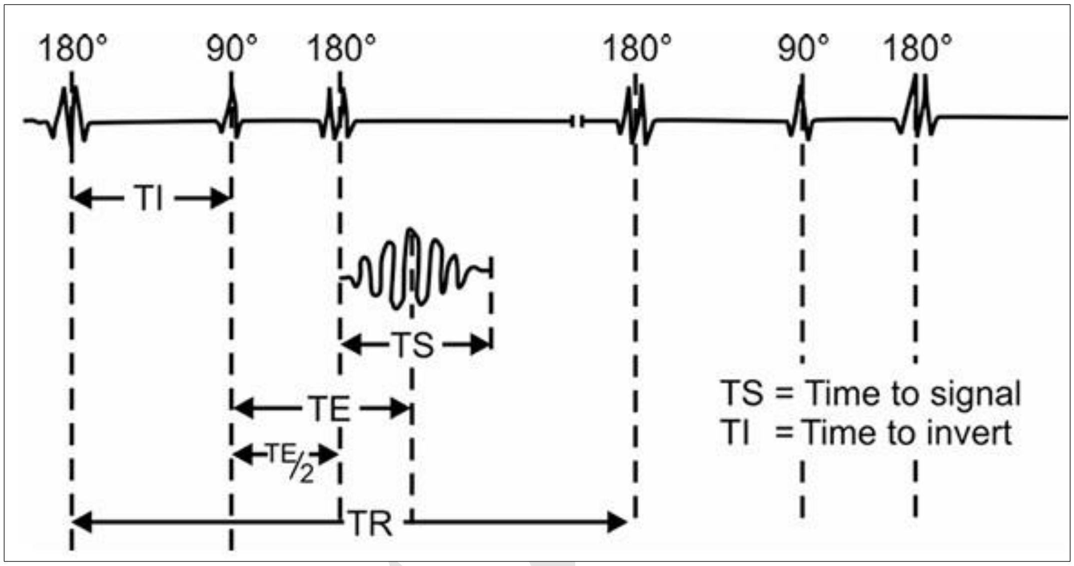


Fig. 7: Inversion recovery (IR) sequence

- **Types of IR Sequences: IR sequences are divided based on the value of TI used as the following:**

A- STIR (Short Inversion Recovery) Pulse Sequence: This sequence is used to suppress the fat signal from the anatomy of interest. Here we use a TI value that corresponds to the time it takes fat to recover from full inversion to the transverse plane so that there is no longitudinal magnetization corresponding to fat. When the 90° RF excitation pulse is applied, the fat is flipped 90o to 180°, so there will not be any fat signal. It will suppress the fat in STIR. Generally, a TI value of around 100-200 ms is used. This TI value may slightly vary depending on the field strength.

B- FLAIR (Fluid Attenuated Inversion Recovery): - It is another variation in the IR pulse sequence which uses a TI value around 2000 ms. Usually, this sequence is used to suppress the signal from CSF containing areas.

4-Echo Planar Imaging (EPI): Scanning time can be reduced by filling multiple lines of K-Space in a single TR. EPI takes this concept to the extreme. All the

lines of K-Space, required to form an image, are filled in a single TR and this is called single shot EPI (SS-EPI).
-If the echoes are generated by multiple 180° pulses, this is termed as spin echo echoplanar imaging (SE-EPI).
- If the gradients are used for the purpose of rephasing in EPI, then this sequence is called GE-EPI.
- GE-EPI and SS-EPI are faster than SE-EPI.

*** Some examples for EPI sequences:**
A-PERFUSION WEIGHTED IMAGING (PWI): - This is a type of dynamic MR imaging by using GRE (or) EPI sequences with contrast enhancement to study the uptake of contrast medium by the lesion. This technique can be used in abnormalities of brain, pancreas, liver and prostate.

B-DIFFUSION WEIGHTED IMAGING (DWI): - In this type of MR imaging either GRE (or) EPI sequences are used to demonstrate the areas with restricted diffusion of extracellular water such as infarcted tissue. High signal intensity appears at the area of restricted diffusion. DWI is mainly useful in brain to differentiate salvageable and nonsalvageable tissue after brain stroke.

C-FUNCTIONAL MRI (FMRI): It is a dynamic MR imaging Technique that acquires images of the brain during stimulus and also at rest. Then the two sets of images are subtracted to demonstrate functional brain activity.

D-MAGNETIZATION TRANSFER (MT) CONTRAST: This is a technique used to suppress the background tissue thereby increasing the conspicuity of vessels and certain disease processes.

E-MAGNETIC RESONANCE ANGIOGRAPHY (MRA): MRA is a technique which allows us to acquire the images with high signal from flowing nuclei and low signal from stationary nuclei. This technique will allow us to see the blood vessels more clearly than surrounding. There are two types of MRA techniques available and these are:
1-Time of Flight MRA (TOF-MRA): This technique commonly uses incoherent GRE pulse sequences in conjunction with TR and flip angle combi nations that saturate background tissue but allowing moving spins to show high signal intensity. This technique is used in demonstrating arterial and venous flow in head, neck and peripheral vessels.

2-Phase Contrast MRA (PC-MRA): This technique usually uses coherent GRE sequences. It provides excellent background suppression. But the scan times with PC-MRA are longer than the scan times of GE pulse sequences.

Posttest: الاختبار البعدي:

Q/What are difference between STIR & FLAIR IR sequences?

References: المصادر:

- **MRI Made Easy: Govind B Chavhan.**
- **Step by Step MRI: Jaganmohan Reddy & V Prasad.**

الجامعة التقنية الوسطى

كلية التقنيات الصحية والطبية/ بغداد

قسم تقنيات الأشعة المادة: التصوير بالرنين المغناطيسي

المرحلة:الرابعة

Title: **العنوان:**

Artifacts and their compensations (9)

Name of the instructor: **اسم المحاضر:**

م.م.علا سالم صادق

Target population: **الفئة المستهدفة:**

طلبة قسم تقنيات الأشعة/ المرحلة الرابعة

Introduction: **المقدمة:**

Magnetic resonance imaging also suffers from artifacts as other radiological modalities. Artifacts can cause significant image degradation and can lead to misinterpretation. It is impossible to eliminate all artifacts though they can be reduced to acceptable level.

Pretest: **الاختبار القبلي:**

Q/Define image artifact?

Scientific Content: المحتوى العلمي:

- **Artifacts may be defined as the false features in the image produced during the imaging process. Artifacts can be rectified easily when the causes are known.**
  - **Artifacts can be classified into different categories and these include the following:**

  1. **Ghosts/Motion Artifacts: Ghosts are replica of something in the image. Ghosts are produced by body part moving along a gradient during pulse sequence resulting into phase mismapping. Ghosts can originate from any structure that moves during the acquisition of data (Fig. 1). Periodic movement such as respiratory, cardiac and vessel pulsation causes ghosts while nonperiodic movement causes a smearing of the image.**

  - **Axis: ghosts almost always seen along phase encoding axis.**
  - **Corrective measures:**

    A-Patient motion: Make patient lie comfortably, stabilize, with straps and cushions, it is important not to use excessively long sequences, as movement for a brief period spoil all the images.

    B- Cardiac motion This type of artifact is caused by the contraction and relaxation of heart (chest) while the scanning is going on. To avoid this type of artifact, cardiac gating is mandatory during the procedure.

    C- Respiratory motion This type of artifact is caused by respiration during the scanning. This can be avoided by respiratory gating and respiratory compensation.

    D- Blood flow motion This type of artifact is caused by the flow of blood throughout the cardiac cycle. The artifact is prominent in axial images. An effective remedy for blood flow motion artifact is 'Spatial Presaturation (SAT) which is a new technique for suppressing these artifacts.

In this technique a spectrally shaped radiofrequency pulse has been applied to selectively saturates spins located in regions outside the image volume.

Note: Another way to reduce the effect of the motion artifacts is by the using of saturation band.

- Saturation Band It is also called REST slab or SAT band and is used to suppress the signal from a part of the FOV (Fig. 2). A 90 degrees RF pulse is sent immediately prior to proper sequence tilting the magnetization in transverse plane in the region of the band. When proper excitation pulse follows there is no longitudinal magnetization in this region to be tilted. Hence this region will not have any signal.

Fig.1: Ghosting/ Movement artifacts

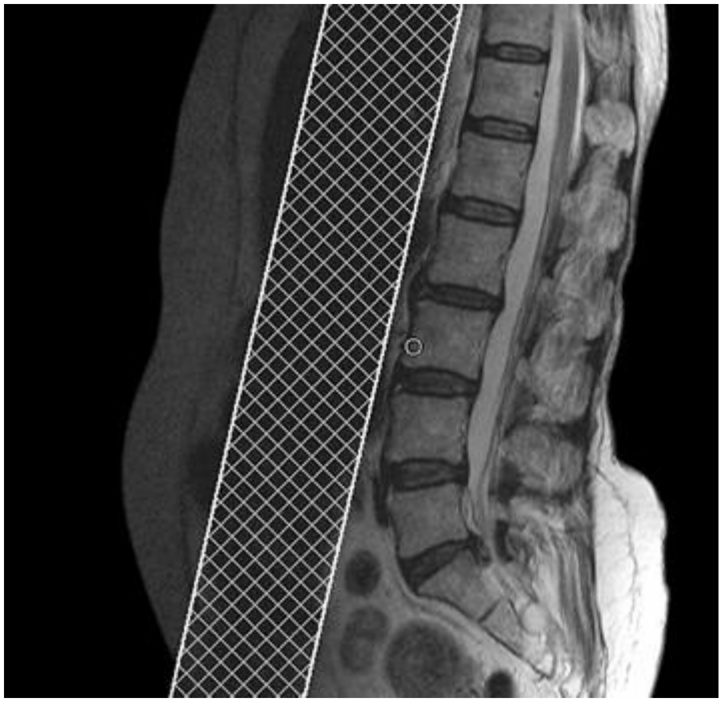


Fig. 2: Image showing saturation band anterior to the spine.

2- Aliasing/ Wraparound: In aliasing, anatomy that exists outside the FOV appears within the image and on the opposite side (Fig. 3). When the imaging field of view is smaller than the anatomy being imaged, aliasing occurs.

-Axis: aliasing can occur along any axis. Aliasing along frequency encoding axis is called frequency wrap and along phase encoding axis is called phase wrap. Aliasing can occur along slice selection axis in 3D imaging.

- Corrective measures:

A-Increase FOV.

B- Filtering the frequency encoded direction.

C- Phase wrap can be corrected by increasing FOV along phase encoding direction.

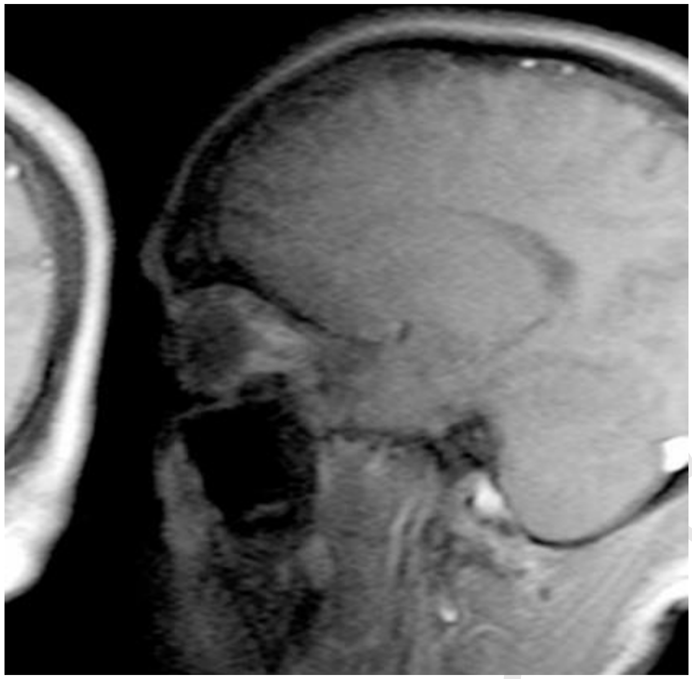


Fig 3: Aliasing artifact

3- Chemical Shift Artifacts: Chemical shift artifacts appear at the interfaces between water and fat because the precessional frequency of protons is slightly different in these two substances. This difference in precessional frequencies of protons in water and fat is called 'chemical shift'. It is expressed in parts per million (ppm). The frequency of water protons is about 3.5 ppm greater than that of fat protons. This chemical shift of 3.5 ppm causes water protons to precess at a frequency 220 Hz higher than that of fat proton at 1.5 Tesla. This leads to misregistration of the signals. They are displayed by the equipment as dark region of signal void on one side of water containing tissue and a region of bright signal at the other end of the water fat interface due to super imposition of fat and water signals on the frequency encoding direction. The chemical shift artifacts are commonly noticed in the abdomen, spine and orbits where fat and other tissues from boarders. This artifact is greater at higher field strength. (fig.4).

-Axis: Frequency encoded direction.

- Corrective measures: The only way to eliminate this artifact is to use a fat suppression technique.

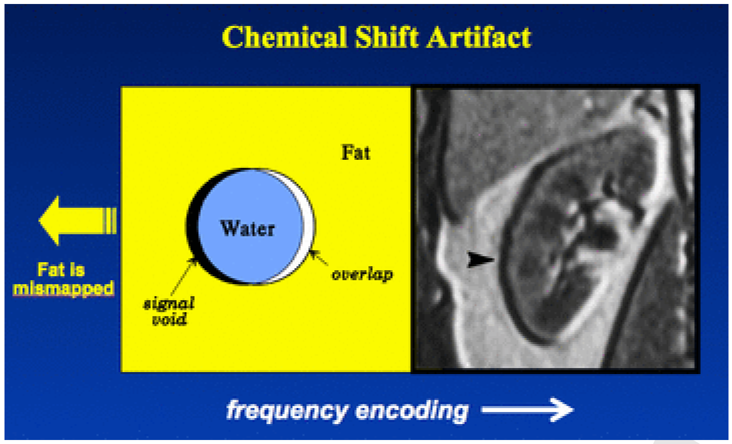


Fig 4: Chemical shift artifact

4-Gibbs or Truncation artifacts: Gibbs or Truncation artifacts are bright and dark lines that are seen parallel and adjacent to boarders of abrupt intensity change, as many be seen at CSF, spinal cord, fat and muscle. (fig.5)

-Axis: Phase encoding direction.

- Corrective measures: Gibbs artifact can be reduced by increasing the matrix and using a filter.

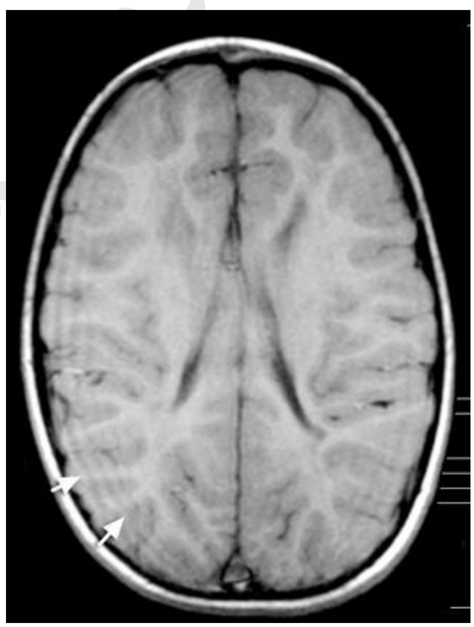


Fig 5: Gibbs artifact

5- Magnetic Susceptibility Artifact: Magnetic susceptibility is the ability of a substance to become magnetized. Some tissues magnetize to different degree than other, resulting into differences in precessional frequency and phase. This causes dephasing at the interface of these tissues and signal loss. For example, magnetic susceptibility difference between soft tissues and air is about 10 ppm. This causes signal loss and distortion of the boundaries of the brain near air sinuses. Other common causes of magnetic susceptibility artifacts include metal. (fig.6)

-Axis: Frequency encoding and phase encoding.

- Corrective measures: Use of SE sequence and remove the metal.

Fig. 6: Susceptibility artifact

6- Zipper Artifacts: This artifact is caused by external RF entering the room at a certain frequency and interfering with inherently weak signal coming from the patient. There are various causes for zipper artifacts in images. Most of them are related to hardware or software problems. The zipper artifacts that can be controlled easily are those due to RF entering the scanning room when the door is open during acquisition of images. RF from radio transmitters will cause zipper artifacts that are oriented perpendicular to the frequency axis of the image. Fig.7

-Axis: Perpendicular to the frequency axis of the image.

-Corrective measures: System generated artifacts should be reported service engineer.

Fig 7: Zipper artifact

7- **Shading Artifacts: In shading artifact image has uneven contrast with loss of signal intensity in one part of the image (Fig. 8). The causes include uneven excitation of nuclei within the patient due to RF pulses applied at f lip angles other than 90- and 180-degree, abnormal loading of coil or coupling of coil and inhomogeneity of magnetic field.**

-Axis: Frequency and phase encoding.

-Corrective measures: 1. Load the coil correctly. 2. Shimming to reduce the inhomogeneity of the magnetic field.

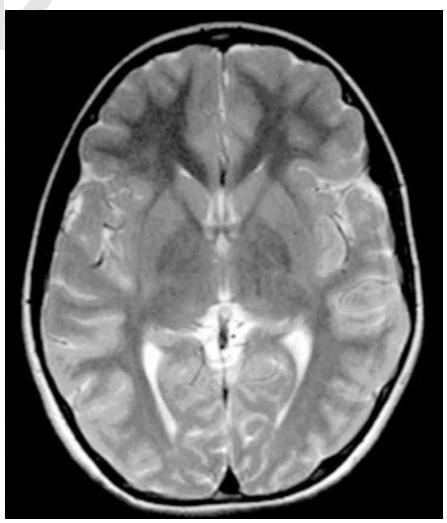


Fig. 8: Shading artifact: T2-w axial image of the brain shows comparatively less signal in the frontal regions. This was because of the improper loading (connection) of the coil in the anterior part.

8- **Cross Excitation:** An RF excitation pulse is not exactly square. As a result, nuclei in slices adjacent to the one excited by RF pulse may also receive energy and be excited. This energy flips NMV of these nuclei into transverse plane. When they are excited by their own RF excitation pulse, they do not have enough longitudinal magnetization to be tilted. This results in reduced signal intensity in the adjacent slices. This phenomenon is called cross excitation (Fig. 9).

-Axis: Slice selection gradient.

-Corrective measures: Increase interslice gap.

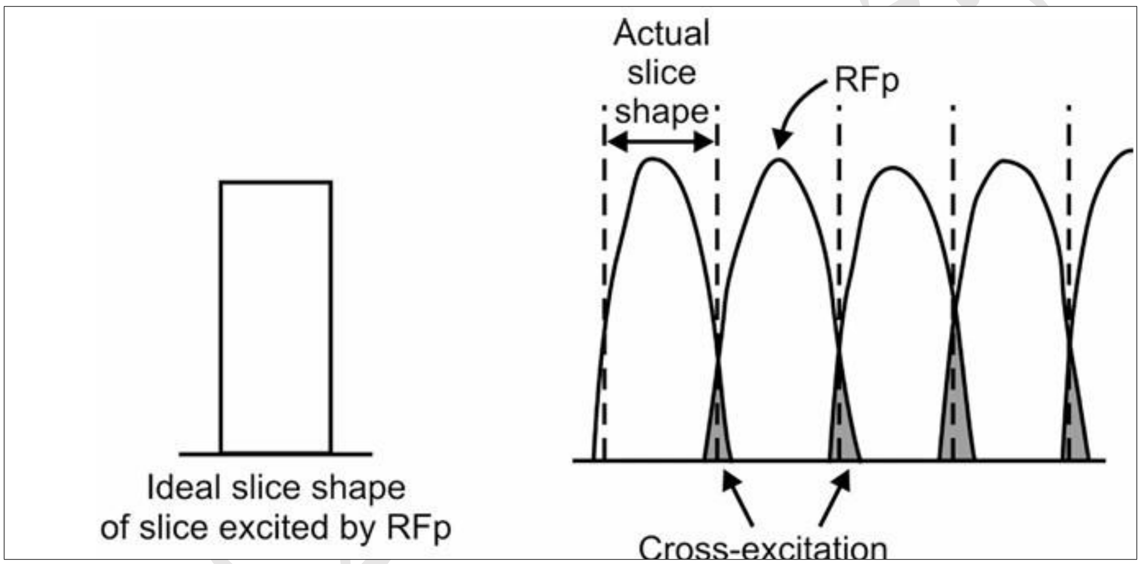


Fig 9: Cross Excitation: Diagram shows excitation of nuclei in the adjacent slices because of parabolic shape of the slice excitation

Posttest: الاختبار البعدي:

Q / Mention the types of MRI image artifacts?

References: المصادر:

- **MRI Made Easy: Govind B Chavhan.**
- **Step by Step MRI: Jaganmohan Reddy & V Prasad.**

الجامعة التقنية الوسطى

كلية التقنيات الصحية والطبية/ بغداد

قسم تقنيات الأشعة المادة: التصوير بالرنين المغناطيسي

المرحلة:الرابعة

Title: **العنوان:**

MRI safety, preparation and contrast agent (10+11)

Name of the instructor: **اسم المحاضر:**

م.م.علا سالم صادق

Target population: **الفئة المستهدفة:**

طلبة قسم تقنيات الأشعة/ المرحلة الرابعة

Introduction: **المقدمة:**

MRI is a valuable diagnostic tool, and safety measures are in place to ensure the well-being of patients and staff. Communication between patients and healthcare providers, as well as adherence to safety protocols, are essential for a safe MRI experience. Patients with concerns about MRI safety should discuss them with their healthcare team to address any specific risks or considerations.

Scientific Content: المحتوى العلمي:

- **Patient preparation and safety:**

- **Identity: - Prior to any examination being performed, the identity of the patient must be checked by the technologist. Patients arriving into MRI department are often worried or apprehensive and this may make it difficult for them to understand the instructions or may produce an apparently aggressive attitude. In such cases, the technologist should convince amicably and soft tone of voice often do a great deal of comfort and gives the patient confidence that he is in an efficient hand. The technologist should make every effort to obtain the willing cooperation of the patient consent. Children and uncooperative patients should be sedated before examination.**
- **Before entering the equipment room, the patient must wear a hospital gown and should remove all personal possessions such as watch, wallet, keys, hair pins, jewels, coils, removable dental bridge work etc. Even credit cards and cell phones must be secured as the scanner will erase the information on them.**
- **Wheelchair and trolleys must always be kept outside the magnet room.**
- **The patient is made to lie down on a table. This table then passes through a tunnel within the equipment. Inside the tunnel, it is quite noisy when the scanning is going on. The region of interest is positioned at the center of the magnet. The patient can hear the voice of the radiologist or technologist and can respond. While the patient lies within the tunnel, images of the interested regions are taken from different angles. These images can be seen on a computer screen. The entire procedure takes 30 to 40 min approximately depending upon the strength of the magnetic field and the parameters set on. It is most important that the patient should remain relaxed and completely still during the scan. The patient can resume the routine activities after getting the scan done.**

  -The patient should always be informed as to what is going to happen and what he expected to do, so that he can cooperate as much as possible.

  -The patient should attend without any makeup because some products may contain metallic particles.

  -The patient must be made comfortable as far as possible because if the patient is in pain or in distress, it is unlikely that he will be able to remain still for long.

- Clear instructions regarding breathing or swallowing should be given and rehearsed to ensure that the patient does hold his breath or swallow when required to do so.

- Due to the high magnetic field strengths used during MRI examination, certain patients are unsuitable for imaging. These include patients who have: -

A- Aneurysm clips (older ferromagnetic types).

B- Cardiac pacemakers.

C- Patients with otologic implants and ocular implants.

D- Cochlear implants.

E- Metallic foreign bodies, esp. within the eye.

- PRECAUTIONS:

1-Always screen the patient and accompanying person for any metallic objects. Metallic objects can form projectile because of strong magnetic attraction. This can lead to life threatening consequences.

2-Always see to it that wires and coils are well insulated and are not touching patient's body. It can cause burns. Patient's body part should also not be touching magnet bore.

3-Avoid loop formation: Wires of pulse oximeter, ECG leads, etc. should never form a loop. Loop formation can lead to induction of current and burns. Even loop formation of body parts for example crossed arms or legs can form a large conductive loop and can result into induction of current.

4-In case of emergency first approach must be to remove the patient out of scanner room as early as possible and start resuscitation.

5-Doors of scanner room should have label with pictures of object that are strictly prohibited to take inside scanner room.

- Effects of RF power: - The RF pulses used in MR causes tissues to absorb RF power under certain conditions. This may cause tissue heating. The amount of heating depends on several factors such as patient size and pulse sequence timing.

-Before the patient is being scanned, the computer estimates the level of heating and compare it to the predetermined exposure limits. If the scan exceeds these limits, the system then adjusts the scan parameters before starting the scan. The complete estimate is based partially on patient weight. Therefore, take care to enter the patient's weight correctly to prevent excessive RF.

- **Claustrophobia and sedation: - Although not thought of as a main safety issue, patient anxiety and claustrophobia (specifically the fear of enclosed spaces) may be sufficient in some instances to prevent the completion of the scan. Claustrophobia and sedation: - Although not thought of as a main safety issue, patient anxiety and claustrophobia (specifically the fear of enclosed spaces) may be sufficient in some instances to prevent the completion of the scan.**
  - Published figures for the percentage of aborted scans in these situations vary widely from 1 to 20%. Undoubtedly, the type of scan (e.g., used of head coil) and the method of entry (head or feet first) makes a significant difference. Methods to improve patient comfort, not only to alleviate stress but also to minimize movement, include bore lighting, ventilation, and head coil mirrors to maintain visible contact with Saff outside the scanner.
- **Emergency preparedness: - MRI facilities have emergency procedures in place in case of accidents. This includes protocols for dealing with metal objects accidentally brought into the MRI room and for responding to medical emergencies that may occur during the scan.**
- **Pregnancy and MRI: - While there is no known harm to the fetus from the MRI magnetic field or radio waves, MRI during the first trimester is generally avoided unless medically necessary. Pregnant patients should inform their healthcare providers and MRI technologists before the scan.**
- **Acoustic noise: It is a consequence of the force exerted on the gradient coils due to the rapidly varying current within them in the presence of the main field. The frequency of the current is such that the coils vibrate against their surroundings and produce noise at an acoustic level. This noise, which increases with field strength and varies considerably with the type of sequence being used, is sufficient to warrant ear protection for all patients.**
- **Quenching: - A magnet quench will result in several days of down time. So, do not press or push the button except in a real emergency. Do not test that button. It should be tested only by qualified service personnel. Quench button is located near the magnet. If the patient needs medical attention,**

press an emergency stop button on the consol or magnet and remove the patient from the scan room.

- **Note:** MRI systems are equipped with laser alignment lights. Exposing eyes to the laser alignment lights may result in eye injury. Do not stare directly into the laser beam. Instruct the patients to close their eyes during land marking in order to avoid eye exposure to the alignment light while the laser light is "ON". Do not leave the laser beam ON after you position the patient.
- **Contrast agents and kidney function:** - Gadolinium-based contrast agents are sometimes used in MRI to enhance the visibility of certain tissues. These agents are generally safe, but they can pose a risk to individuals with impaired kidney function. Patients with kidney problems should closely monitored and may need to undergo alternative imaging tests.
- **Contrast media:** Depending on relaxivity, MR contrast media classified into:

  A- Positive relaxation agents (T1 agents) These agents affect T1 relaxation of the tissues. T1 of the tissue in which contrast media is accumulated is reduced. Reduction in T1 results into increase in the signal intensity on T1-W images hence these agents are called positive relaxation agents like Gadolinium.

  B- Negative relaxation agents (T2 agents) They affect T2 relaxation and reduce T2 of the tissue where they accumulate. This results in reduction in the signal intensity of the tissue on T2-W images and is called negative relaxation agents like Iron oxide.
- **Gadolinium:** - (Gd) is a paramagnetic agent. It has a large magnetic moment and when it used the T1 relaxation times of nearby water protons are therefore reduced, resulting in an increased signal intensity on T1WI. For this reason, Gd is known as T1 enhancement agent.

  - Gadolinium is a rare-earth metal that cannot be excreted by the body and would cause long term side effects, as it binds to membranes.

  - Side effects: -

  1- A slight transitory increase in bilirubin and blood iron.
  2- Mild transitory headaches.
  3- Nausea.
  4- Vomiting.
  5- Hypotension.
  6- Gastro-intestinal upset.
  7- Rash.

  -Contra-indications: -

  1- Hematological disorders.

2- Sickle cell anemia.
3- Pregnancy.
Administration: - The effective dosage of Gd is 0.1 millimole (mmol) per kilogram (kg) of body weight (mmol/kg), approximately 0.2ml/kg.

- **Clinical applications: -** Gadolinium has proven very useful in imaging the CNS because of its ability to pass through breakdown in the blood-brain barrier (BBB). Clinical indications for Gd include: -

1- Tumors pre- and post-surgery.
2- Pre and post radiotherapy.
3- Infection.
4- Infarction.
5- Inflammation.
6- Post-traumatic lesions.
7- Post- operation lumbar disc.
8- Breast disease.
9- Prostatic disease.

- **Iron oxide: -** It shorten relaxation times of nearby hydrogen atoms and therefore reduce the signal intensity in normal tissues. This result in a signal loss on proton density or heavily T2WI. Super-paramagnetic iron oxides are known as T2 enhancement agent.
- **Side effects: -**
  1- Mild to severe back, leg and groin pain is experienced and, in a few cases, head and neck pain.
  2- Patient experience digestive side-effects including nausea, vomiting and diarrhea.
  3- Anaphylactic like reactions and hypotension have been reported in a few patients.
  - Contra-indications: -
  - 1-Contra-indicated in patients with known allergies/hypersensitivity to iron.
  - 2-Since the infusion is dark in color, skin surrounding the infusion site might discolor if there is extravasation.
- **Administration: -** The recommended dose of iron oxide is 0.56 mg of iron per kg of body weight. If using Feridex dilute in 100 ml of 50% dextrose and give I.V. over 30min.
- - **Clinical applications: -** This is mainly used in liver imaging where normal liver is dark on T2WI and lesions appear bright.

- **Other contrast agents: - Gastrointestinal contrast agents are sometimes used for bowel enhancement. These include barium, ferromagnetic agents and fatty substances. However, due to constant peristalsis, these agents enhance bowel motion artifacts more often than enhancing pathologic lesions. The use of anti-spasmodic agents helps to retread peristalsis to decrease these artifacts. Other agents include helium which is inhaled and assists in the evaluation of lung perfusion.**

References: المصادر:

- **Step by step MRI: Jagan Mohan Reddy & V Prasad.**
- **MRI made easy: Govind B Chavhan**