Al-Mustaqbal University
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Radiological Techniques Department

Magnetic Resonance Imaging

First Semester
Lecture 7,8 : Pulse sequences and Image Contrast

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Introduction:

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

Scientific Content:

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.

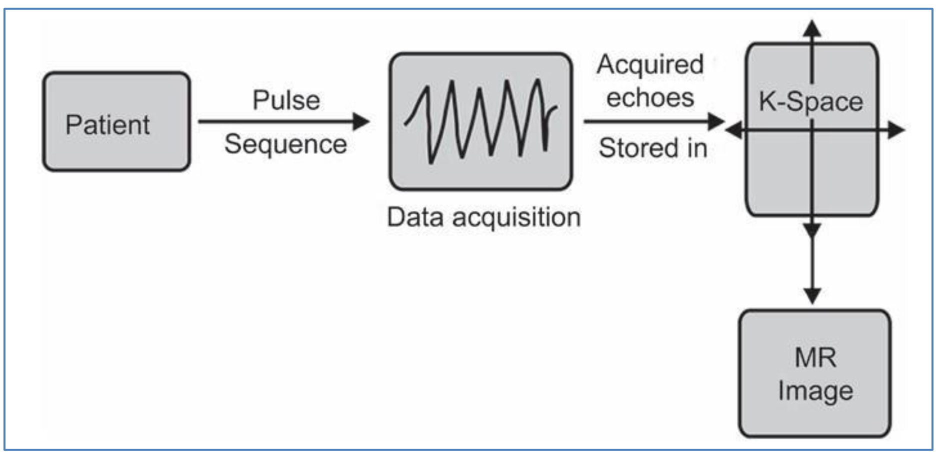

Fig. 1: Steps in image acquisition

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.

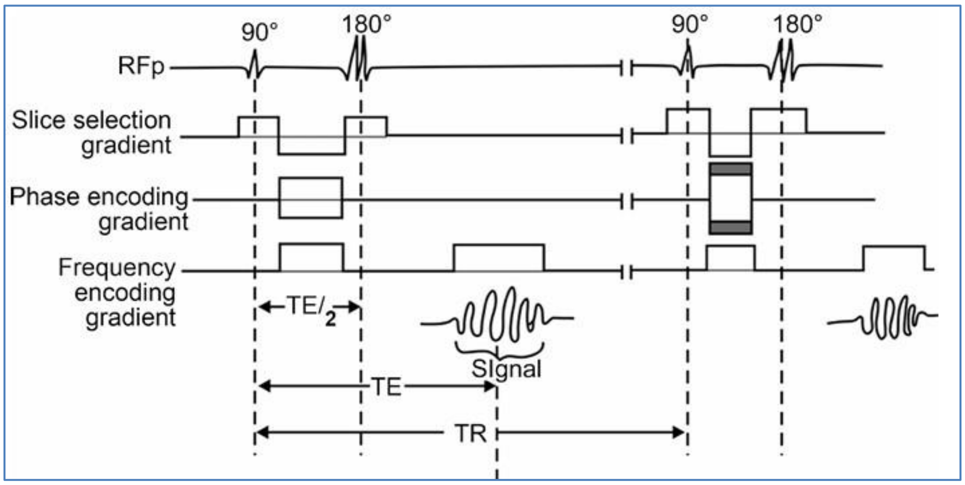

Fig. 2: Spin-echo (SE) sequence

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:

1- 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.

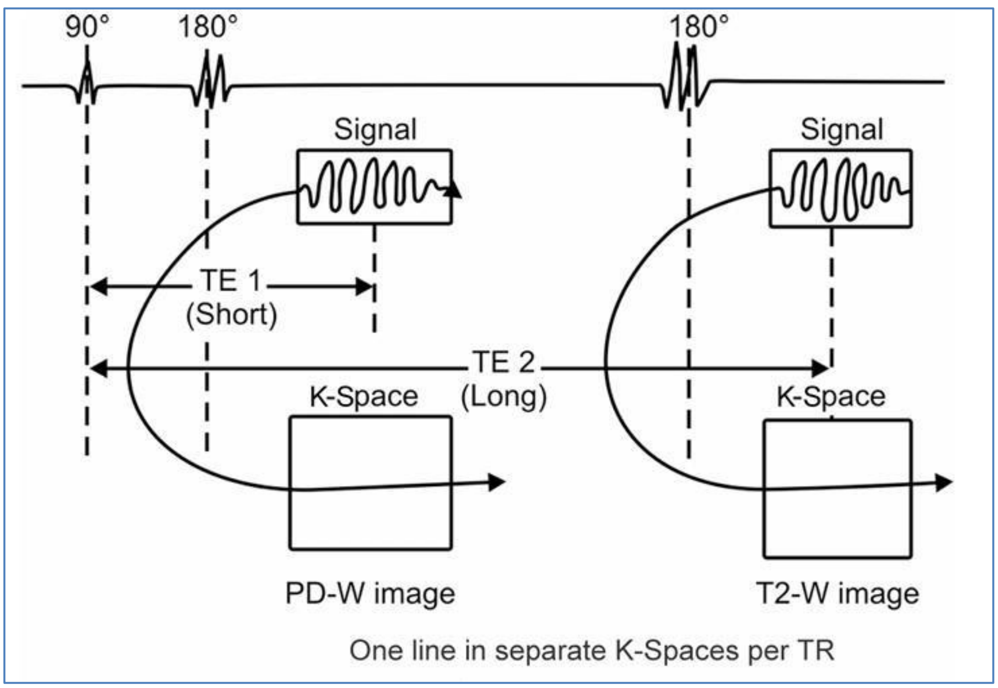

Fig. 3: Double Echo sequence

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.

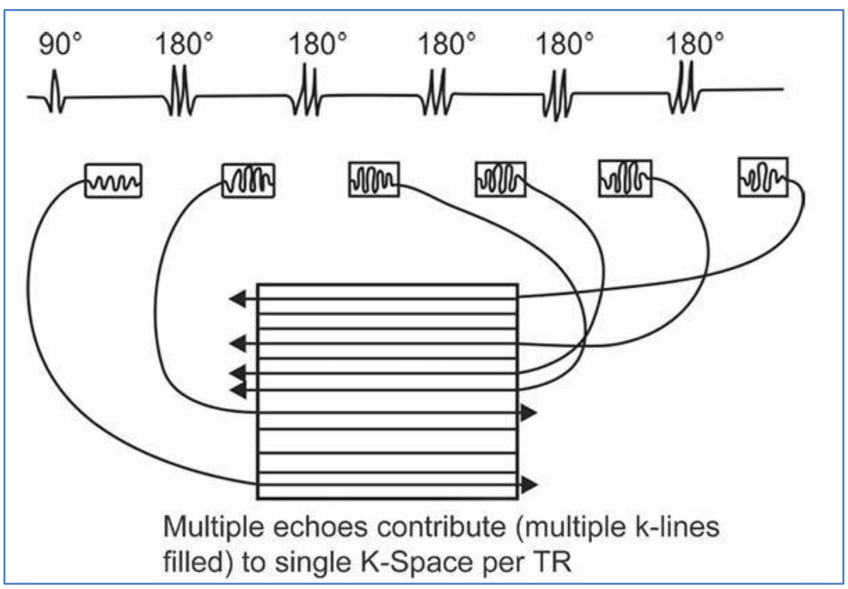

Fig. 4: Fast/Turbo spin echo sequence

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, <u>not only all K-Space lines are acquired in a single excitation</u> 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.**

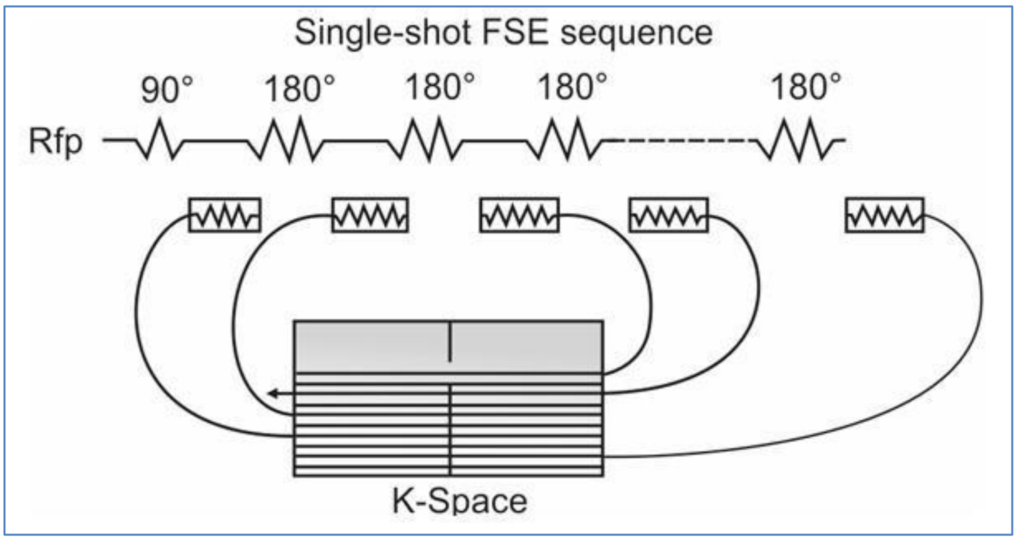

Fig. 5: Single-shot fast spin-echo sequence

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 flip 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.

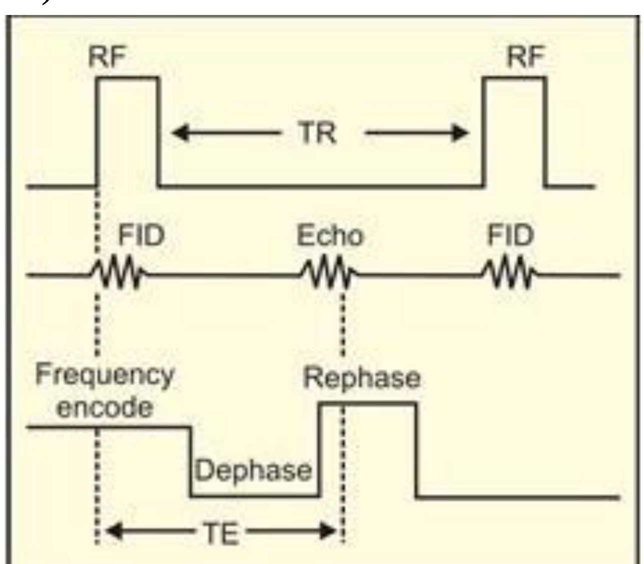

Fig. 6: Schematic illustration of gradient echo pulse sequence

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.

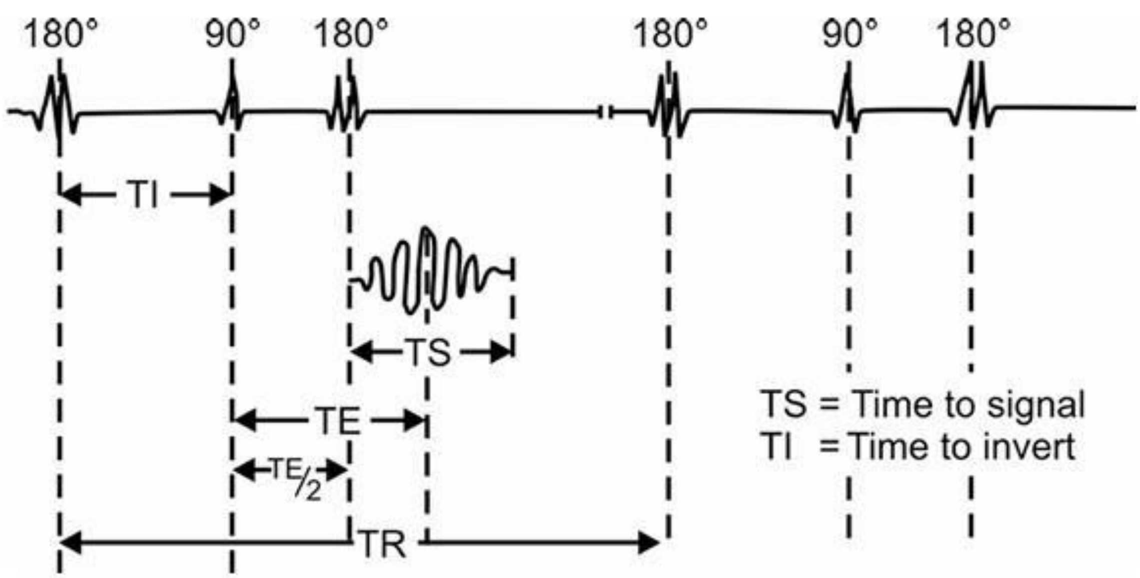

Fig. 7: Inversion recovery (IR) sequence

•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 combinations 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.