RAD 465 (MRI)

Lecture one (Pulse Sequences)

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Outline :

- Spine echo pulse sequence SE
- Fast spin echo pulse sequence FSE
- Inversion recovery pulse sequence IR
- Gradient pulse sequence GS

Pulse sequences

- Pulse sequence definition: is a series of RF pulses, gradients application and intervening time periods

- The pulse sequence can control:

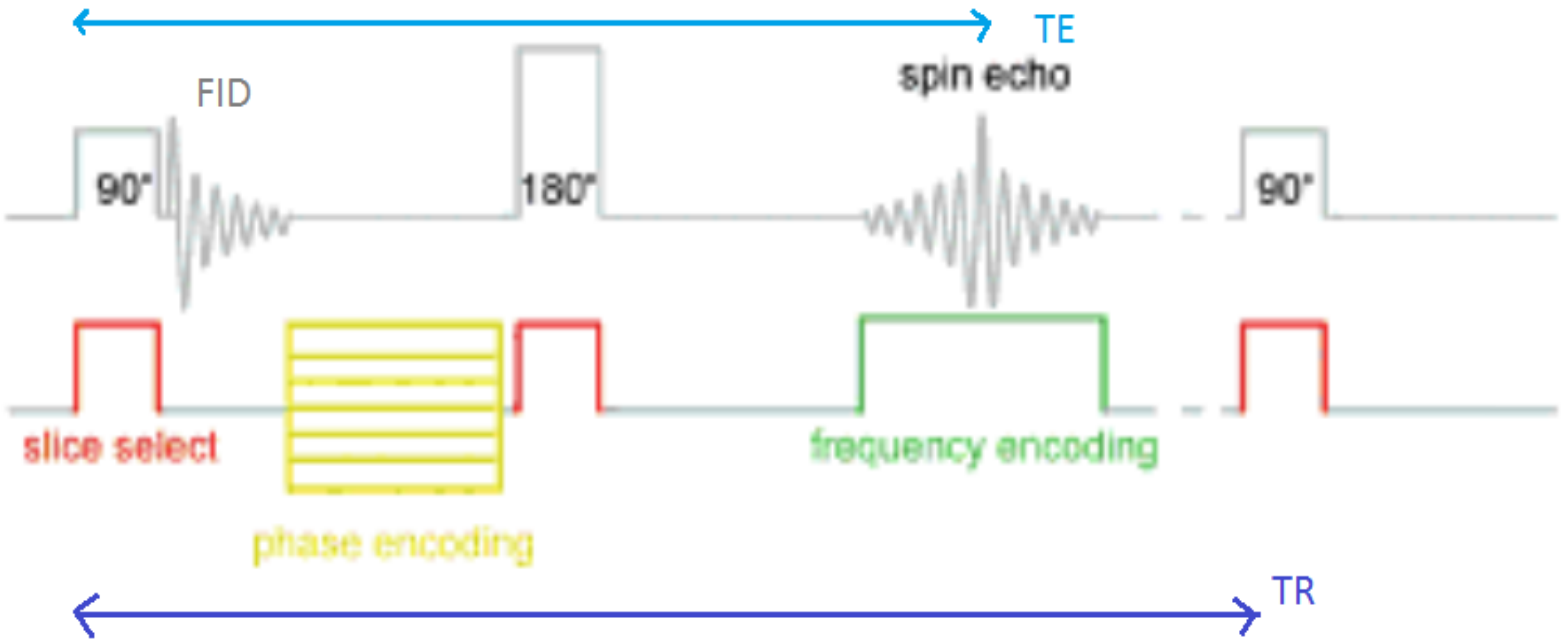
1. Slice location
2. Slice thickness
3. Number of the slice
4. Resolution (FOV and matrix)
5. Image contrast (TR, TE, TI, flip angle and diffusion
6. Artifact correction (for example: saturation pulse, flow compensate and fat suppression)

Spin echo (conventional spin echo SE)

- In the spin echo pulse sequence usually 90° excitation RF pulse followed by a 180° (rephrasing) pulse (one or two) is used to produce the signal
- SE pulse sequences are the most commonly applied sequences as they produce image with ideal signal and ideal contrast [1]
- We can produce T1 ,T2 or PD weighted images by select the TR and TE.

What are the TR and TE ?

- The repetition time (TR) : is the time between successive 90 RF excitation pulses is
- it controls the amount of recovery allowed in longitudinal plane to enhance the contrast between tissues
- The echo time: is the time between the applied 90 RF pulse and the center of the acquisition.
- It controls the amount of dephasing allowed in the transverse plane to enhance the contrast between tissues



Timing Diagram of the spin pulse sequence

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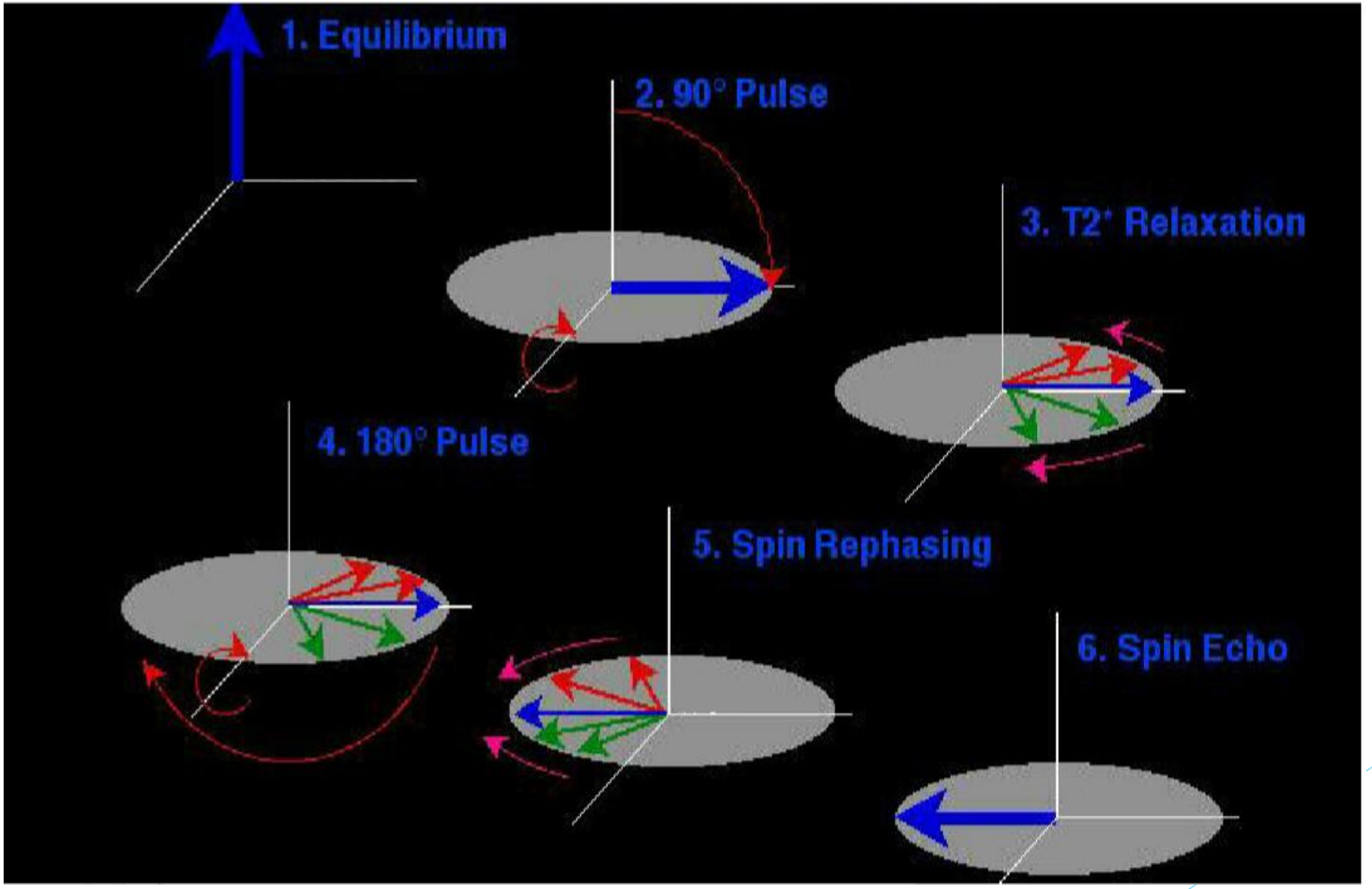

1. Equilibrium
2. 90° Pulse
3. T2' Relaxation
4. 180° Pulse
5. Spin Rephasing
6. Spin Echo

Using of the spin echo pulse sequence

- T1 weighted image has (short TE and short TR) which is useful to show the anatomy
- T1 weighted image + contrast media is used to demonstrate the enhancement of the pathology with contrast media.
- T2 weighted image is acquired with (long TE and long TR) which demonstrates the pathology
- PD weighted is acquired with (short TE and long TR)

Advantages and disadvantages of SE:

- Advantages:
- Good image quality with high SNR
- Easy to understand the image contrast
- Less artifact in the image
- T2 weighted is sensitive to pathology

- Disadvantages:
- Scan time is long
- TR is long so it is not suitable to 3D acquesation
- SAR is higher than gradient pulse sequence WHY?

Scan time in SE:

$$scan\ time^{min} = \frac{TR^{msec} \times NEX \times \#\ phase\ encoding}{60000}$$

Reduce the scan time

As the scan time is a function of the TR, NEX and number of phase encoding, in order to reduce the scan time, one or more of these factors should be reduced.

Fast spin echo or turbo spin echo

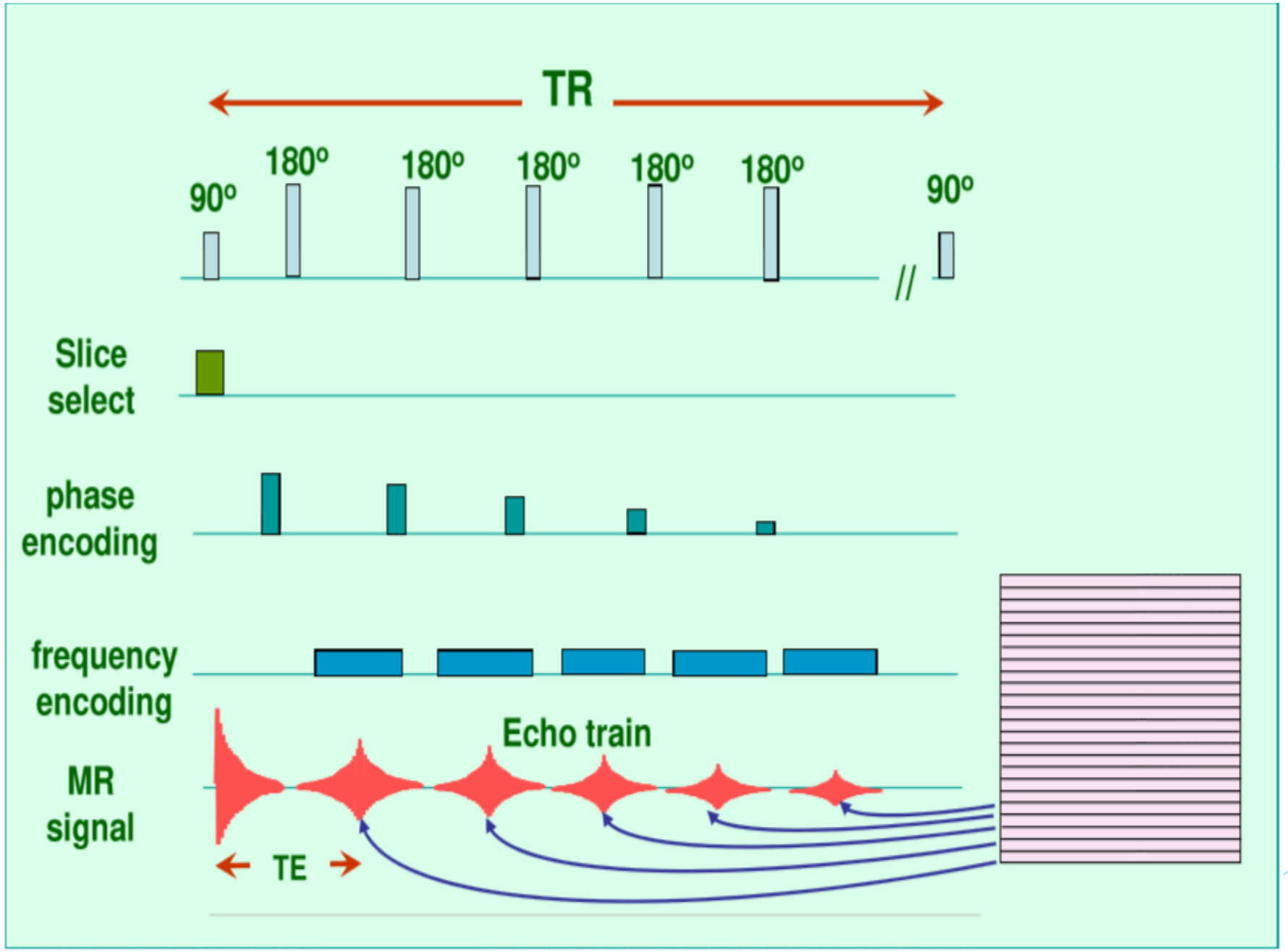
- Fast spin echo (FSE) uses a 90° flip angle followed by several 180° rephasing pulses to produce several SE in a given TR
- In the FSE all the echoes are collected with same slice selection gradient amplitude
- However, each echo has different phase encoded amplitude of gradient slope, so the data from each echo are collected and stored in a different line of k-space.

Fast spin echo or turbo spin echo

- Number of the 180° rephasing pulses applied known as echo train length ETL or turbo facto.

- In the FSE more than one line are filled in the k-space each TR. So the scan time decrease by ETL

- $$scan\ time^{min} = \frac{TR^{msec} \times NEX \times \#\ phase\ encoding}{60000 \times ETL}$$


TR
90°
180°
180°
180°
180°
180°
90°
//
Slice select
phase encoding
frequency encoding
Echo train
MR signal
TE

Single-shot FSE (SS-FSE)

- Single- shot can be named as HASTE (half acquisition single-shot turbo spin echo)
- This pulse sequence has long ETLs that fill all of k-space in one shot with half-Fourier acquisition techniques
- In this technique only half of k-space are acquired and then transfer data into the other half.
- The adventage of this technique that it is very rapid acquisitions, which is used in multiple-slice breath-hold and real-time imaging

Single-shot FSE (SS-FSE)

- Disadvantages:

1. less SNR as only half the k-space data really acquired

1. Higher SAR (specific absorption rate)

Solution can be used to decrease the SAR if necessary ?

Use less refocussing pulse rather than 180 (for example 120 degree); however, that will drop the SNR

Advantages of the FSE:

Advantages:

- Decrease the scan time by ETL
- Higher resolution and multiple NEX to improve the SNR
- Although the contrast in the FSE is similar to SE; however, there are some differences.
- In the central nervous system, pelvis and musculoskeletal resign FSE has replaced the SE (especially in T2)

Disadvantages of the FSE:

1- One of these differences is that fat remains bright on T2-weighted images and fat suppression techniques may be needed to compensate for this.

Why does the fat remain bright on T2- Weighted image?

Because the multiple 180° RF pulses used in FSE sequences leads to lengthening of the T2 decay time of fat that the signal intensity of fat on T2W in FSE images is higher than in SE.

Disadvantages of the FSE:

2- some of the flow and motion affects increased.

3- required a special hardware and software

4- Too much acoustic noise which need double hearing protection

Disadvantages of the FSE:

5- In addition to that, in FSE sequences, artifact as blurring in the image is often come up with long ETL sequences.

- This occurs because each line of k-space contains data from echoes with a different TE.
- When long ETL sequences is used, the very late echoes have a low signal amplitude and, as the outer lines of k-space are filled with data from these echoes, there are insufficient data to provide adequate resolution.
- Image blurring is most commonly seen at the edges of tissues with different T2 decay times.
- The blurring is increase with long echo train length

Fast Spin Echo

blurring

SE TE 20

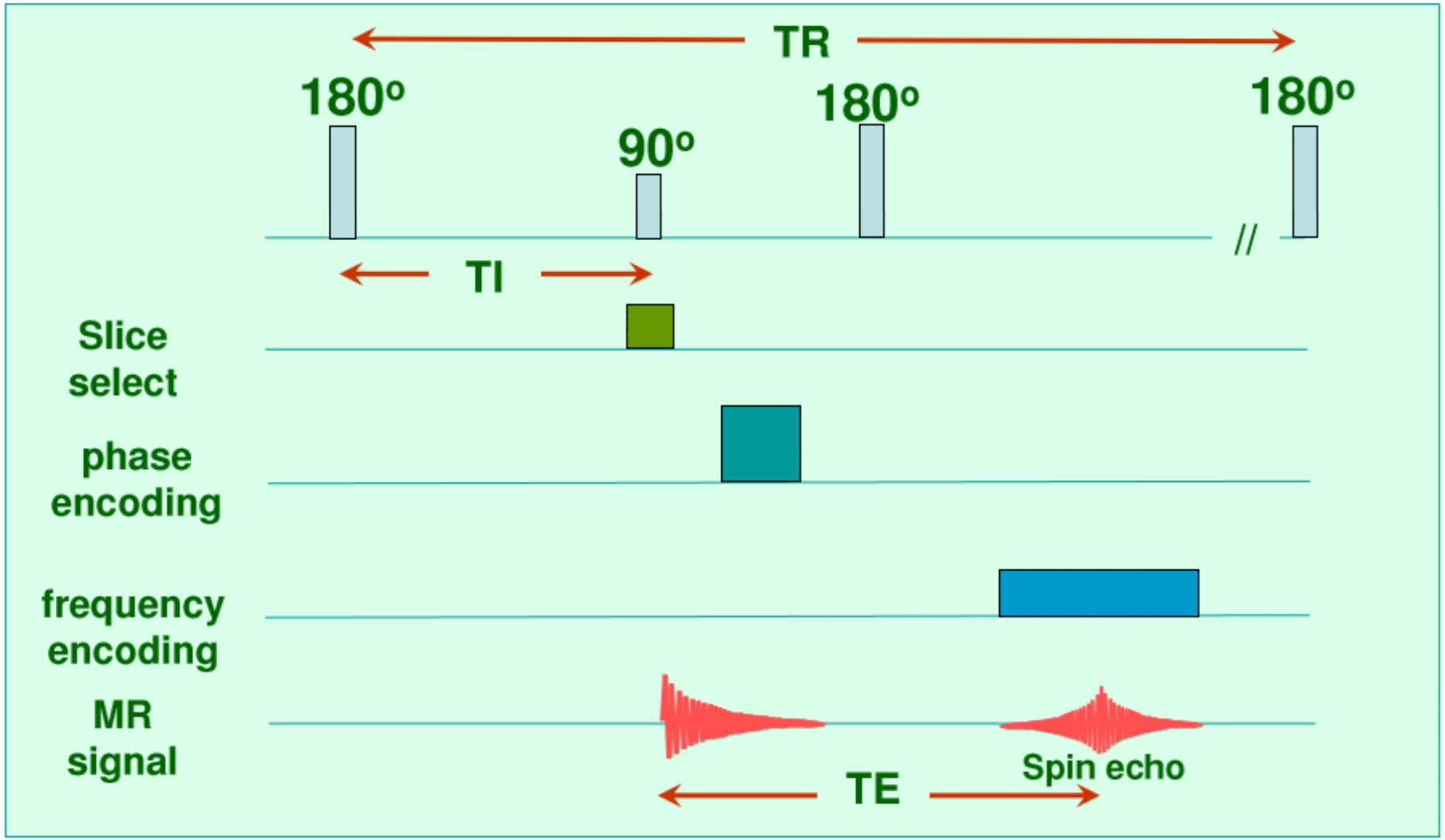
FSE TE 20

Disadvantages of the FSE:

- That blurring can be reduced by decreasing the size of the FOV in the phase direction or by selecting a broad receive bandwidth.
- What is the parameter trade-off come up with these two solutions ?
- However, these solutions improve overall image quality by reducing blurring, but they also reduces the SNR.
- Lastly, FSE is not always compatible with options such as phase-reordered RC, and therefore, conventional SE or breath-hold sequences are often the sequence of choice with respiratory artefact.

Inversion recovery (IR/IR-FSE)

- It was used a t the begging to produce a good T1 contrast in low field system [2]
- IR pulse sequences begin with a 180° pulse that inverts the net magnetization into (–Z axis) which known as full saturation
- The magnetization begins to recover and return towards B0 (Z axis) after the 180 inverted pulse removed
- After a specific time TI (inversion time), a 90° RF pulse is applied to transfers the magnetization that has recovered to B0 into the transverse plane
- In IR-FSE, several 180° rephasing pulses are applied as in FSE, so that more than one line of k-space can be filled per TR, so reducing the scan times.


TR
180°
90°
180°
180°
//
TI
Slice select
phase encoding
frequency encoding
MR signal
Spin echo
TE

Inversion recovery types:

- At the beginning the IR is most commonly used to produce heavily T1-weighted images.
- Because there is a big contrast difference between the fat and the water.
- But IR and IR-FSE can be used to suppress the signal from any tissues.
- by applying the 90° excitation pulse when the magnetization in that tissue has recovered into the transverse plane and therefore no longitudinal component of that tissue.
- IT = 0.69 × (T1 relaxation time for nulling tissue).

Inversion recovery types:

- In the IR pulse sequences, the contrast in the image depend on TI in addition to other contrast parameters.

- The TI is also depend on the field strength.

Advantages and disadvantages:

- Advantages:

1. Good SNR the TR is long
2. Give a good T1 contrast + a good enhancement of the tissue when the contrast media given

- Disadvantages:

Longer scan time unless it is used with FSE

The type of the inversion recovery(IR)

- There are two main uses of the IR: STIR and FLAIR
- STAIR (short tau inversion recovery) has short inversion time to nulling the signal from the fat.
- STIR is not suitable to be used with contrast media enhancement. Why?
- Because the enhancement tissue will be shorten their T1 relaxation make them near from the fat and they null as well
- FLAIR (fluid attenuation inversion recovery) which has long inversion time to nulling the signal from the cerebrospinal fluid (CSF).

Using of the FLAIR

- It is used in the brain and spin to visualize periventricular and cord lesion (multiple sclerosis, subarachnoid hemorrhage and meningitis)

Gradient pulse sequences:

- The gradient pulse sequence use a flip angle different than 90 + using a frequency encoding gradient to rephase the FID pulse instead of 180 pulse in the SE pulse sequence
- So the TR decrease, and T2* and PD image contrast can be acquired with less time
- The TE will decrease as well
- Frequency encoding gradient is applied negatively (to increase the dephase the FID and then positively (to refocus the signal)

Gradient pulse sequences:

- However, the gradient will not be able to eliminate inhomogeneities of the magnetic field, so the T2* relaxation will have effect on the image contrast.

Uses :

1. Acquiring T2*, T1 or proton density image contrast
2. Produce a single-slice or volume breathe hold in the abdominal
3. Dynamic contrast enhancement
4. Angiography (because the GS sensitive to the blood flow)

Advantages and disadvantages of the gradient echo:

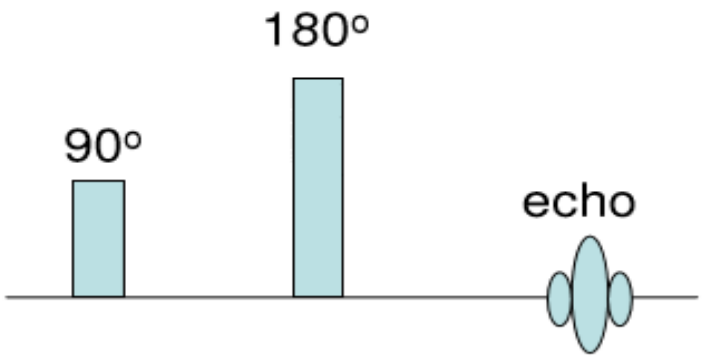
advantages

- faster imaging can use shorter TR and shorter TE than SE
- low flip angle deposits less energy
- more slices per TR than SE
- compatible with 3D acquisitions

Advantages and disadvantages of the gradient echo:

- Disadvantages:

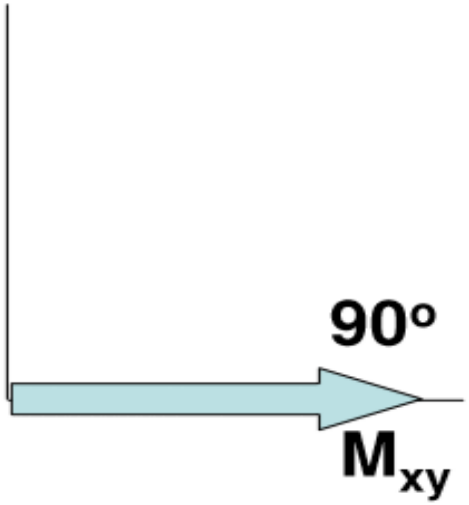
1. Difficult to generate good T2 weighting
2. magnetic field inhomogeneities cause signal loss
3. The disadvantages worse with increasing TE times
4. susceptibility effects increase
5. dephasing of water and fat protons

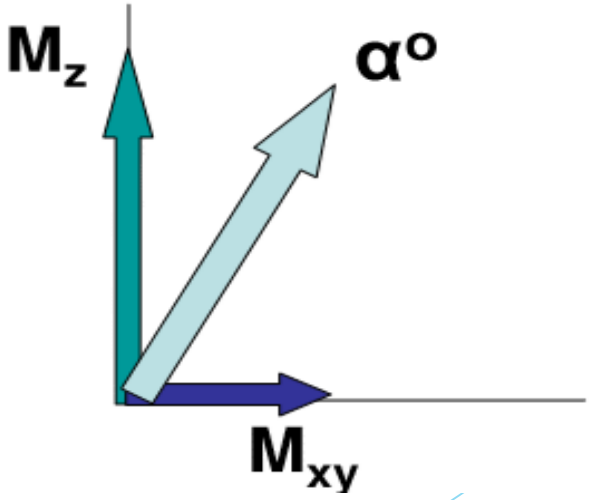

180°
90°
echo


α°
echo


Frequency
encoding


Frequency
encoding

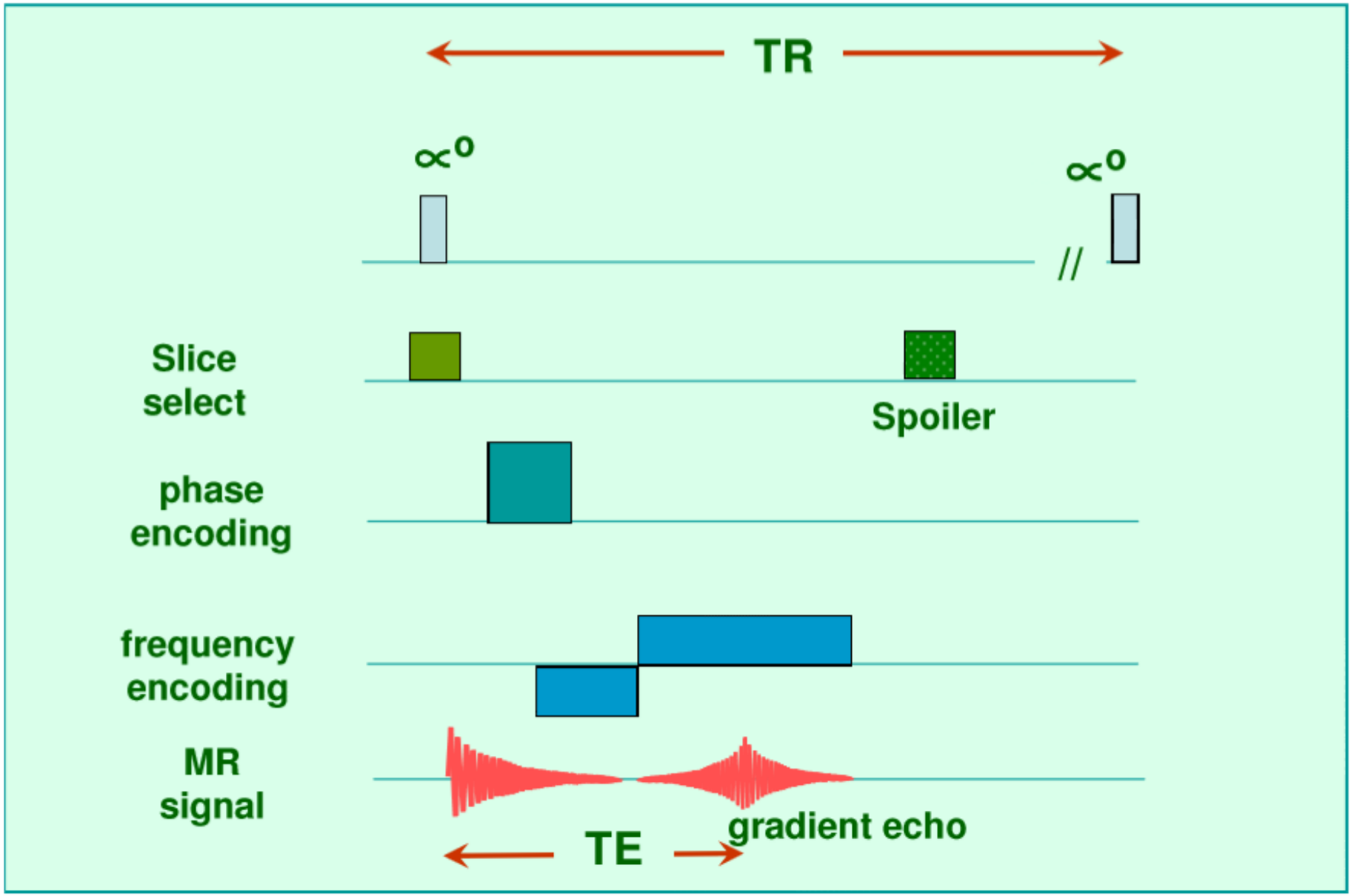

90°
Mxy


Mz
α°
Mxy

- There are different type of the Gradient echo
- The signal can be produced from the spin in the longitudinal magnetization M z,(or and) part from the steady state (transverse magnetization) M xy

1- Incoherent(spoiled)gradient echo (T1/PD) (SPGR, T1 FFE OR FLASH (fast low angle shot)

- Use variable flip angle + gradient rephrasing (instead of 90°+ 180° in the spin echo sequence).
- The signal come from the longitudinal magnetization only for the next excitation.
- As the transverse magnetization (the spins in the transvers plane from the previous pulse) has been spoiled or diphase to reduce the effect of the T2 or T2*
- This pulse sequence produce T1 WI and PD.


TR
∝°
∝°
//
Slice select
Spoiler
phase encoding
frequency encoding
MR signal
gradient echo
TE

Advantages and disadvantages of the Incoherent (spoiled) gradient echo:

Advantages:

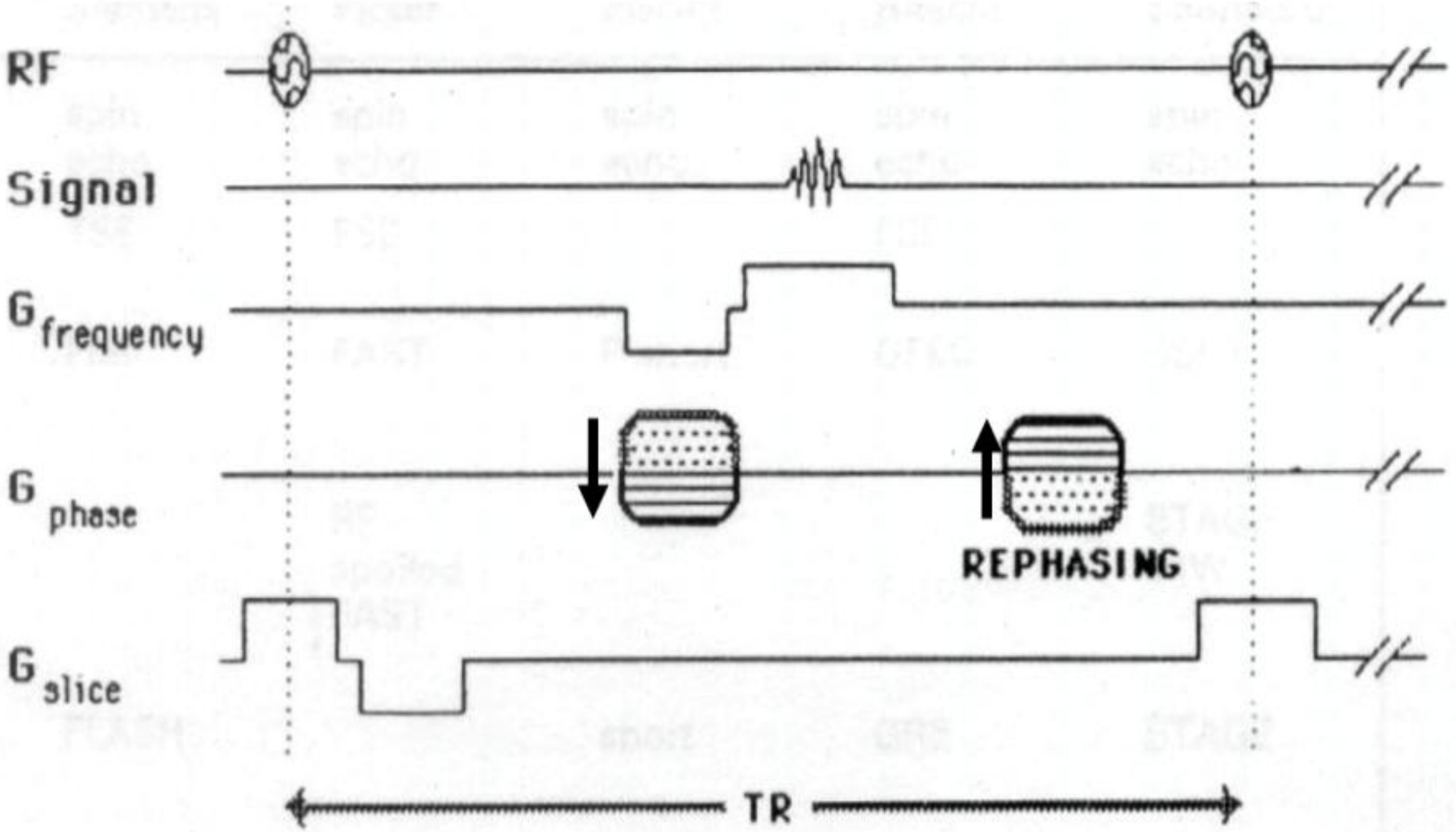
- Produce T1 weighted image in the breath hold technique image (liver and chest).
- Showing the anatomy and pathology in the post contrast image.
- Can be used for 2D or 3D image.

Disadvantages:

- Prone to the artifact
- Less SNR (as the transvers magnetization is spoiled)

2- gradient echo (T2*) (GRASS/2-Coherent FFE/FISP)

- Use a variable flip angle followed by gradient rephasing to produce a GR echo.
- This is achieved by a reversal of the phase encoding gradient prior to each repetition that rephases this transverse magnetization.
- In this way, the coherence of the transverse magnetization is maintained, so that mainly signal steady state GRE images represents a mixed contribution from both the longitudinal and transverse components of the tissue magnetization by using a reminder gradient.
- It is usually used in angiography because it is sensitive to the flow
- Fast scan and can produce volume imaging or breath hold technique


RF
Signal
G frequency
G phase
REPHASING
G slice
TR

Homework:

- Q1 From the clinical application give an example of difficulties in the diagnosis of some of the pathology come up with different in the contrast between the FSE and SE ? Then give a solution can be given to solve this problem?

References:

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2. MRI in practice, Forth Edition. Catherine Westbrook, Carolyn Roth & John Talbot

3. physical basis of MRI pulse sequences review. Abdullah Jamea