Al-Mustaqbal University
College of Engineering and Technical Technologies
Biomedical Engineering Department

Subject: Biomedical Instrumentation Design_II.

Class (code): 5th (MU0115103)

Lecture: *4*

BMID

MRI Design: 8. T1 Recovery

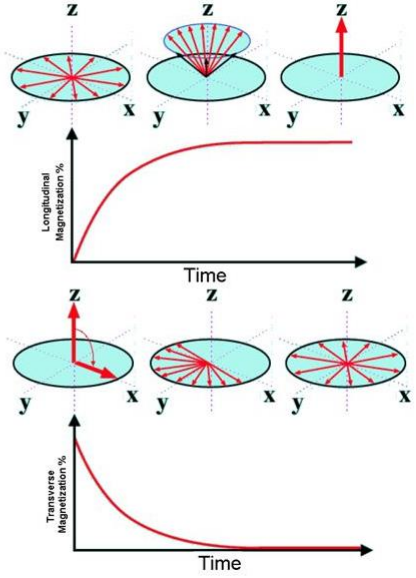
- **T1 recovery** is caused by the exchange of energy from spins to their surrounding environment or lattice. It is called **spin lattice energy transfer**.
- As the spins dissipate their energy their magnetic moments relax or return to B0; thus they regain their longitudinal magnetization.
- T1 recovery is an exponential process and it takes place at different rates in different tissues. It is defined as the time it takes for 63% of the longitudinal magnetization to recover in that tissue.

MRI Design: 9. T2 Decay

- **T2 decay** is caused by the interaction between the magnetic fields of neighbouring spins (**spin–spin**).
- This produces a loss of phase coherence or dephasing, and results in an exponential decay of the NMV in the transverse plane. It occurs at different rates in different tissues.
- The T2 decay time is the time it takes for 63% of the transverse magnetization to be lost due to dephasing; that is, transverse magnetization is reduced by 63% of its original value (37% remains).
- The TE therefore determines how much T2 decay occurs in a particular tissue.

MRI Design: 9. T2 Decay

- T1-Relaxation: Recovery
  - Recovery of longitudinal orientation.
  - 'T1 time' refers to interval where 63% of longitudinal magnetization is recovered.
- T2-Relaxation: Dephasing
  - Loss of transverse magnetization.
  - 'T2 time' refers to interval where only 37% of original transverse magnetization is present.



MRI Design: 10. T1 Weighting

- All intrinsic contrast mechanisms affect image contrast, regardless of the pulse sequence used. Tissues with a low proton density and air, are always dark on an MR image, and tissues in which spins move may be dark or bright depending on their velocity and the pulse sequence used
- An **MRI pulse sequence** is a programmed set of changing magnetic gradients. Each sequence will have a number of parameters and multiple sequences grouped together into an MRI protocol.
- In order to produce images where the contrast is predictable, parameters are selected to weight the image towards one contrast mechanism and away from the others.
- This is achieved by manipulating the extrinsic contrast parameters to accentuate one intrinsic contrast parameter and diminish the others. Proton density effects cannot be changed. T1 and T2 influences are manipulated by changing the TR and TE in the following way.

MRI Design: 10. T1 Weighting

- In a **T1 weighted image**, differences in the T1 relaxation times of tissues are accentuated and T2 effects are reduced.
- To achieve this, a **TR** is selected that is **short** enough to ensure that the NMV in neither fat nor water has had time to fully relax back to B_0 before the application of the next excitation pulse.
- The NMV in both fat and water is saturated.
- If the TR is long, the NMV in both fat and water recovers and the respective T1 relaxation times can no longer be distinguished.

MRI Design: 10. T1 Weighting

- A T1 weighted image is an image whose contrast is predominantly due to the differences in T1 recovery times of tissues.
- For T1 weighting, differences between the T1 times of tissues are exaggerated, and to achieve this, the ***TR must be short***.
- At the same time, however, T2 effects must be minimized to avoid mixed weighting.
- To diminish T2 effects, ***TE must also be short***.

MRI Design: 10. T1 Weighting

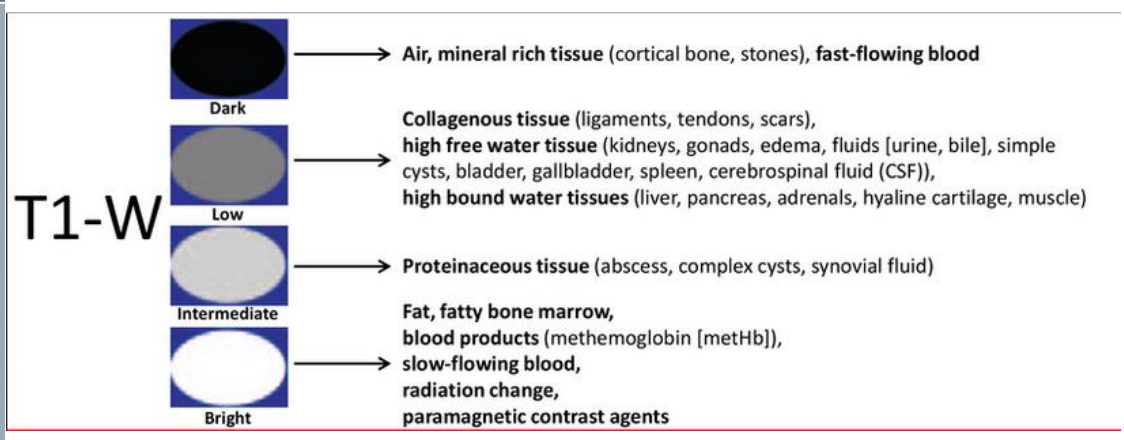
- In T1 weighted images, tissues containing a *high proportion of fat*, with short T1 relaxation times, are bright (high signal, hyper-intense), because they recover most of their longitudinal magnetization during the short TR period and Therefore, more magnetization is available to be flipped into the transverse plane by the next RF pulse and contribute to the signal.
- Tissues containing a *high proportion of water*, with long T1 relaxation times, are dark (low signal, hypo-intense), because they do not recover much of their longitudinal magnetization during the short TR period. Therefore less magnetization is available to be flipped into the transverse plane by the next RF pulse and contribute to the signal.

MRI Design: 10. T1 Weighting

Table 10.1 Signal intensities seen in T1 weighted images.

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

MRI Design: 10. T1 Weighting



MRI Design: 10. T1 Weighting

› Typical values

✓ TR: 400–700 ms (shorter in gradient echo sequences).

✓ TE: 10–30 ms (shorter in gradient echo sequences).

› The principal pulse sequences that are capable of producing T1 weighted images are:

✓ spin echo (produced by two successive RF pulses);

✓ turbo spin echo (produced by rapid acquisition with relaxation enhancement);

✓ inversion recovery (a conventional spin echo (SE) sequence preceded by a 180° inverting pulse);

✓ incoherent gradient echo (the utilization of gradient fields to generate transverse magnetization flip angles of less than 90°).

MRI Design: 11. T2 Weighting

› A T2 weighted image is an image whose contrast is predominantly due to the differences in the T2 decay times of tissues.

› In a **T2 weighted image** the differences in the T2 relaxation times of tissues are accentuated and T1 effects are reduced.

› Thus, a long TE is selected to ensure that the NMV in both fat and water has had time to decay.

› For T2 weighting the differences between the T2 times of tissues are exaggerated, therefore the *TE must be long*. At the same time, however, T1 effects must be minimized to avoid mixed weighting. To diminish T1 effects *the TR must be long*.

MRI Design: 11. T2 Weighting

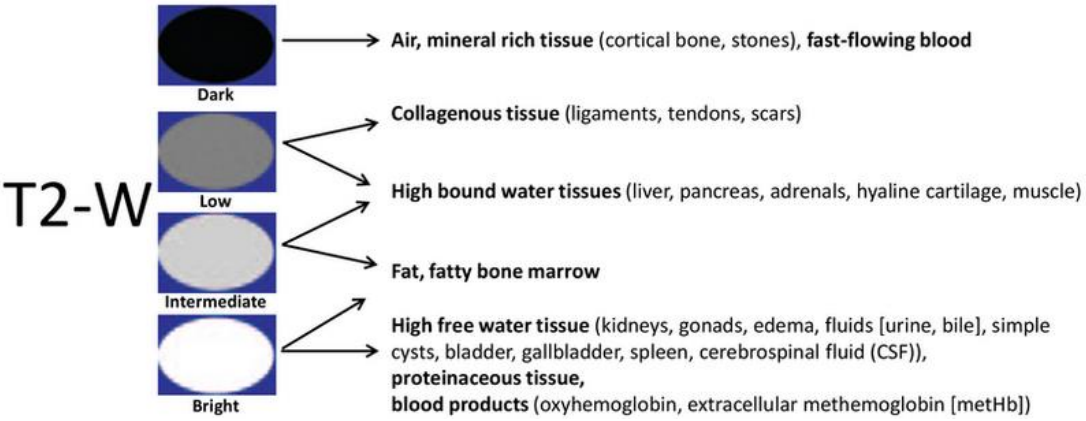
- Tissues containing a high proportion of fat, with a short T2 decay time, are dark (low signal, hypo-intense) because they lose most of their coherent transverse magnetization during the TE period.
- Tissues containing a high proportion of water, with a long T2 decay time, are bright (high signal, hyper-intense),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

MRI Design: 11. T2 Weighting

Table 11.1 Signal intensities seen in T2 weighted images.

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

MRI Design: 11. T2 Weighting



MRI Design: 11. T2 Weighting

› Typical values

✓ TR: 2000+ ms (much shorter in gradient echo sequences)

✓ TE: 70+ ms (shorter in gradient echo sequences)

› The principal pulse sequences that are capable of producing T2 weighted images are:

✓ spin echo.

✓ turbo spin echo.

✓ STIR/FLAIR (STIR: stands for Short-T1 Inversion Recovery and is typically used to null the signal from fat. FLAIR: Fluid Attenuated Inversion Recovery).

› The following pulse sequences produce T2* weighting that has similar characteristics in that water is bright. However, contrast in other tissues may be different.

✓ coherent gradient echo.

✓ balanced gradient echo.

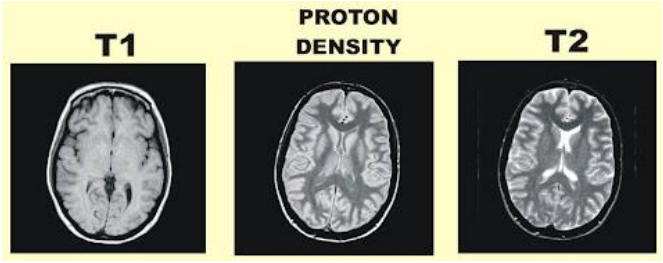
MRI Design: 12. PD Weighting

- A proton density weighted image is an image whose contrast is predominantly due to differences in the proton density (number of hydrogen protons in the tissue) of the tissues.
- Tissues with a low proton density, and air, are always dark on an MR image, and tissues in which nuclei move may be dark or bright depending on their velocity and the pulse sequence used.
- To demonstrate the differences in the proton densities, both T1 and T2 effects are diminished. Selecting a long TR reduces T1 effects and T2 effects are diminished by selecting *a short TE*.
- Tissues with a low proton density are dark (low signal, hypointense) because the low number of protons results in a small component of transverse magnetization. Tissues with a high proton density are bright (high signal, hyper-intense) because the high number of protons results in a large component of transverse magnetization.

MRI Design: 12. PD Weighting

Table 12.1 Signal intensities seen in PD weighted images.

High signal	CSF synovial fluid slow-flowing blood infection inflammation oedema cysts fat
Low or no signal	air fast-flowing blood tendons cortical bone scar tissue calcification



MRI Design: 12. PD Weighting

› Typical values

✓ TR: 2000ms+

✓ TE: 10–30ms

› The main pulse sequences that are used to obtain PD weighting are:

✓spin echo

✓turbo spin echo.

MRI Design: 13. Conventional Spin Echo

› Pulse sequences: a series of RF pulses, gradient applications and intervening time intervals. All pulse sequences contain these elements. They differ only in the way they are coordinated and timed.

› Conventional spin echo (SE or CSE) pulse sequences are used to produce T1, T2 or proton density weighted images and are one of the most basic pulse sequences used in MRI.

› In a spin echo pulse sequence, there is a 90° excitation pulse followed by a 180° rephasing pulse followed by an **echo**.

MRI Design: 13. Conventional Spin Echo

Mechanisms of CSE

- After the application of the 90° RF pulse, the magnetic moments of the spins lose precessional coherence because of an increase or decrease in their precessional frequency caused by the magnetic field inhomogeneities. This results in a decay of coherent magnetization in the transverse plane and the ability to generate a signal is lost.
- Magnetic moments that experience an increase in precessional frequency gain phase relative to those that experience a decrease in precessional frequency, which lag behind. Dephasing can be imagined as a 'fan' where magnetic moments that lag behind precess more slowly, and those that gain phase precess more quickly.
- A 180° RF pulse flips magnetic moments of the dephased spins through 180°. The fast edge of the fan is now positioned behind the slow edge. The fast edge eventually catches up with the slow edge, therefore **rephasing** the spins.

MRI Design: 13. Conventional Spin Echo

Mechanisms of CSE

- The coherent signal in the receiver coil is regenerated and can be measured. This regenerated signal is called an **echo** and because an RF pulse has been used to generate it, it is specifically called a **spin echo**.
- Rephasing the spins eliminates the effect of the magnetic field inhomogeneities. Whenever a 180° RF rephasing pulse is applied, a spin echo results.
- Rephasing pulses may be applied either once or several times to produce either one or several spin echoes.

MRI Design: 13. Conventional Spin Echo

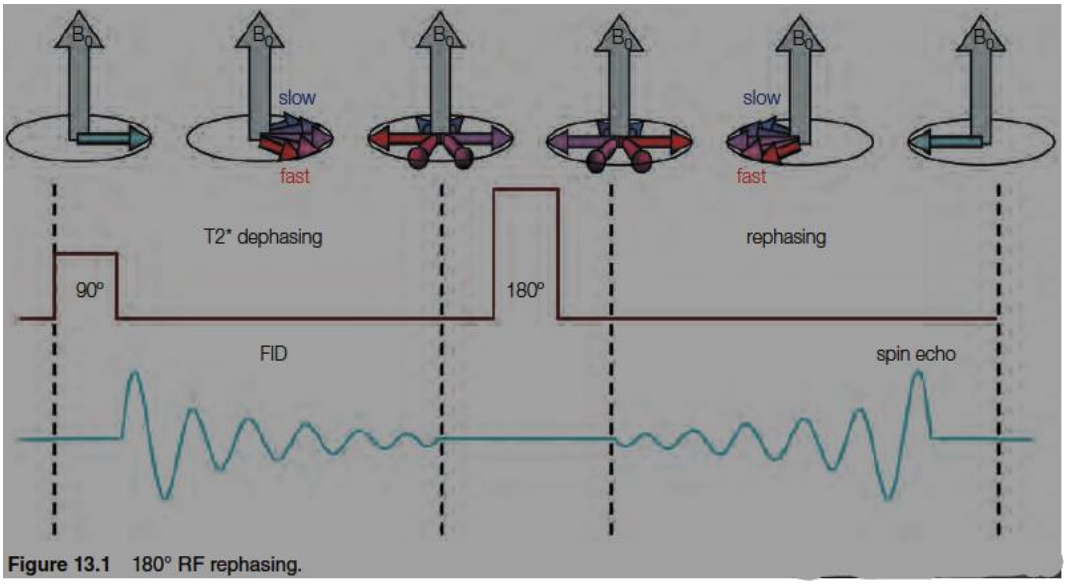


Figure 13.1 180° RF rephasing.

MRI Design: 13. Conventional Spin Echo

Contrast in CSE

CSE is usually used in one of two ways:

- A **single spin echo** pulse consists of a single 180° RF pulse applied after the excitation pulse to produce a single spin echo. This a typical sequence used to produce a T1 weighted set of images.
- The **TR** is the length of time from one 90° RF pulse to the next 90° RF pulse in a particular slice. For T1 weighted imaging a short TR is used.
- The **TE** is the length of time from the 90° RF pulse to the midpoint or peak of the signal generated after the 180° RF pulse; that is, the spin echo. For T1 weighted imaging a short TE is used.

MRI Design: 13. Conventional Spin Echo

Contrast in CSE

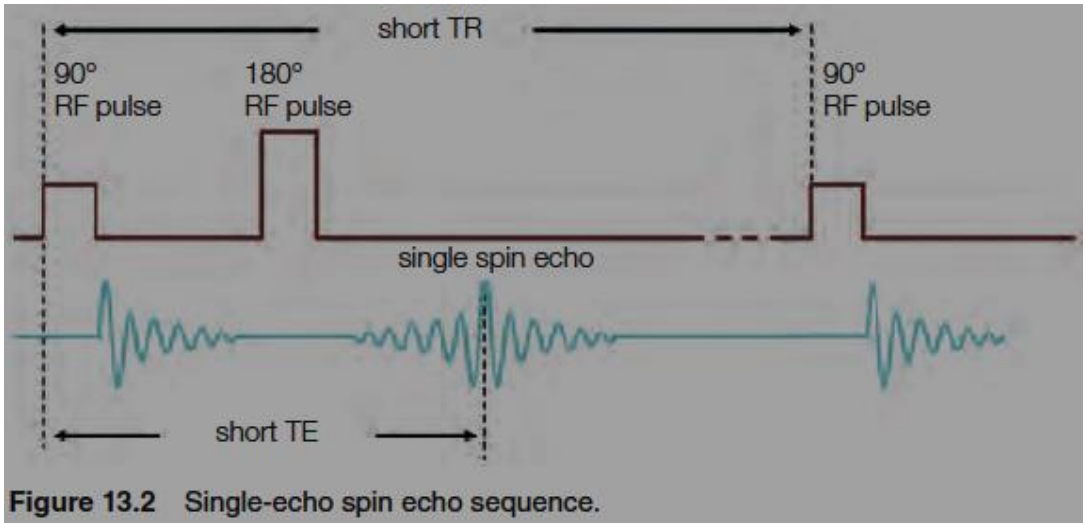


Figure 13.2 Single-echo spin echo sequence.

MRI Design: 13. Conventional Spin Echo

Contrast in CSE

CSE is usually used in one of two ways:

- A **dual echo sequence** consists of two 180° pulses applied to produce two spin echoes. This is a sequence that provides two images per slice location: one that is proton density weighted and one that is T2 weighted. The first echo has a short TE and a long TR and results in a set of proton density weighted images.
- The second echo has a long TE and a long TR and results in a T2 weighted set of images. This echo has less amplitude than the first echo because more T2 decay has occurred by this point.

MRI Design: 13. Conventional Spin Echo

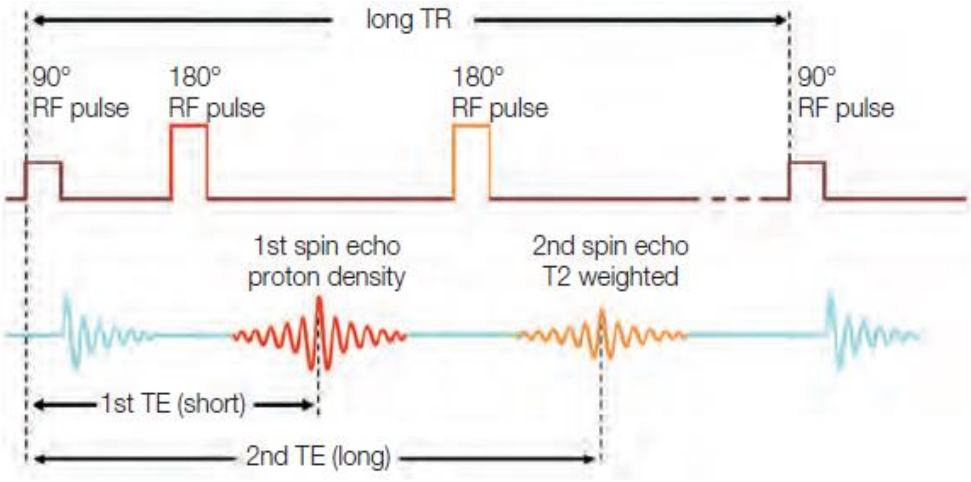


Figure 13.3 Dual-echo spin echo sequence.

MRI Design: 13. Conventional Spin Echo

Typical values

› Single echo (for T1 weighting): • TR: 400–700ms, • TE: 10–30ms

› Dual echo (for PD/T2 weighting): • TR: 2000+ms, • TE1: 20ms, • TE2: 80ms

Table 13.1 Advantages and disadvantage of conventional spin echo.

Advantages	Disadvantage
Good image quality Very versatile True T2 weighting Available on all systems Gold standard for image contrast and weighting	Long scan times


THANK
YOU!