Radiological Equipment Techniques

Magnetic Resonance Imaging

By

Assist. lecturer
Hussein Ali Madlool
M.Sc. Theoretical Physics

Second Semester

Experimental 4

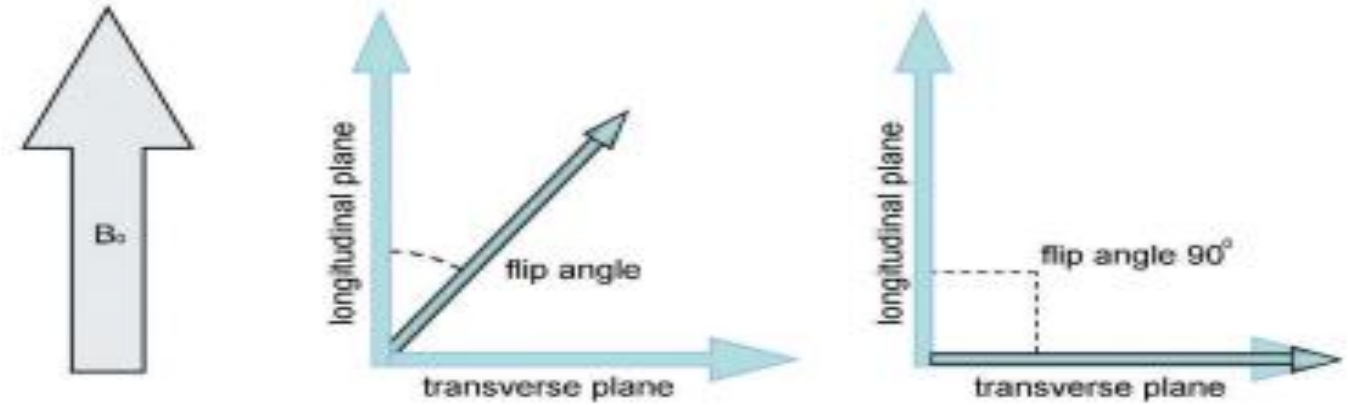
2022-2023

Outline

- Flip Angle
- Pulse Timing Parameters
- Magnetization
- Relaxation in Different Tissues
- PD Weighting
- T1 Weighting
- T2 Weighting

Flip Angle

- The flip angle is an MRI phenomenon by which the axis of hydrogen proton shifts from its longitudinal plane (static magnetic field B0) Z axis to its transverse plane XY axis by excitation with the help of radiofrequency (RF) pulses at the precise Larmor frequency .
- A larger flip angle will increase the signal to noise ratio because there is more net magnetization being moved into the transverse plane for a better signal.
- A small flip puts less net magnetization into the transverse plane so a strong signal is not possible.



The flip angle.

Pulse Timing Parameters

The Echo Time (TE) is the time from the application of the RF pulse to the peak of the signal induced in the coil and is also measured in (ms).

- The TE determines how much decay of transverse magnetization is allowed to occur.
- A long TE results in reduced signal in tissues like white matter and gray matter since the protons are more likely to become out of phase. Protons in a fluid will remain in phase for a longer time since they are not constrained by structures such as axons and neurons.
- A short echo time reduces the amount of dephasing that can occur in tissue like white matter and gray matter. In other words, TE controls the T2 relaxation time of the tissue by allowing a certain amount of the net magnetization to decay in the transverse plane before a signal is read.
- A long TE decreases signal to noise because all of the net magnetization has decayed when the signal is read.
- A short TE increases signal-to-noise because there is net magnetization in the transverse plane to contribute to the signal

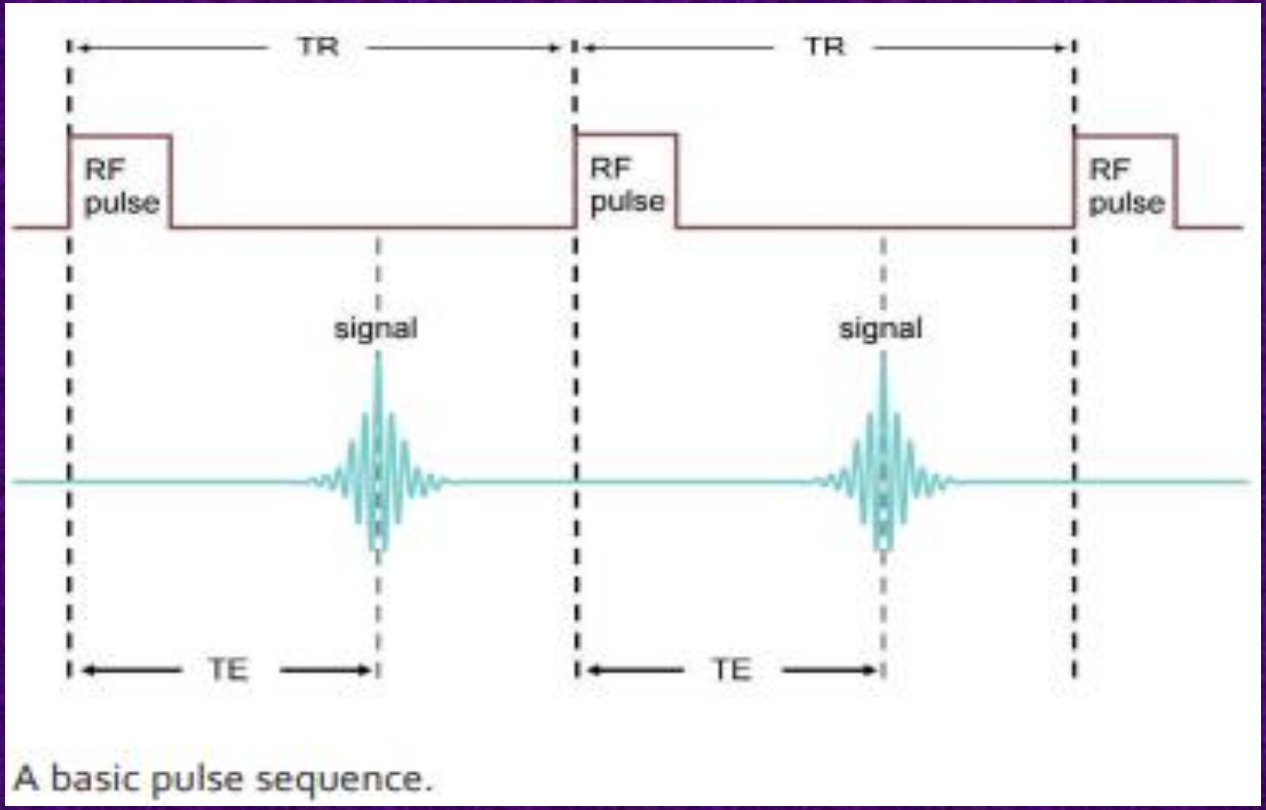
Pulse Timing Parameters

The Repetition Time (TR) is the time from the application of one RF pulse to the application of the next RF pulse for each slice and is measured in milliseconds (ms).

- The TR determines the amount of longitudinal relaxation that is allowed to occur between the end of one RF pulse and the application of the next.
- A long TR allows the protons in all of the tissues to relax back into alignment with the main magnetic field.
- A short repetition time will result in the protons from some tissues not having fully relaxed back into alignment before the next measurement is made decreasing the signal from this tissue.
- A long TR will increase signal to noise ratio because more net magnetization has regrown back to equilibrium and is available to be excited and flipped once again into the transverse plane.

TR thus determines the amount of T1 relaxation

TE thus controls the amount of T2 relaxation

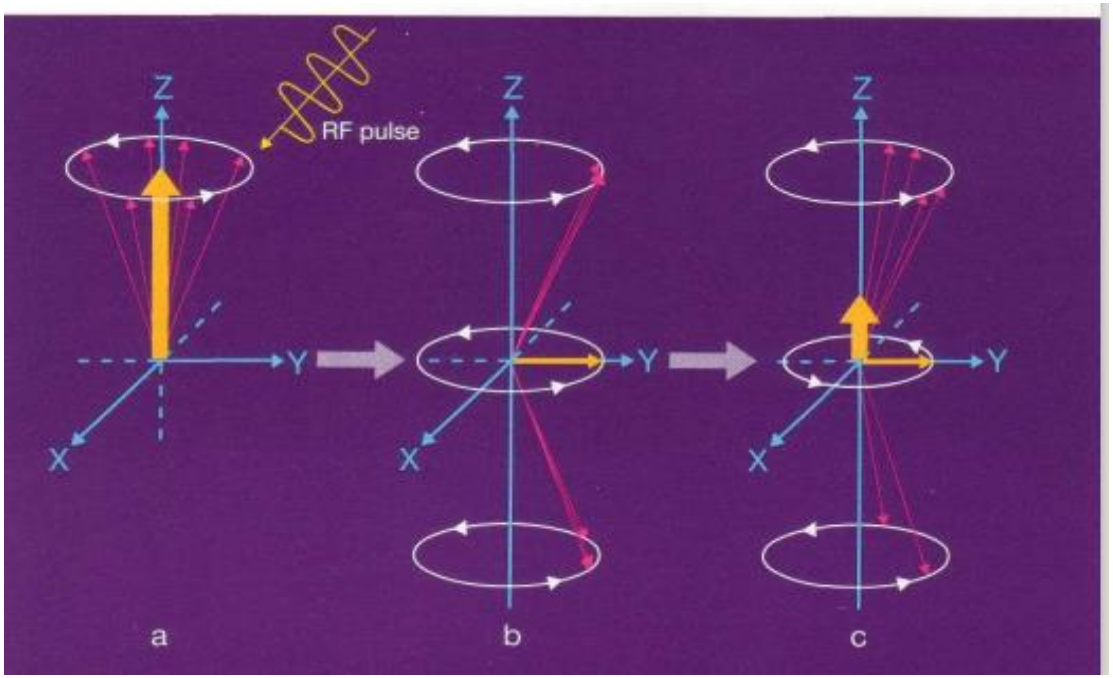


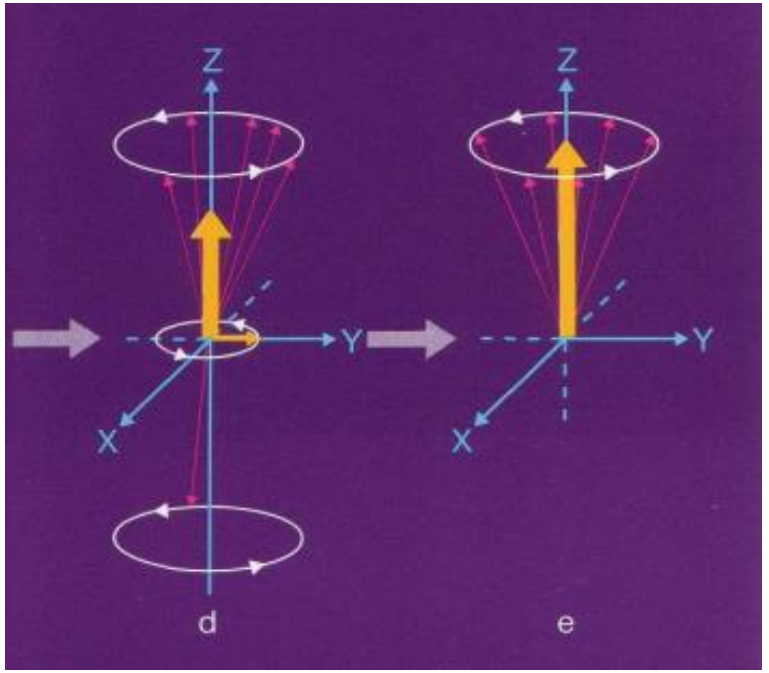
A basic pulse sequence.

Longitudinal Magnetization

T1 relaxation results in the recovery of longitudinal magnetization due to energy dissipation to the surrounding lattice

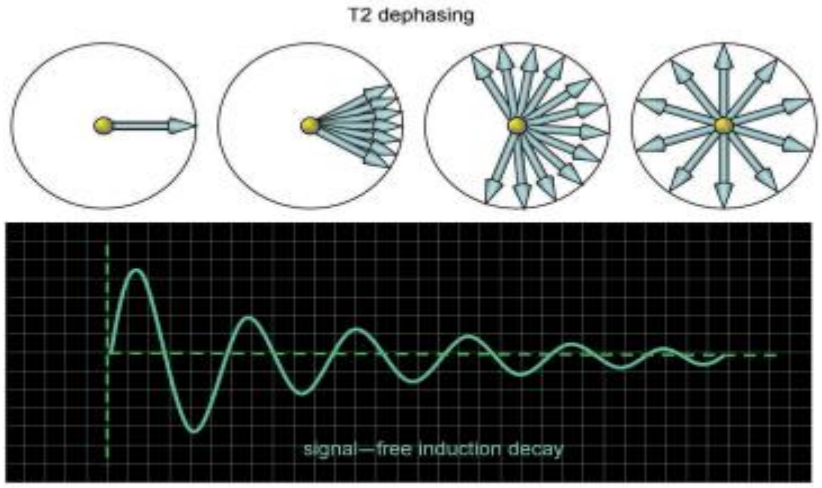
Spin–lattice relaxation time, also known as longitudinal relaxation time. Characterizes the recovery of the longitudinal magnetization Mz towards Mo



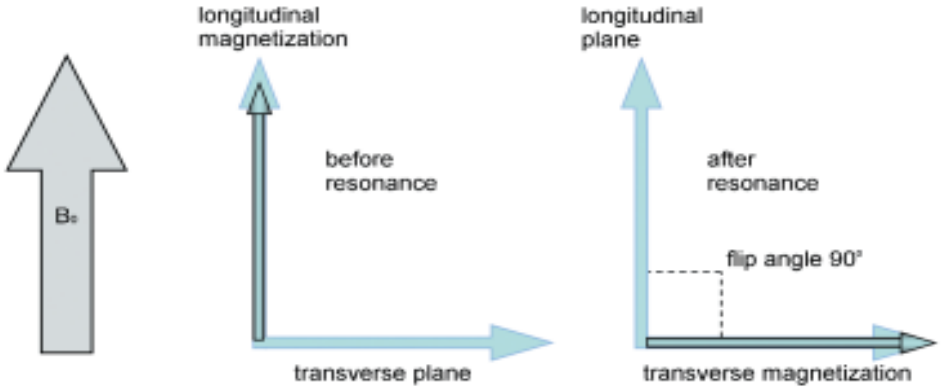


Transverse Magnetization

- T2 relaxation results in the loss of coherent transverse magnetization due to interactions between the magnetic fields of adjacent nuclei
- Spin–spin relaxation time, also known as transverse relaxation time. Characterizes the decay of transverse magnetization Mxy to zero



Dephasing and free induction decay (FID).



Longitudinal and transverse magnetization.

Fat and water

- Fat molecules contain atoms of hydrogen arranged with carbon and oxygen. They consist of large molecules called lipids that are closely packed together and whose molecular tumbling rate is relatively slow.

- Water molecules contain two hydrogen atoms arranged with one oxygen atom (H2O). Its molecules are spaced apart and their molecular tumbling rate is relatively fast.

- The oxygen in water tends to steal the electrons away from around the hydrogen nucleus. This renders it more available to the effects of the main magnetic field.

Relaxation in Different Tissues

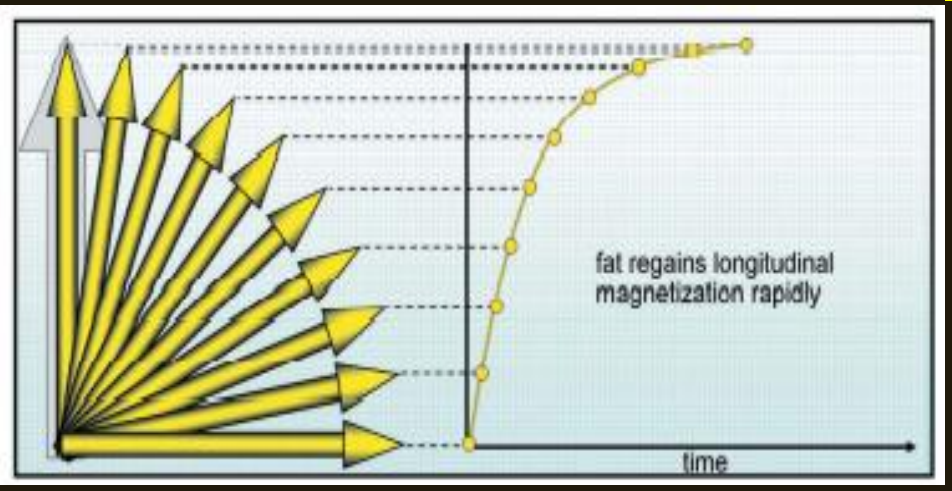
T1 recovery occurs due to nuclei giving up the energy acquired from the RF excitation pulse to the surrounding lattice.

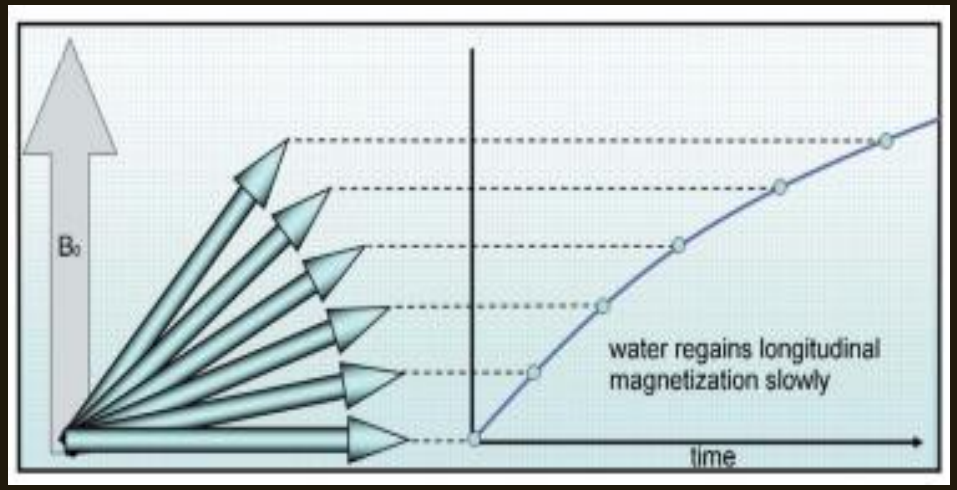
T1 recovery in fat

Fat has a low inherent energy and can easily absorb energy into its lattice from hydrogen nuclei. The slow molecular tumbling in fat allows the recovery process to be relatively rapid

T1 recovery in water

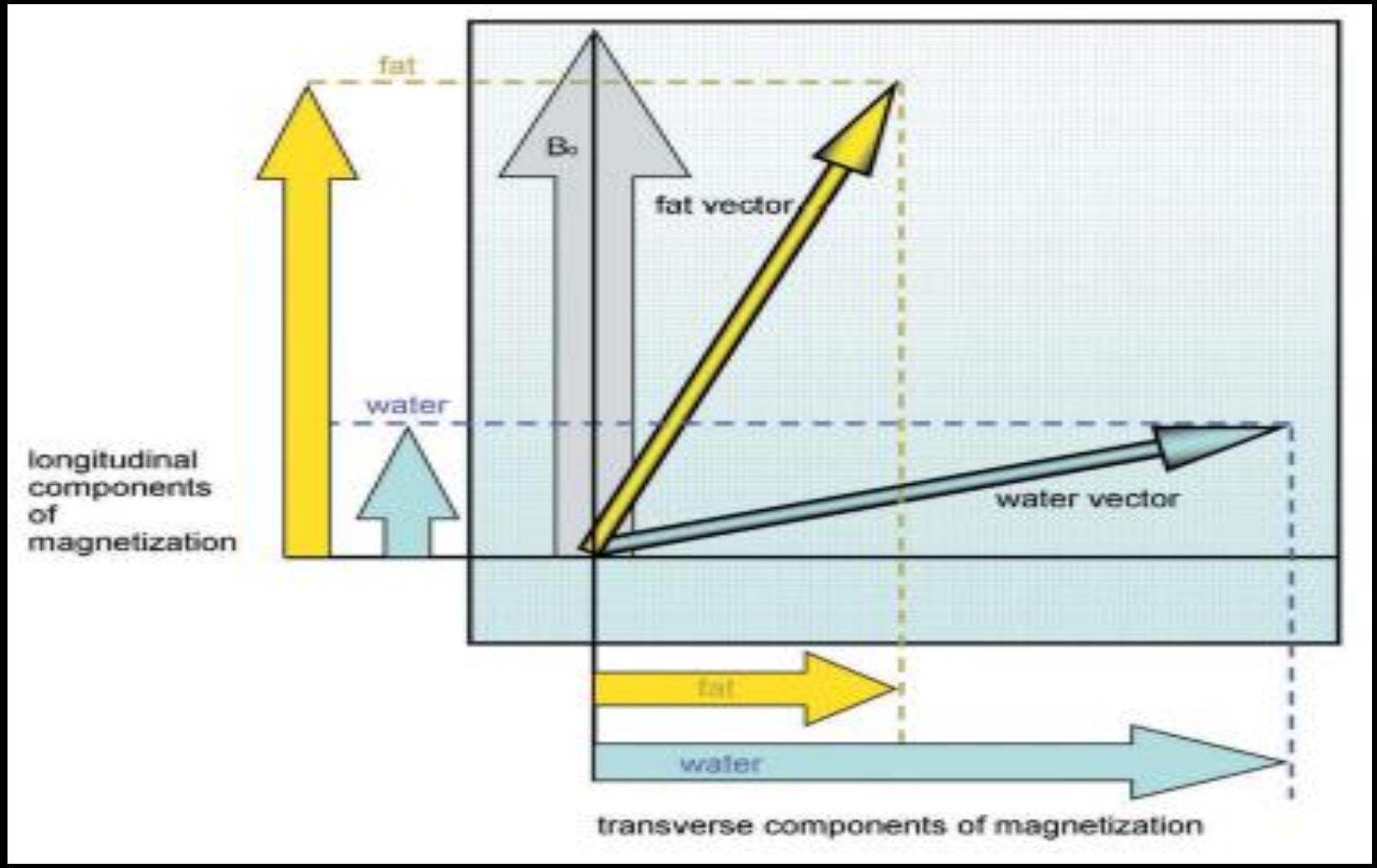
Water has a high inherent energy and cannot easily absorb energy into its lattice from hydrogen nuclei. In water, molecular mobility is high, resulting in less efficient T1 recovery The magnetic moments of water take longer to relax and regain their longitudinal magnetization.





The NMV of water takes longer to realign with B0 and so the T1 time of water is long

The magnitude of transverse magnetization vs amplitude of signal.

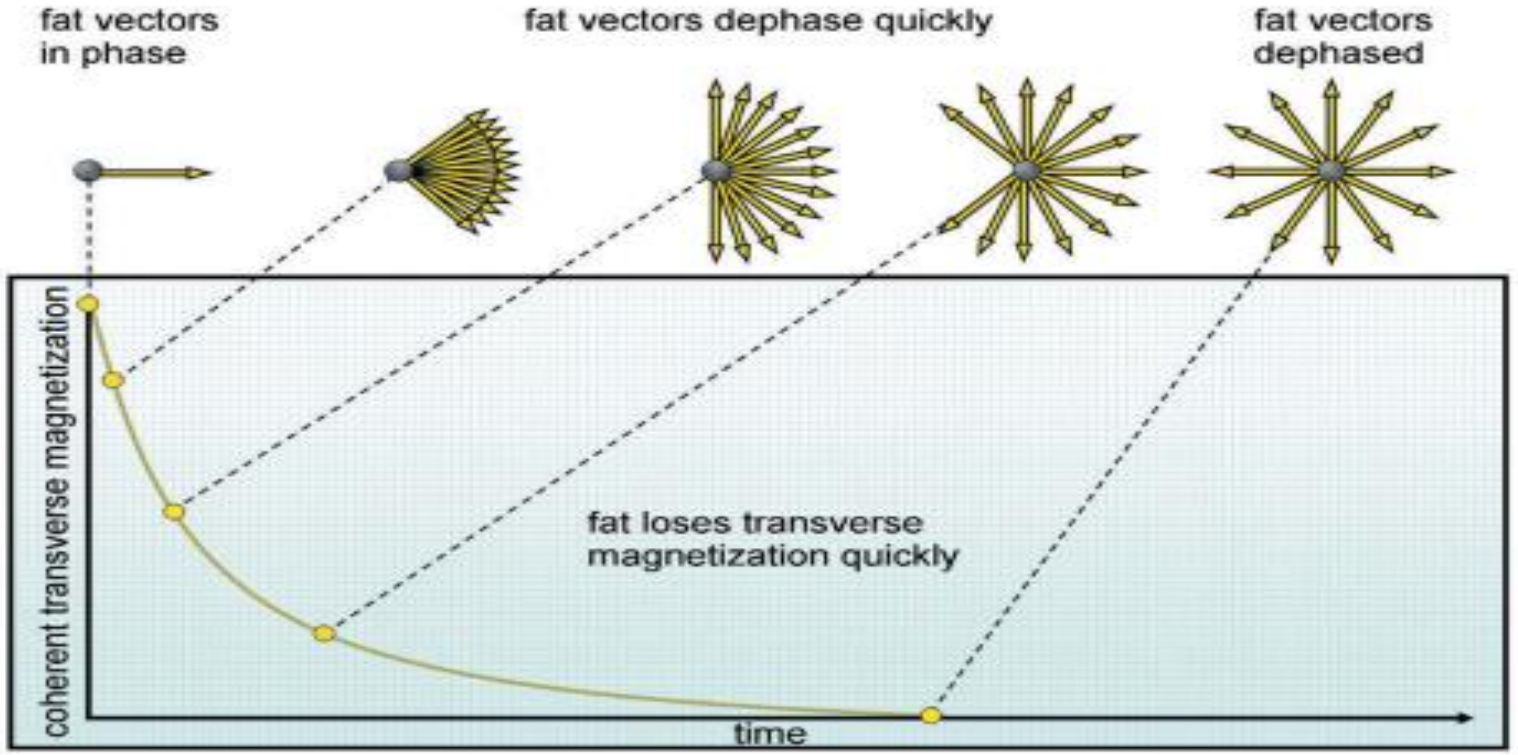


Relaxation in Different Tissues

T2 decay occurs as a result of the magnetic fields of the nuclei interacting with each other.

T2 decay in fat

This process is efficient in hydrogen in fat as the molecules are packed closely together and therefore spin - spin interactions are more likely to occur.



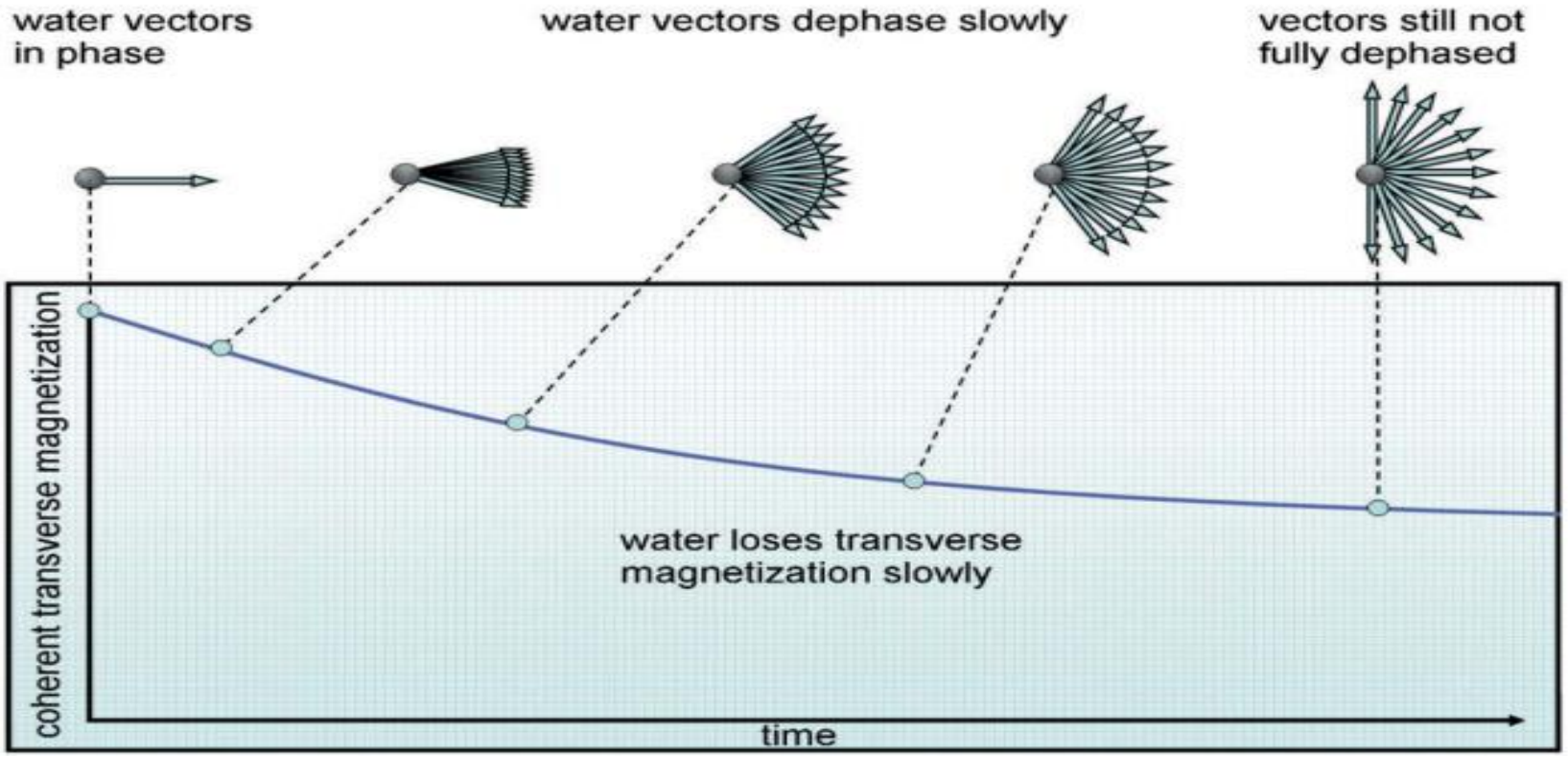
As a result spins dephase quickly and the loss of transverse magnetization is rapid. The T2 time of fat is therefore short

Relaxation in Different Tissues

T2 decay occurs as a result of the magnetic fields of the nuclei interacting with each other.

T2 decay in water

T2 decay in water is less efficient than in fat, as the molecules are spaced apart and spin–spin interactions are less likely to occur.



As a result, spins dephase slowly and the loss of transverse magnetization is gradual. The T2 time of water is therefore long

Typical T1 recovery times of brain tissue at 1 T

Tissue	T1 recovery time (ms)
Water	2500
Fat	200
CSF	2000
White matter	500

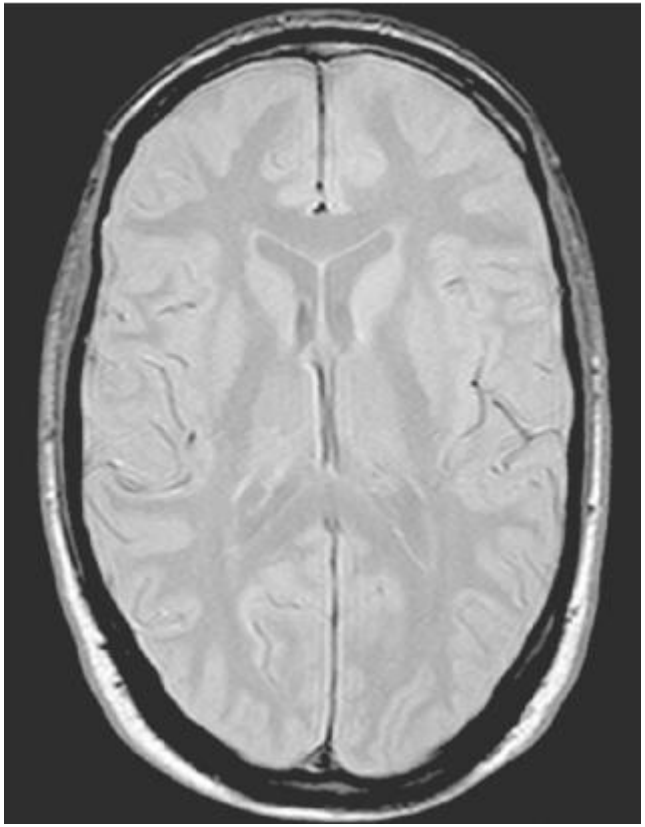
Typical T2 decay times of brain tissue at 1 T

Tissue	T2 decay time (ms)
Water	2500
Fat	100
CSF	300
White matter	100

Proton Density (PD)

A proton density image is one where the difference in the numbers of mobile hydrogen protons per unit volume in the patient is the main determining factor in forming image contrast

- Tissues with a high proton density (e.g. brain tissue) have a large transverse component of magnetization (and therefore a high signal)



Tissues with a low proton density (e.g. cortical bone) have a small transverse component of magnetization (and therefore a low signal) and are dark on a proton density contrast image

PD Weighting

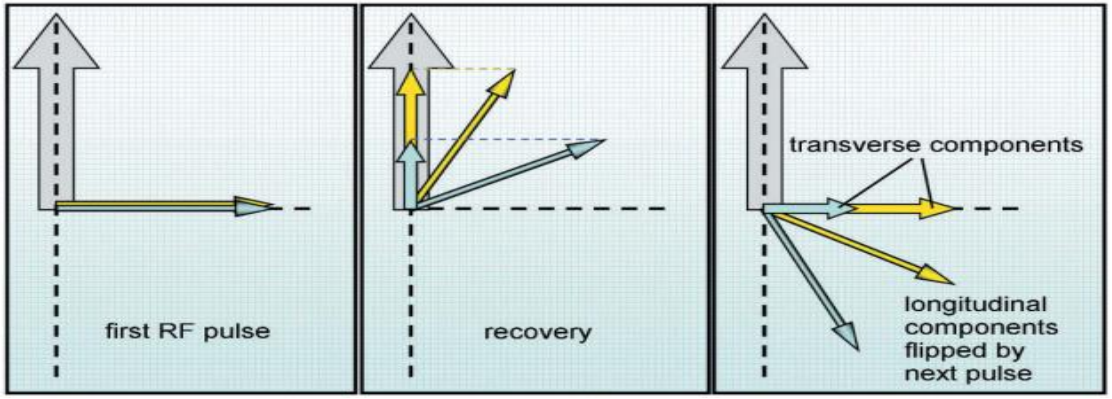
To Achieve Proton Density Weighting:

the effects of T1 and T2 contrast must be diminished so that proton density weighting can dominate.

- **A long TR** allows both fat and water to fully recover their longitudinal magnetization and so diminishes T1 weighti ng.
- **A short TE** does not give fat or water ti me to decay and so diminishes T2 weighting.

T1 Contrast

the next RF excitation pulse is applied. The RF excitation pulse flips the longitudinal components of magnetization of both fat and water into the transverse plane (assuming a 90 ° pulse is applied) as in



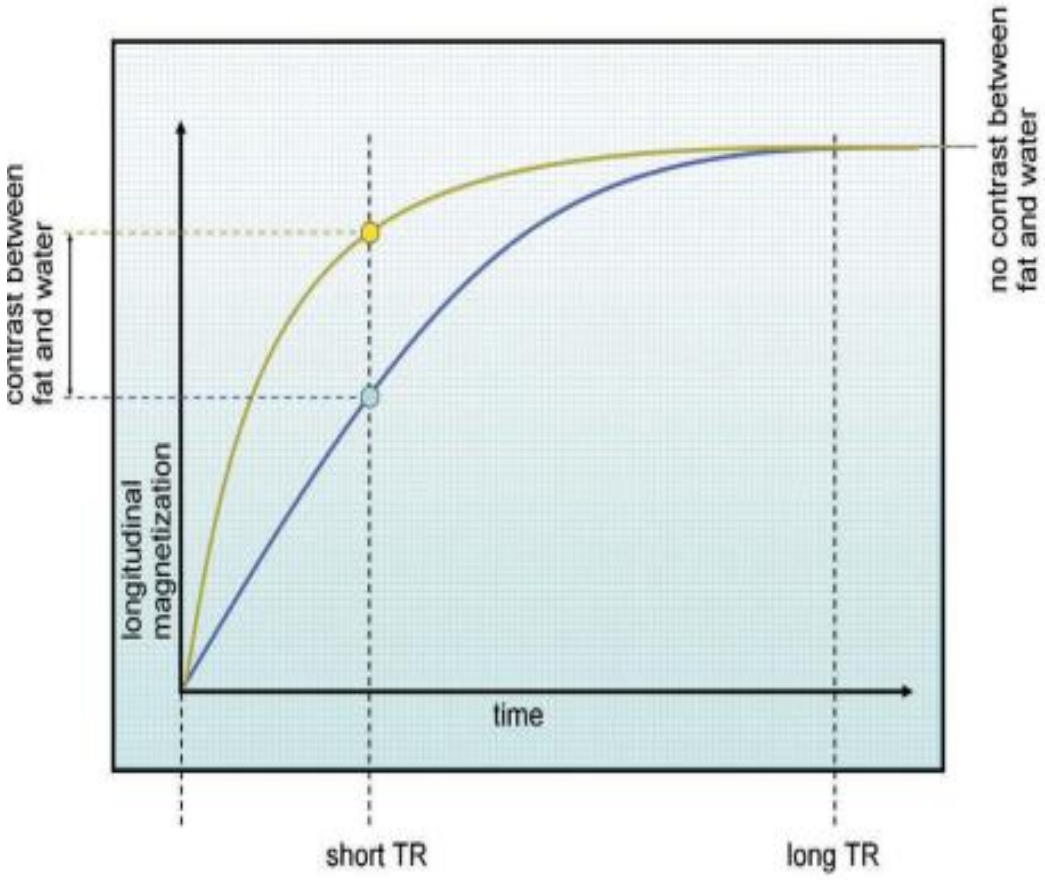
there is more transverse magnetization in fat after the RF pulse. Fat therefore has a high signal and appears bright on a T1 contrast image

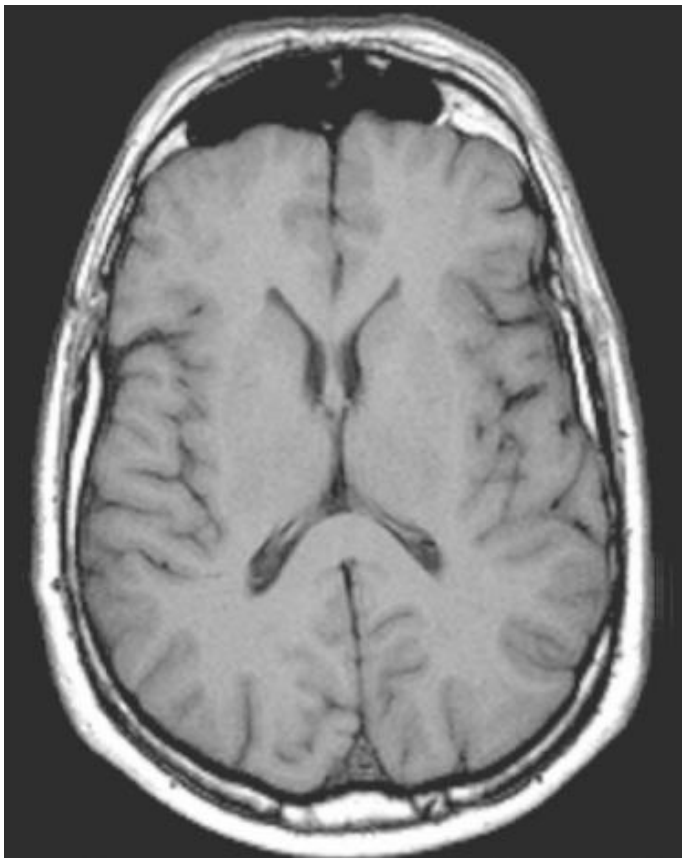
there is less transverse magnetization in water after the RF pulse. Water therefore has a low signal and appears dark on a T1 contrast image. Such images are called T1 weighted images

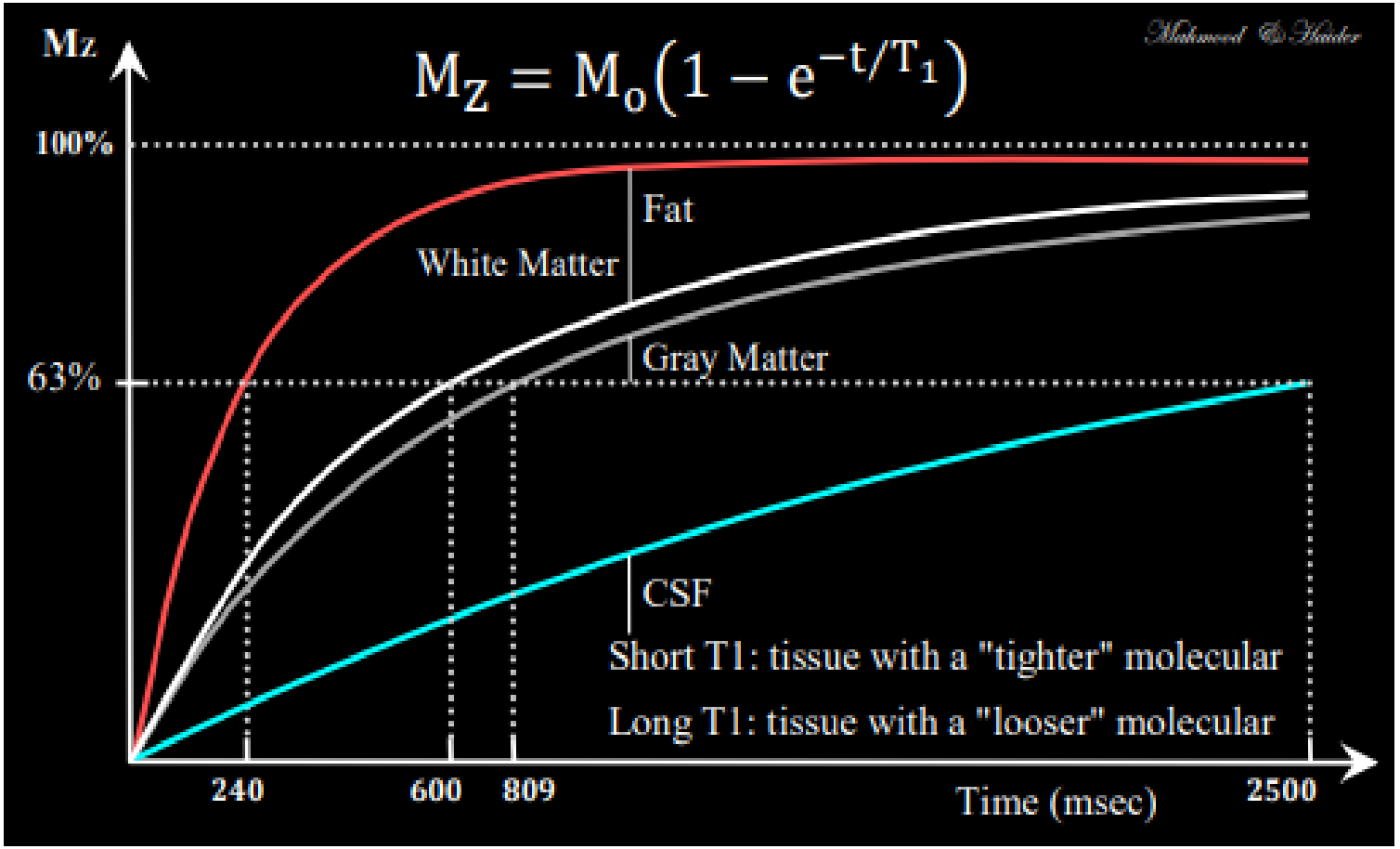
T1 Weighting

A T1 weighted image is one where the contrast depends predominantly on the differences in the T1 times between tissues

To Achieve T1 Weighting:
the TR must be short enough so that neither fat nor water has sufficient time to fully return to B0



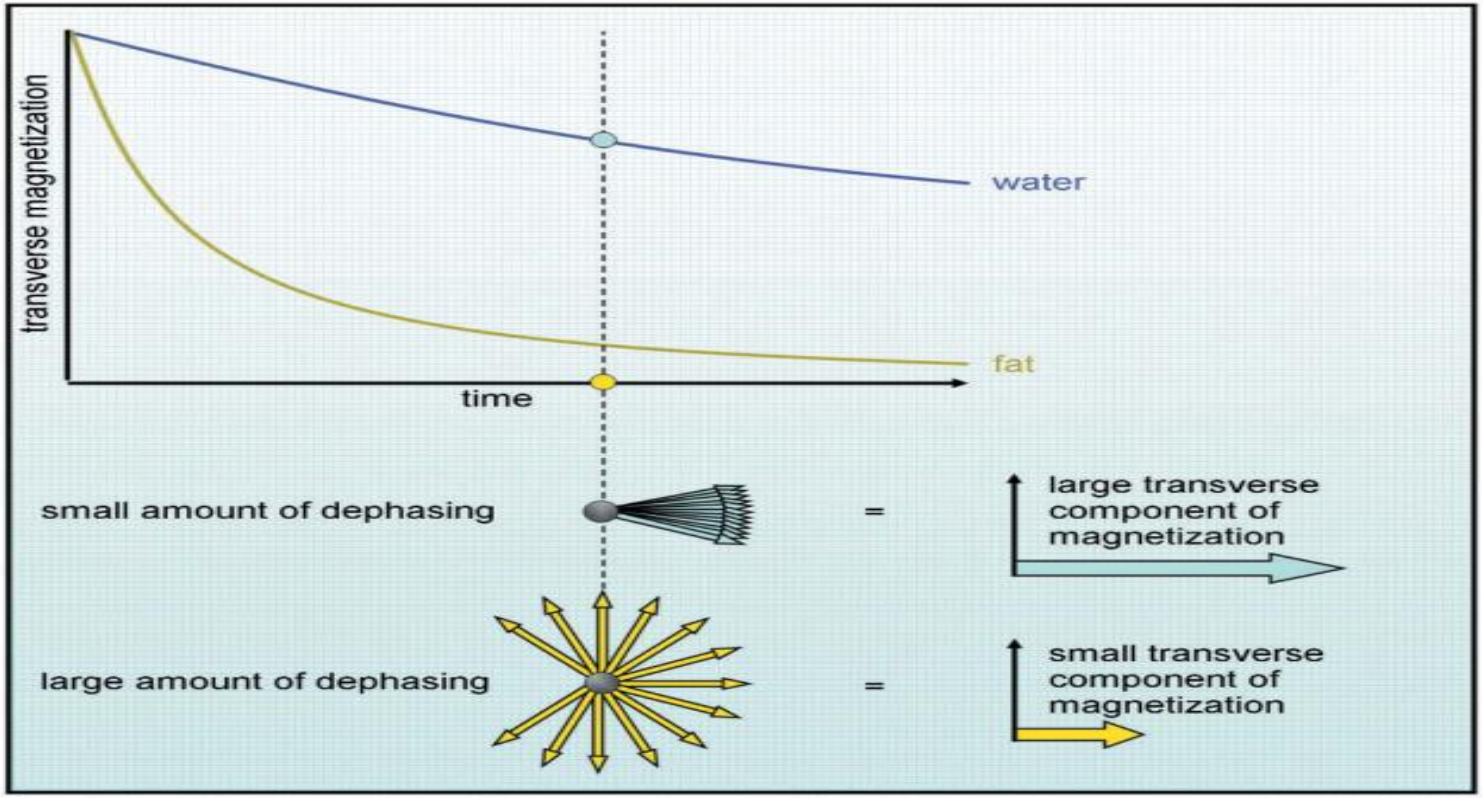



Mz
$M_Z = M_o(1 - e^{-t/T_1})$
100%
63%
Fat
White Matter
Gray Matter
CSF
Short T1: tissue with a "tighter" molecular
Long T1: tissue with a "looser" molecular
240
600
809
Time (msec)
2500

T2 Contrast

The T2 time of fat is shorter than that of water, so the transverse component of magnetization of fat decays faster.

However, the magnitude of transverse magnetization in fat is small. Fat therefore has a low signal and appears dark on a T2 contrast image

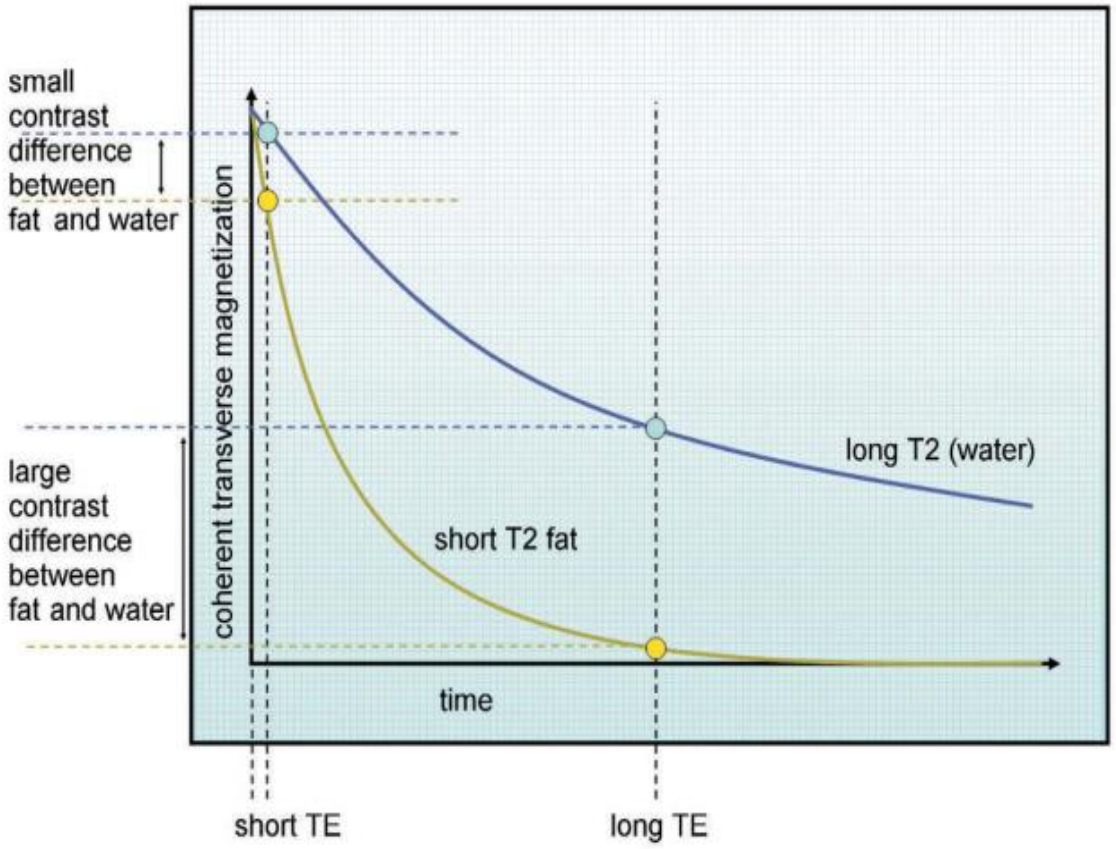


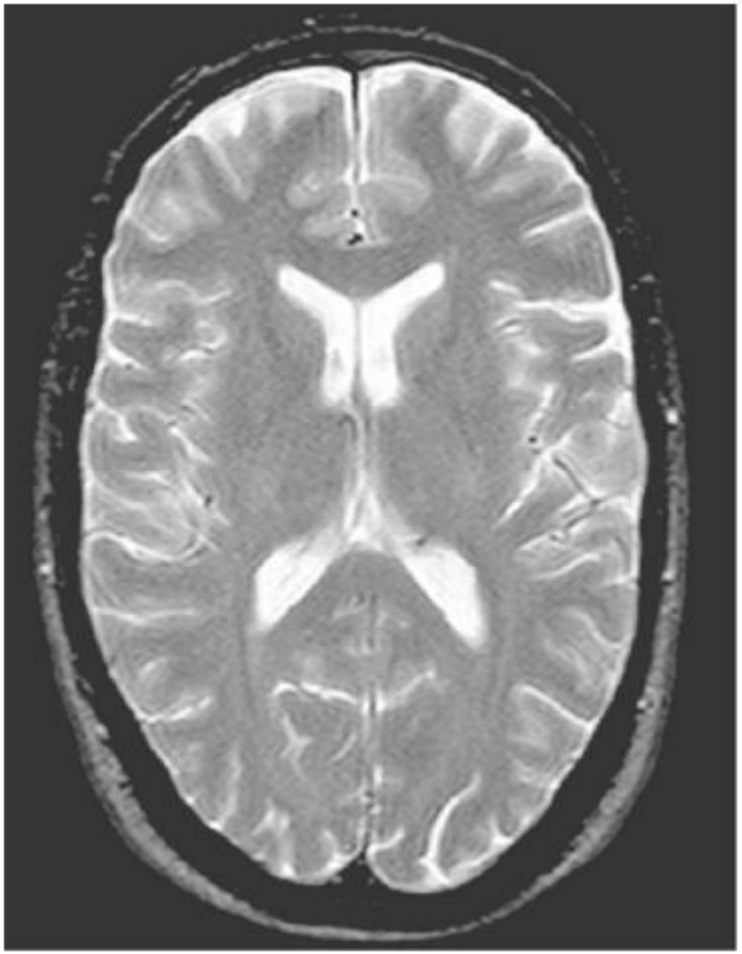
The magnitude of transverse magnetization in water is large. Water has a high signal and appears bright on a T2 contrast image.

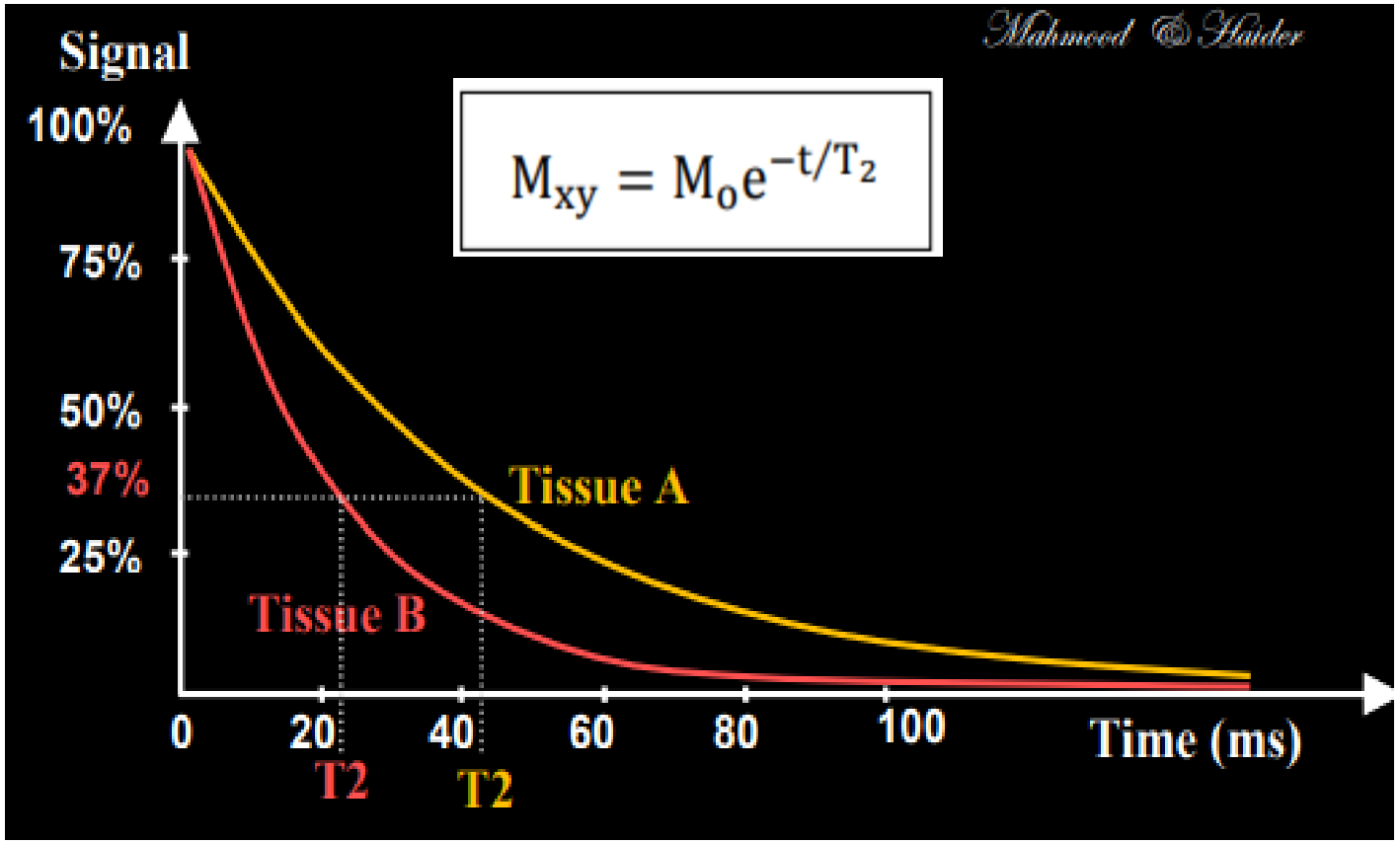
T2 Weighting

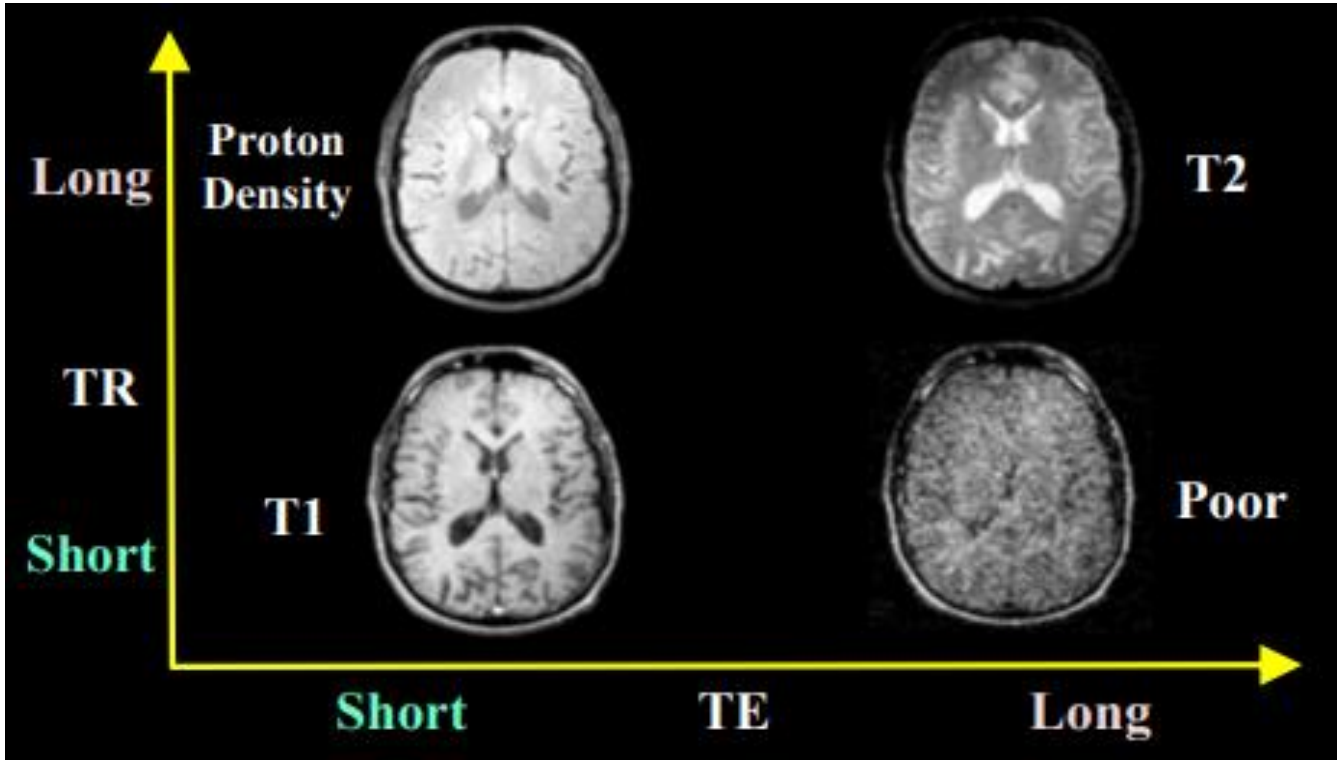
A T2 weighted image is one where the contrast predominantly depends on the differences in the T2 times between tissues.

To Achieve T2 Weighting:
the TE must be long enough to give both fat and water time to decay.






Mahmood & Haider
Signal
100%
75%
50%
37%
25%
$M_{xy} = M_o e^{-t/T_2}$
Tissue A
Tissue B
0
20
40
60
80
100
Time (ms)
T2
T2



Summarize of TR-TE combinations which also shows some brain images impressively demonstrating the effects of relaxation weighting on the contrast.