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M.SC. Theoretical Physics

Course Two

Lecture 12: Image Contrast: T1, T2, and Proton Density

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MR Signal

The MR signal depends on (i) proton density (PD), (ii) T1 and T2 (tissue properties), and (iii) TR and TE (machine properties).

In general, the MR signal (S) is given by the equation:

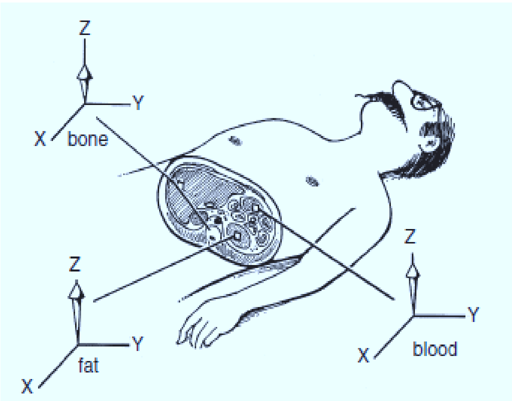
$$S \propto PD \{1-e^{-TR/T1}\} e^{-TE/T2}$$

- (PD) Proton Density
- T1 and T2 are relaxation times
- Repetition time (TR): is the time between successive RF pulses
- Echo time (TE): is the time at which the electrical signal induced by the spinning protons is measured

Proton Density

One of the parameters that affects the amplitude of the magnetic resonance (MR) signal is the number of hydrogen nuclei within the volume of the sample

- Voxels with high hydrogen concentration or proton density (PD) appear bright. This reasoning holds true only to a certain extent.

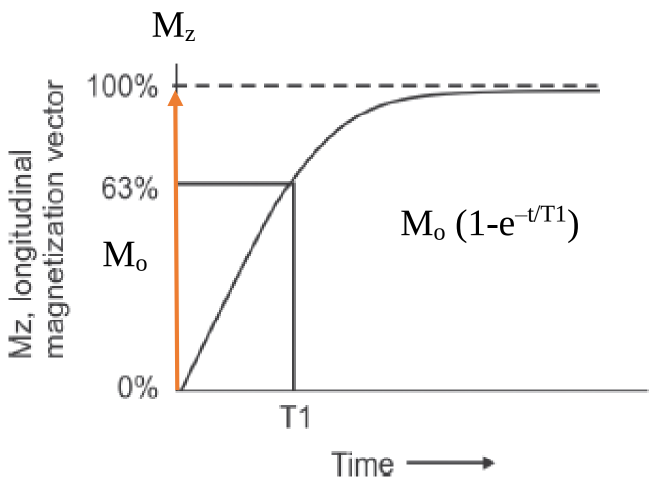


- These three voxels each have different PDs.

T1 Relaxation

Return of Mz to the equilibrium value Mo, require exchange of energy between spin and tissue lattice, which is called spin-lattice relaxation. It is an exponential event and measured by a time constant, T1.

The T1 is a time required to recover 63% of the longitudinal magnetization, M_Z



- The curve shows at time = 0 that there is no magnetization in the Z-direction right after the F-pulse. But immediately the MZ starts to recover along the Z-axis

The recovery of MZ versus time is given by the relation:

$$M_Z\,(t) = M_o\,(1\text{-}e^{-TR/T1})$$

Example: After TR=5T1

M_z=M_o(1−$e^{-5T1/T1}$)

=M_o(1−e^{-5})

=0.99 Mo or 99% Mo

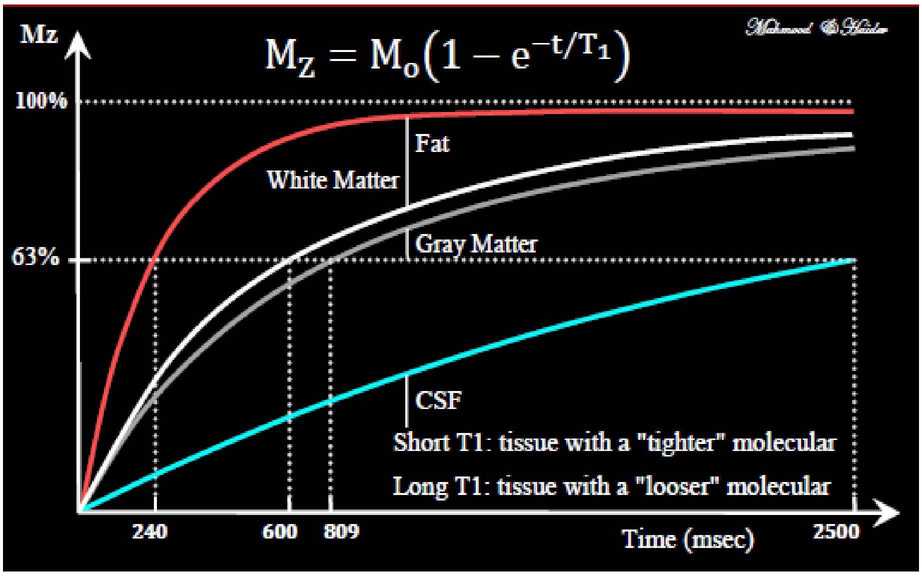
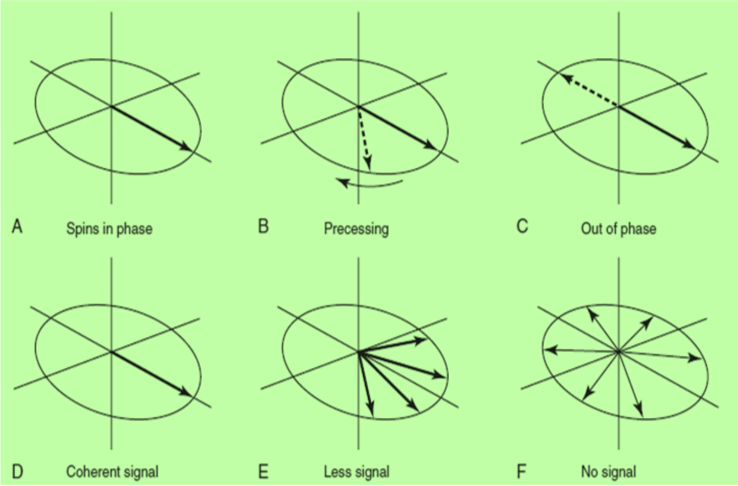
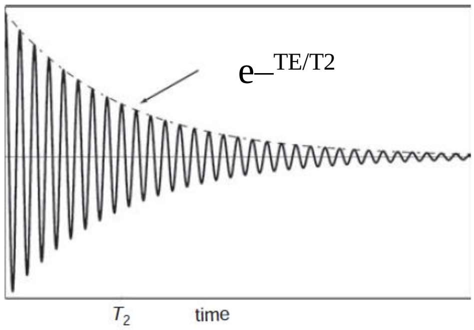


Figure above which illustrates four tissues found in the head. Each tissue will release energy (relax) at a different rate and that's why MRI has such good contrast resolution.

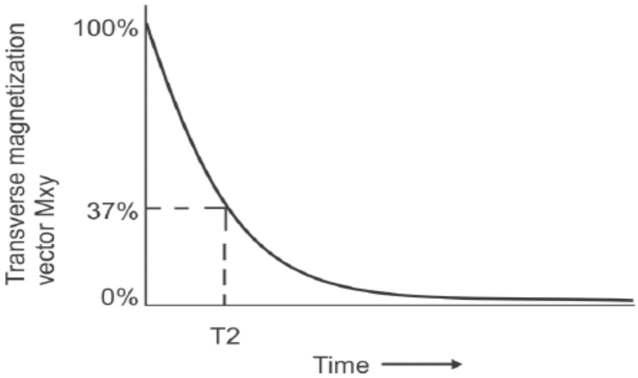
T2 Relaxation

Decay of transverse magnetization, Mxy, requires exchange of energy between spin and spin. Due to loss of phase coherence, some spins travel faster and some slower. This is called spin-spin relaxation, which is a exponential decay.





- It is measured by a time constant, T2. It is the time taken to reduce the transverse magnetization vector to 37% of the peak value



The transverse and equilibrium vector is given by the relation,

$$M_{XY}(t) = M_o e^{-t/T2},$$

- The rate of **de-phasing** is different for each tissue. Fat tissue will de-phase quickly, while water will de-phase much slower.
- T2: it happens much faster than T1 relaxation. T2 relaxation happens in tens of milliseconds, while T1 can take up to seconds

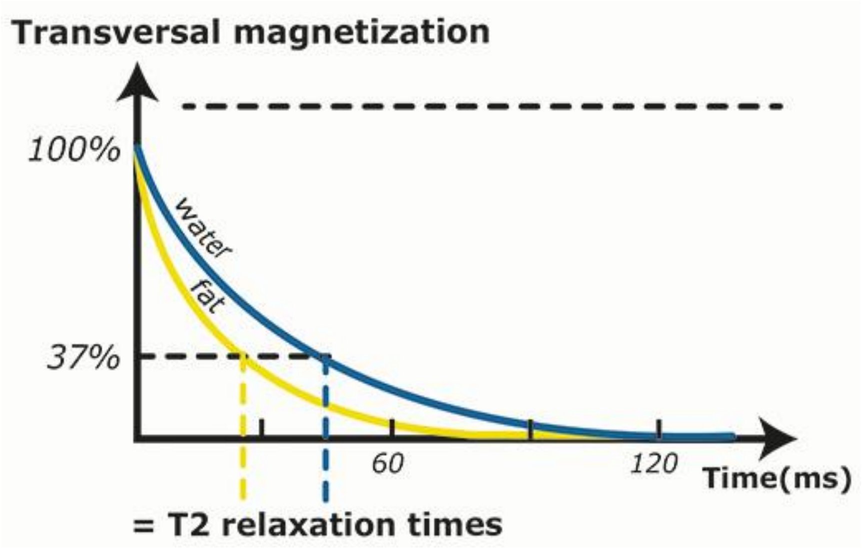


Image Contrast

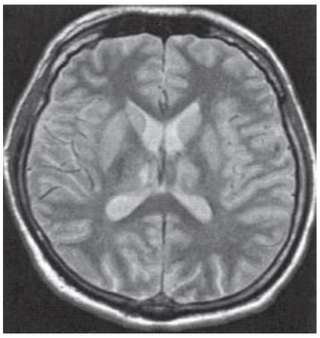
MR image consists of three tissue properties, namely, PD, T1, and T2. Whereas TE, TR are the machine parameters, that weigh the contrast in the image.

Brightness of the pixel depends on

1. Proton density
2. Recovery of Mz (length of T1, compared to TR)
3. Decay of Mxy, (length of T2, compared to TE)

PD Weighted Image

Spin density weighting mainly relies on differences in the number of protons per cc. Greater the spin density, larger the longitudinal magnetization (e.g. lipids, fats).

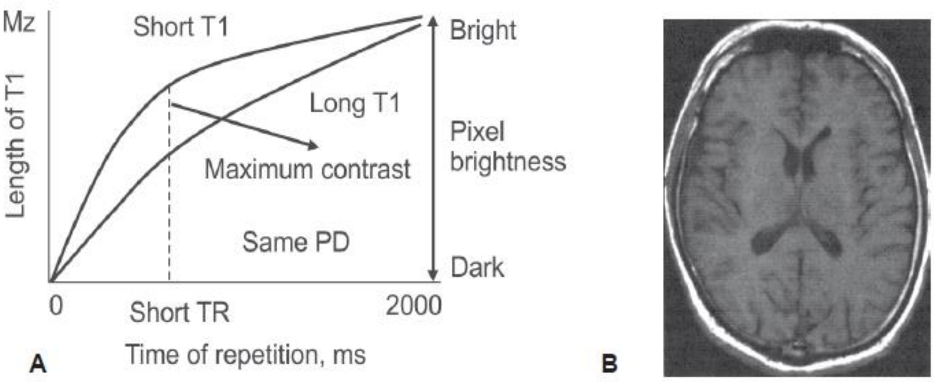


- Proton density weighted brain image with long TR = 2400 ms and short TE = 30 ms
- Higher the PD brighter the image, and hence CSF appears white, but white matter appears black.

T1 Weighted Image

T1 weighted image produce contrast based on T1 characteristics of tissues by de-emphasizing T2. It employs short TR, (300–800 ms) to maximize the contrast and short TE, (15 ms) to minimize T2 dependency.

The image contrast is due to recovery properties of T1 and shorter the T1, brighter the image.

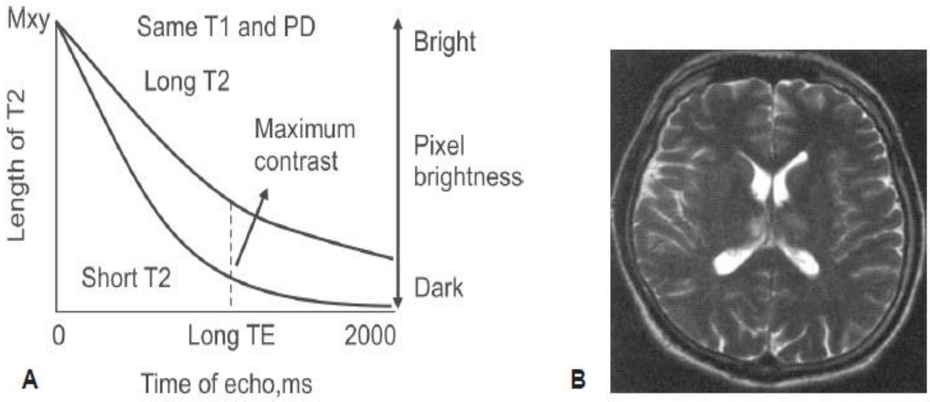


- In brain, cerebral tissues, fat, white matter, gray matter, and CSF are well distinguished in T1 weighted image (Fig.15.19).
- Fat is most inte.nse and appear as white, but CSF lowest signal and appear as black.

T2 Weighted Image

T2 weighted image produces contrast based on T2 characteristics of tissues, by de-emphasizing T1.

- It employs long TR (1000–2000 ms) to reduce T1 contrast and long TE (90–140 ms), to maximize T2 contrast.
- The image contrast is due to recovery properties of T2, and longer the T2, brighter the signal.



- Weighted image of brain, long TR = 2400 ms, and long TE= 90 ms
- In T2 weighted brain image, CSF is brighter than Fat see figure above.

Table 1: Approximate Values of Spin Density and Relaxation Times (Tl, T2) for Various Tissues

Tissue	SD	Tl (ms)	T2 (ms)
Water	100	2700	2700
Skeletal muscle	79	720	55
Cardiac muscle	80	725	60
Liver	71	290	50
Fat	-	360	30
Bone	<12	<100	<10
Spleen Kidney	79 81	570 505	50
Gray matter	84	4053/2	105
White matter	70	345	65