

Physics of Medical Imaging and Radiotherapy

Magnetic Resonance Imaging

Lecture 2; Section 1: Determination of spin-lattice relaxation time, T_1

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Section 1

Determination of the spin-lattice relaxation time, T_1

What does it take to make an MRI image

NMR can be used to generate signals that depend on the concentration of ^1H in tissue; the basis of an imaging technique

The spin-lattice and spin-spin relaxation times, T_1 and T_2 respectively, depend on tissue type—so can be used to distinguish neighbouring tissues

To generate an image need to:

- Extract T_1 and T_2 ; and
- Spatially localise the signal

Relaxation times revisited

Tissue Type	T1 (ms)	T2 (ms)
Adipose tissues	240-250	60-80
Whole blood (deoxygenated)	1350	50
Whole blood (oxygenated)	1350	200
Cerebrospinal fluid (similar to pure water)	4200 - 4500	2100-2300
Gray matter of cerebrum	920	100
White matter of cerebrum	780	90
Liver	490	40
Kidneys	650	60-75
Muscles	860-900	50

Relaxation times characteristic of tissue type

For materials important for human imaging
 $T_1 > T_2$

T_1 characteristic of recovery of longitudinal magnetisation

T_2 must be extracted from the decay of the transverse magnetisation which is characterised by T_2^* which is related to T_2 by:

$$\frac{1}{T_2^*} = \frac{1}{T_2} + \frac{1}{T_2'}$$

Free induction decay revisited

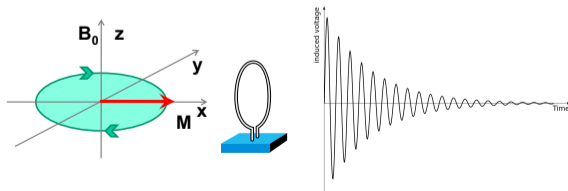
System set up in equilibrium; net magnetisation, \mathbf{M}_0 , parallel to \mathbf{B}_0 and of magnitude M_0

90° RF magnetic field pulse applied to rotate net magnetisation, \mathbf{M}_0 , into x, y plane

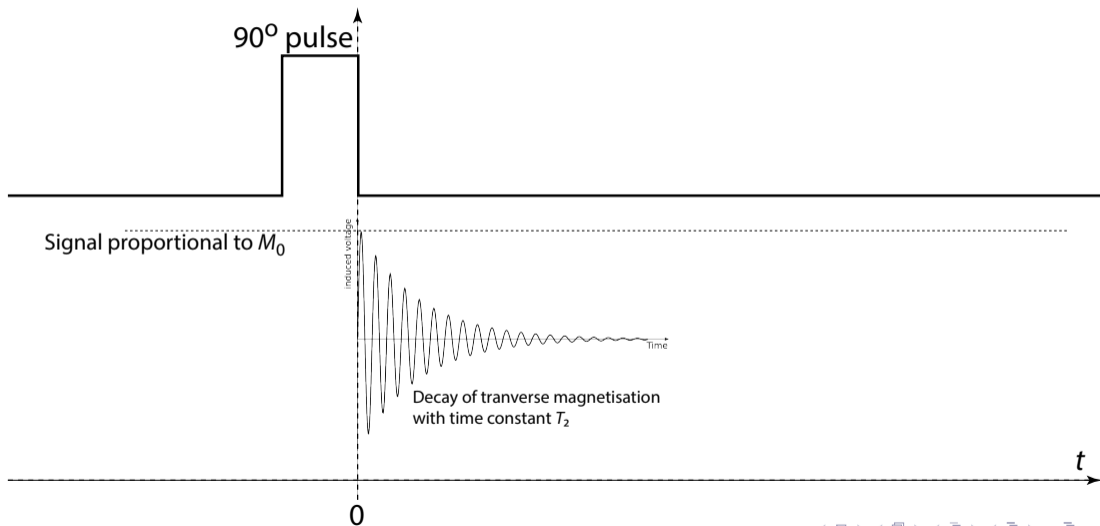
Take $t = 0$ to be time at which 90° degree pulse ends. Magnitude of transverse magnetisation, M_{xy} , at $t = 0$:

$$M_{xy}(t = 0) = M_{xy}(0) = M_0$$

M_{xy} decays exponentially, as described in lecture 8



Application of 90° pulse and spin-spin relaxation time, T_2



Recovery of longitudinal polarisation and spin-lattice relaxation time, T_1

Longitudinal magnetisation recovers according to:

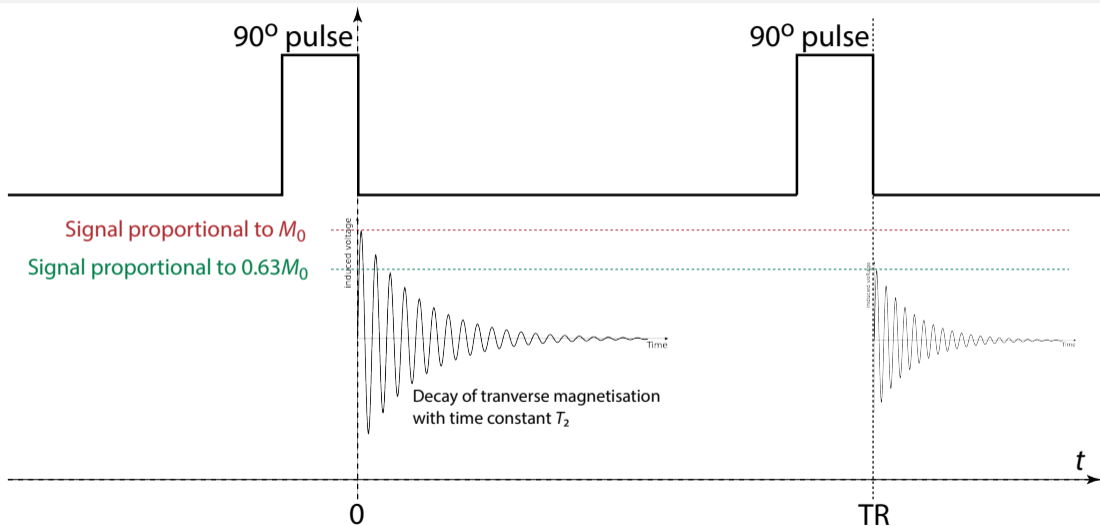
$$M_z(t) = M_0 \left[1 - \exp\left(-\frac{t}{T_1}\right) \right]$$

So, for $t \gtrsim 5T_1$, $M_z - M_0 \lesssim 0.5\%$, i.e. longitudinal magnetisation has recovered

If a second 90° pulse is applied for $t < 5T_1$ then the resulting M_{xy} will be less than M_0

For example, if the second 90° pulse is applied at $t = T_1$, then $M_{xy}(t = T_1) = 0.63M_0$

Application of multiple 90° pulses



The time to repetition, TR, and extraction of T_1

Longitudinal magnetisation recovers according to:

$$M_z(t) = M_0 \left[1 - \exp\left(-\frac{t}{T_1}\right) \right]$$

So, for $t \gtrsim 5T_1$, $M_z - M_0 \lesssim 0.3\%$, i.e. longitudinal magnetisation has recovered

If a second 90° pulse is applied for $t < 5T_1$ then the resulting M_{xy} will be less than M_0

In general:

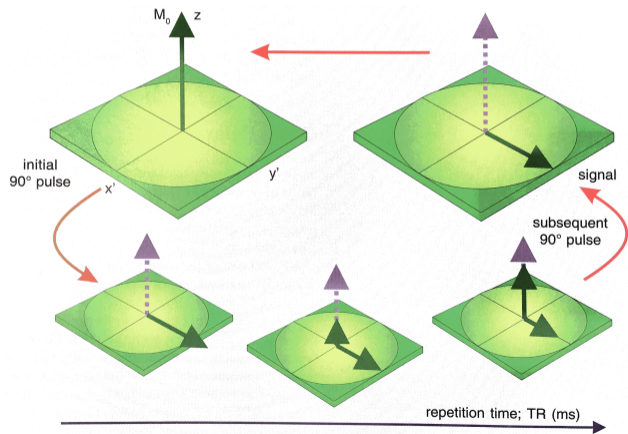
$$M_z(\text{TR}) = M_0 \left[1 - \exp\left(-\frac{\text{TR}}{T_1}\right) \right]$$

So, repetition of 90° pulse at $t = \text{TR}$ gives $M_{xy}(\text{TR}) = M_z(\text{TR})$

Can extract T_1 by measuring $M_{xy}(\text{TR})$ as a function of TR

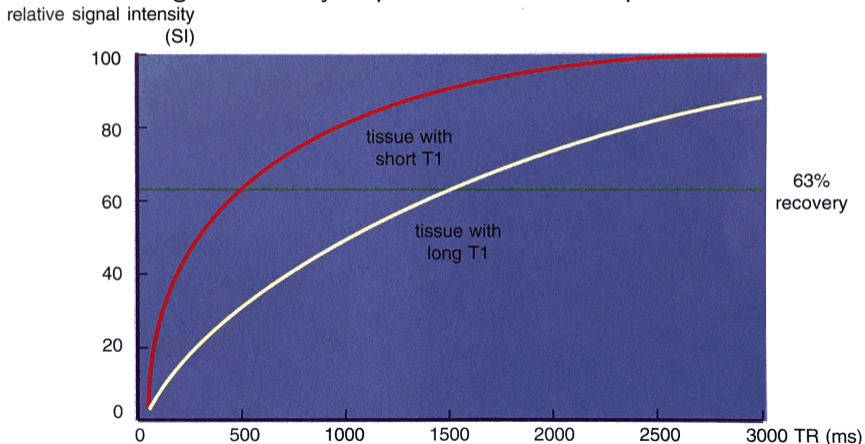
Partial saturation pulse sequence

“Partial saturation pulse sequence”, graphical representation of evolution of magnetisation

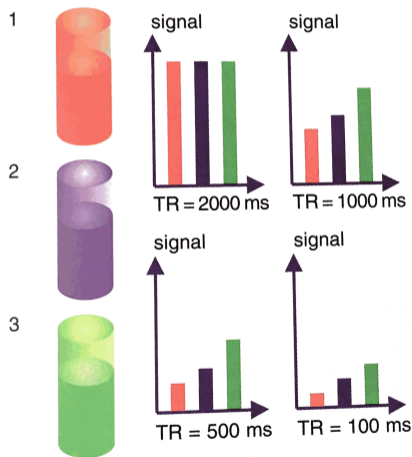


Extraction of spin-lattice relaxation time constant, T_1

Comparison of relative signal intensity in partial saturation sequence for two different tissues



Using TR to distinguish between different tissues



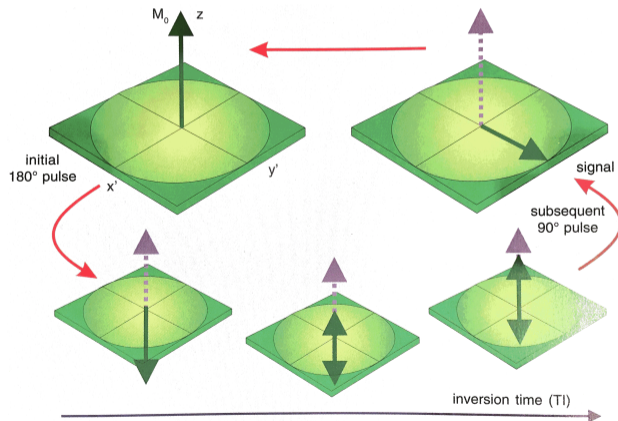
Example three types of tissue:

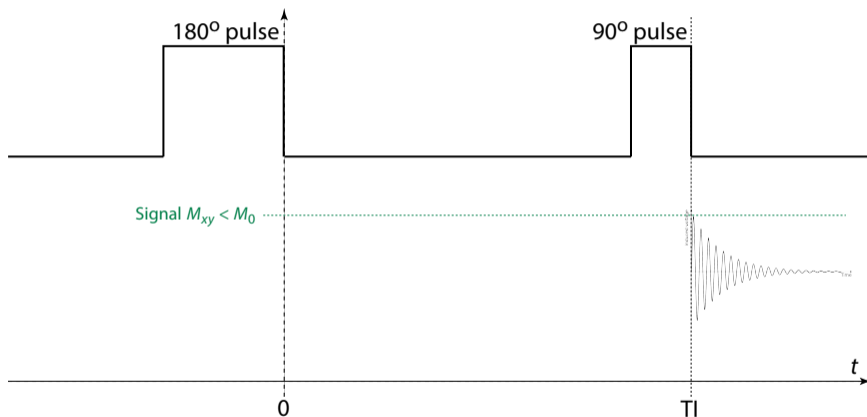
- 1 Blood: $T_1 = 1350$ ms
- 2 Muscle: $T_1 = 875$ ms
- 3 Fat: $T_1 = 230$ ms

Note how tissues can be distinguished by comparing signal behaviour as a function of TR

Inversion recovery pulse sequence and time to inversion, T_1

“Inversion recovery pulse sequence”, graphical representation of evolution of magnetisation



Inversion recovery: using TI to extract T_1 

$$M_z(TI) = M_0 \left[1 - 2 \exp\left(-\frac{TI}{T_1}\right) \right]$$

Summary of section 1

T_1 , the longitudinal or spin-lattice, relaxation time constant can be reconstructed using pulse sequences in which the net magnetisation is repeatedly rotated into the x, y plane and the evolution of the maximum of the transverse magnetisation is observed

Pulse sequences used to obtain T_1 :

- 90° pulse sequence
- Inversion recovery pulse sequence