Centre for the Clinical Application of Particles

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Nuclear diagnostics and Magnetic Resonance Imaging

Week 5; Lecture 11; Magnetic resonance imaging: contrast

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Section 1

Spin-echo sequence for proton-density weighted image

Generation of an MRI image

Tissue specificity in MRI is generated principally by three physical quantities:

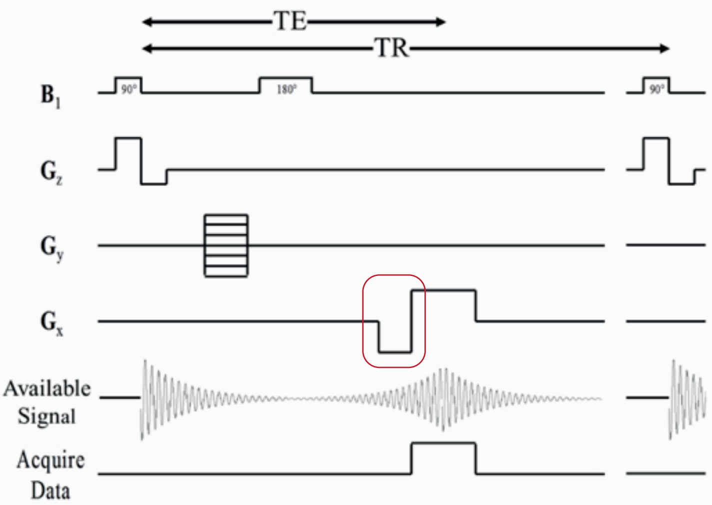
- The net magnetisation at equilibrium, $M_{\rm eqm}$:
  - This is a measure of "proton density";
  - Often referred to as proton density and $M_{\rm eqm}$ expressed as the fraction its value for water
- T_1: the spin-lattice relaxation time constant; and
- T_2: the spin-spin relaxation time constant

In a spin-echo sequence the time to repetition, TR, and the time to echo, TE, are adjusted to enhance the sensitivity of the signal amplitude to these three basic characteristics

The instantaneous signal intensity is proportional to the instantaneous magnitude of the magnetisation transverse to $\mathbf{B}_0$

This statement is **important** to get to grips with the generation of contrast in MRI

Pulse sequence; reminder



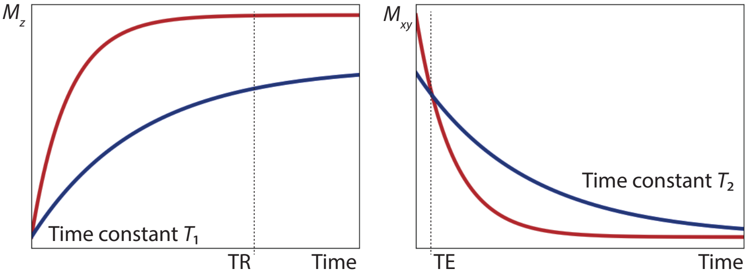
Note presence of "pre-winding pulse" circled in red

- Phase-encoding pulse causes phase to be position dependent
- Incoherence induces causes a loss of signal, so
- "Negative" gradient pulse applied in frequency encoding direction to "pre-wind" spins and cause an echo re-enforcing the signal at readout

Values of the basic parameters for a variety of tissues

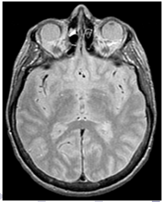
Tissue	Proton density	1.5 T T_1 ms	1.5 T T_2 ms	3 T T_1 ms	3 T T_2 ms
Cartilage	0.94	1024	42	1168	37
Skeletal muscle	0.95	1084	37	1416	41
Blood	0.97	1441	308	1932	275
Fat	0.94	343	160	380	130
CSF	1.00	4550	60	4550	30
Brain matter (white)	0.99	688	81	833	68
Brain matter (grey)	1.00	1195	97	1436	93

Proton-density weighted image



$B_0 = 3\,\mathrm{T}$; set $\mathrm{TR} = 2500\,\mathrm{ms}$ and $\mathrm{TE} = 10\,\mathrm{ms}$

	T_1 (ms)	$\frac{\mathrm{TR}}{T_1}$	T_2 (ms)	$\frac{\mathrm{TE}}{T_2}$	Relative brightness
Blood	1932	1.29	275	0.04	Medium
CSF	4550	0.55	30	0.33	Low
White matter	833	3.00	68	0.15	High
Grey matter	1436	1.74	83	0.12	Medium



Proton-density weighted image

Tissue	Proton density	1.5 T		3 T	
		T_1 ms	T_2 ms	T_1 ms	T_2 ms
Cartilage	0.94	1024	42	1168	37
Skeletal muscle	0.95	1084	37	1416	41
Blood	0.97	1441	308	1932	275
Fat	0.94	343	160	380	130
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Brain matter (white)	0.99	688	81	833	68
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Proton-density weighted image:

- TR long: long enough that $M_{\rm eqm}$ is restored between repetitions
- TE short: such that effects of different $T2$ are not allowed to evolve

Such images have strong signal from all tissues, but relatively low contrast between them

Summary of section 1

Proton-density weighted image:

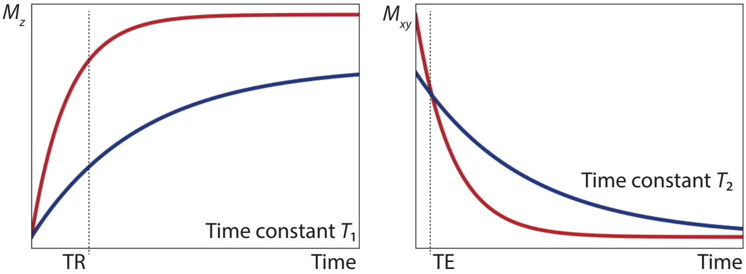
- TR long
- TE short

Strong signal from all tissues, relatively low contrast compared to other sequences

Section 2

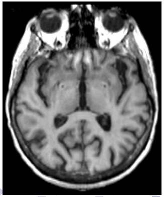
Spin-echo sequence for T_1-weighted image

T_1 weighted image



$B_0 = 3\,\text{T}$; set $\mathrm{TR} = 500\,\text{ms}$ and $\mathrm{TE} = 10\,\text{ms}$

	T_1 (ms)	$\frac{\mathrm{TR}}{T_1}$	T_2 (ms)	$\frac{\mathrm{TE}}{T_2}$	Relative brightness
Blood	1932	0.25	275	0.04	Low/Medium
CSF	4550	0.11	30	0.33	Low
White matter	833	0.60	68	0.15	High
Grey matter	1436	0.35	83	0.12	Medium/Low



T_1 weighted image

Tissue	Proton density	1.5 T		3 T	
		T_1 ms	T_2 ms	T_1 ms	T_2 ms
Cartilage	0.94	1024	42	1168	37
Skeletal muscle	0.95	1084	37	1416	41
Blood	0.97	1441	308	1932	275
Fat	0.94	343	160	380	130
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T_1 weighted image enhancing signal from e.g. fat, white mater:

- TR short: such that M_{eqm} can only recover fully between repetitions in tissues with low T_1
- TE short: enough that the effects of different $T2$ are not allowed to evolve

Tissues such as fat appear bright in such images

Summary of section 2

T_1 weighted image:

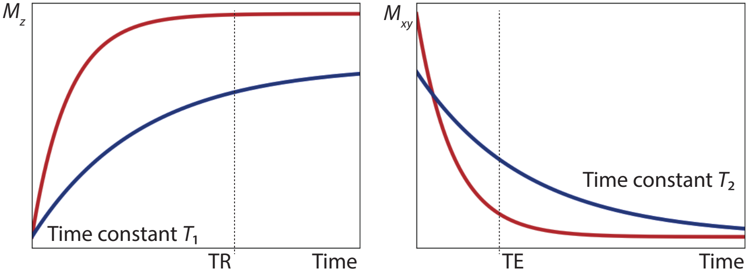
- TR short
- TE short

Tissues such as fat appear bright in such images

Section 3

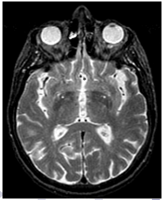
Spin-echo sequence for T_2-weighted image

T_2-weighted image



$B_0 = 3\,\mathrm{T}$; set $\mathrm{TR} = 2500\,\mathrm{ms}$ and $\mathrm{TE} = 100\,\mathrm{ms}$

	T_1 (ms)	$\frac{\mathrm{TR}}{T_1}$	T_2 (ms)	$\frac{\mathrm{TE}}{T_2}$	Relative brightness
Blood	1932	1.29	275	0.4	Medium
CSF	4550	0.55	30	3.3	High
White matter	833	3.00	68	1.5	Low
Grey matter	1436	1.74	83	1.2	Medium/Low



T_2-weighted image

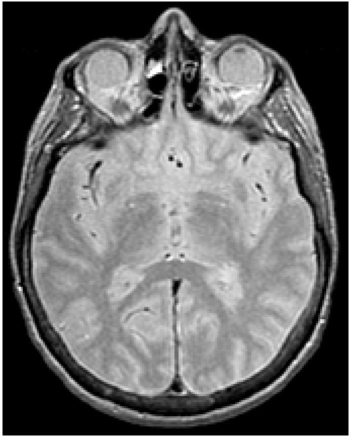
Tissue	Proton density	1.5 T		3 T	
		T_1 ms	T_2 ms	T_1 ms	T_2 ms
Cartilage	0.94	1024	42	1168	37
Skeletal muscle	0.95	1084	37	1416	41
Blood	0.97	1441	308	1932	275
Fat	0.94	343	160	380	130
CSF	1.00	4550	60	4550	30
Brain matter (white)	0.99	688	81	833	68
Brain matter (grey)	1.00	1195	97	1436	93

T_2 weighted image enhancing signal from e.g. blood:

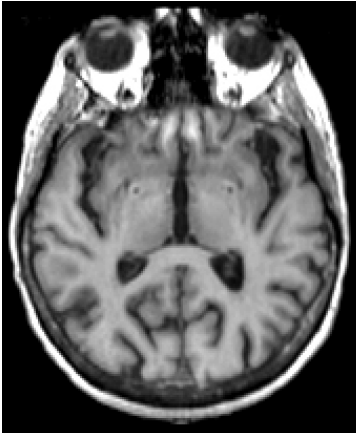
- TR long: long enough that M_{eqm} is restored between repetitions
- TE long: enough that the decay rates determined by $T2$ **are** allowed to evolve

“Tissues” such as blood appear bright in such images

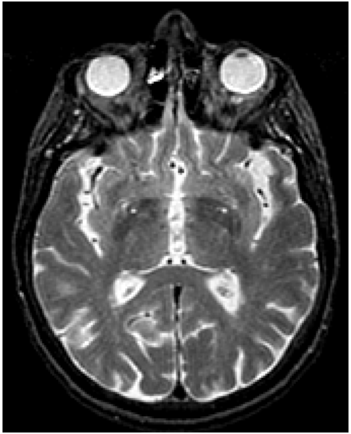
Comparison of T_1, T_2, and proton-density weighting



Proton-density weighted



T_1 weighted



T_2 weighted

Summary of section 3

T_2 weighted image:

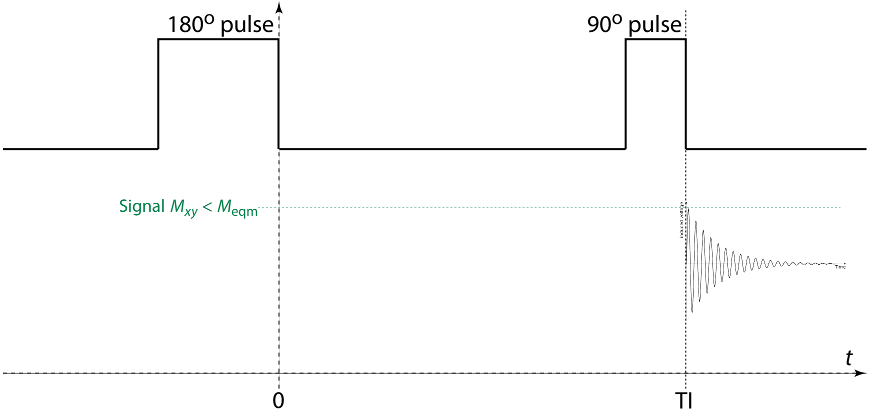
- TR long
- TE long

Tissues such as blood appear bright in such images

Section 4

Inversion recovery

Inversion recovery pulse sequence; reminder

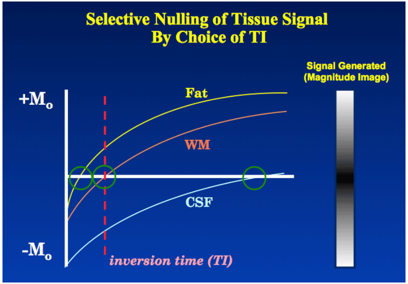


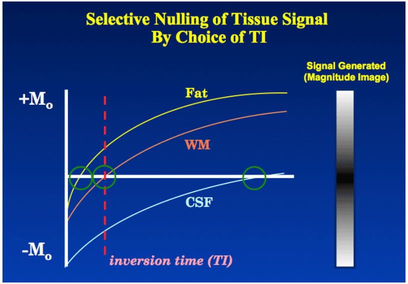
$$M_z(\mathrm{TI}) = M_{\mathrm{eqm}}\left[1 - 2\exp\left(-\frac{\mathrm{TI}}{T_1}\right)\right]$$

Advantages of inversion recovery

Inversion recovery provides contrast in three ways:

1. Suppress ("null") the signal from particular tissues
2. Enhanced T_1 contrast
3. Additive (rather than competitive) T_1 and T_2 effects





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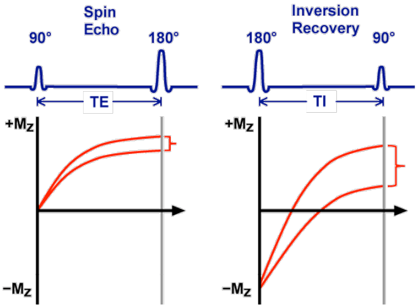

$$M_z(\mathrm{TI}) = M_{\mathrm{eqm}}\left[1 - 2\exp\left(-\frac{\mathrm{TI}}{T_1}\right)\right]$$

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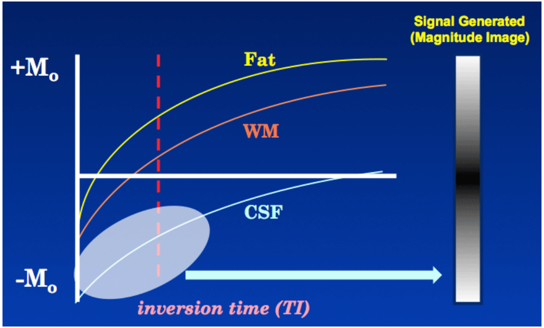
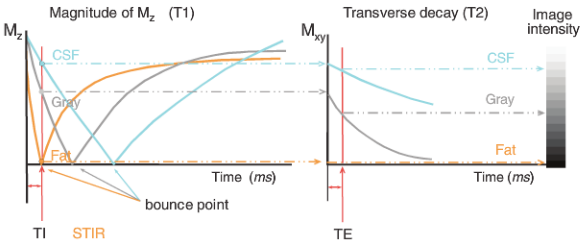


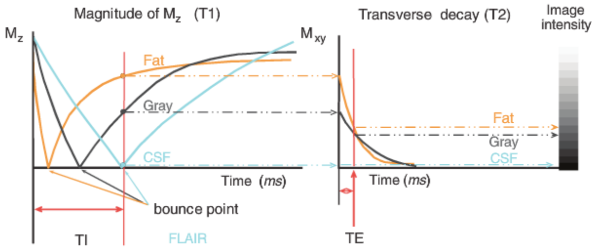
When TI is less than the "null point", the net magnetisation is the magnetisation of the tissues with long T_1 will remain inverted and enhance the transverse magnetisation the decay of which is characterised by T_2

Inversion recovery image

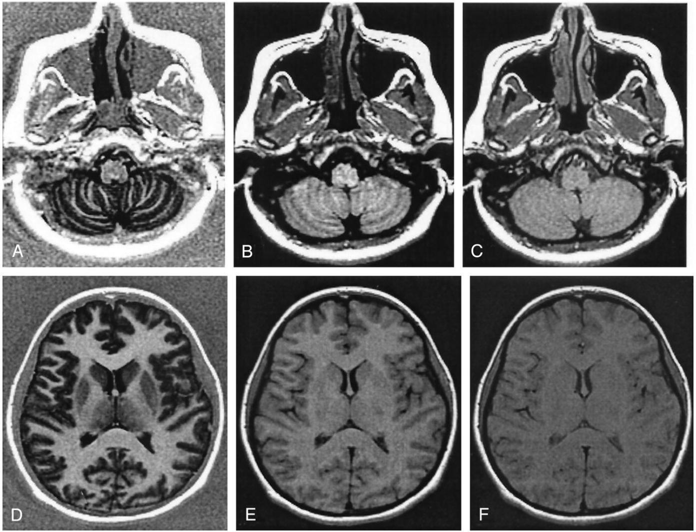


Short TI inversion recovery

Fluid attenuated inversion recovery



Inversion recovery image of brain



Summary of section 4

Inversion-recovery image allows:

- Signal from selected tissues to be suppressed
- T_1 contrast to be enhanced
- Contrast from T_1 and T_2 differences to be used in combination