Outline for Today

MR Contrast Mechanisms and pulse sequences

- Proton density (PD) contrast
- T_1 contrast
- T_2 contrast
- T_2^* contrast

Functional Magnetic Resonance Imaging, Huettel, Chapter 5

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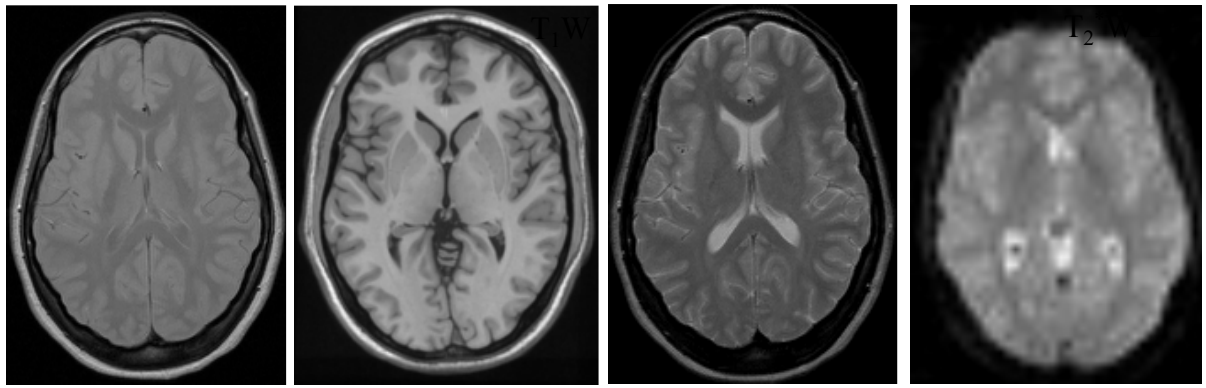
MRI Review

- based on the NMR phenomenon
- large magnetic field and radio waves
- image water distribution
- can select contrast weighting based on water content (PD) or relaxation mechanisms (T_1, T_2, T_2*)



MR Contrast Mechanisms

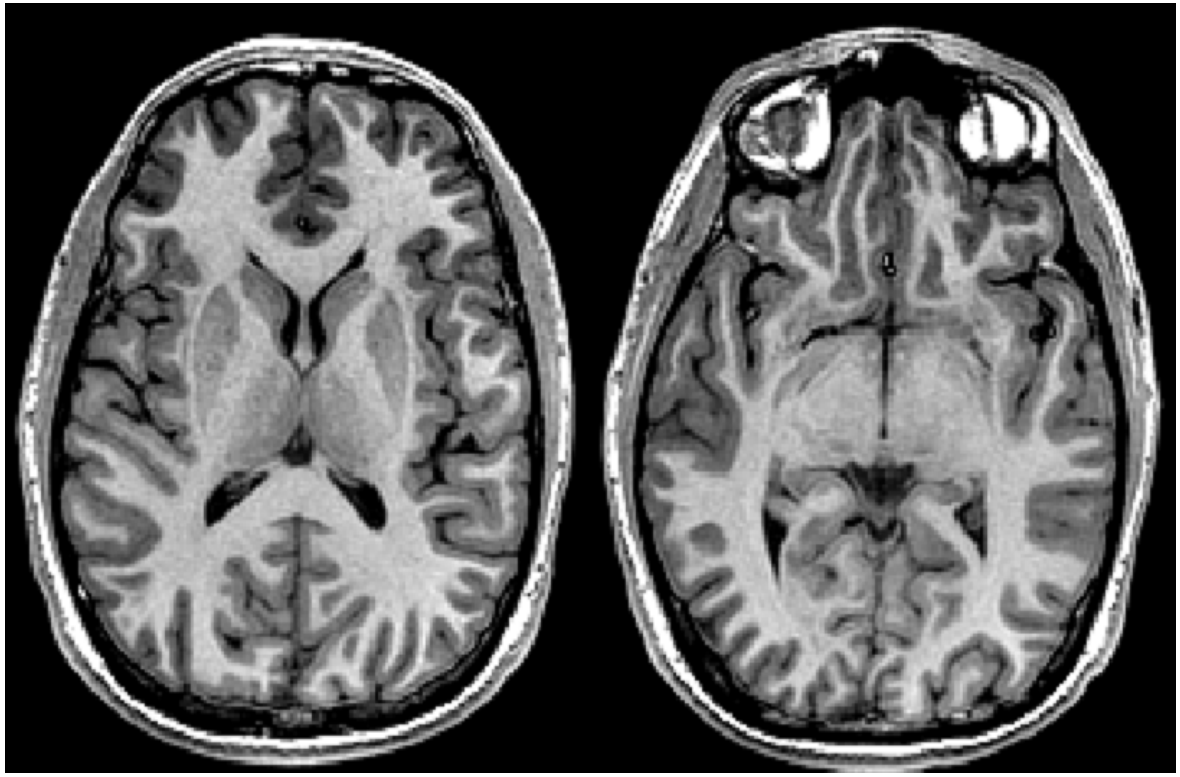
- Static Contrast
  - Sensitive to type, number and relaxation (e.g., T_1 and T_2) of spins
- Motion Contrast
  - Sensitive to movement of spins in space
  - E.g., Dephasing, Diffusion, Perfusion
- Endogenous Contrast
  - Depends upon intrinsic properties of tissue
  - E.g., BOLD fMRI
- Exogenous Contrast
  - Uses injection of foreign substance to track changes
  - E.g., injection of gadolinium-DTPA

Static Contrast

The Concept of Contrast

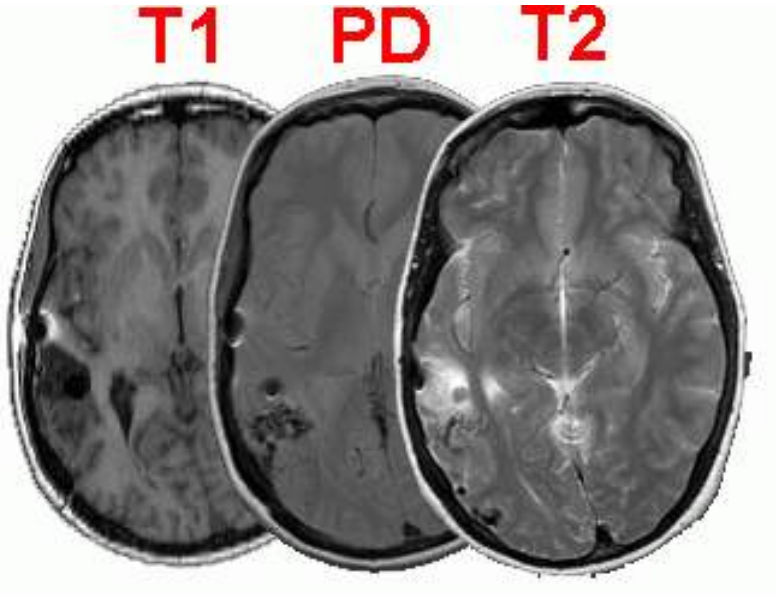
Contrast = difference in signals emitted by water protons between different tissues

For example, grey-white contrast is possible because T_1 relaxation time is different between these two types of tissue

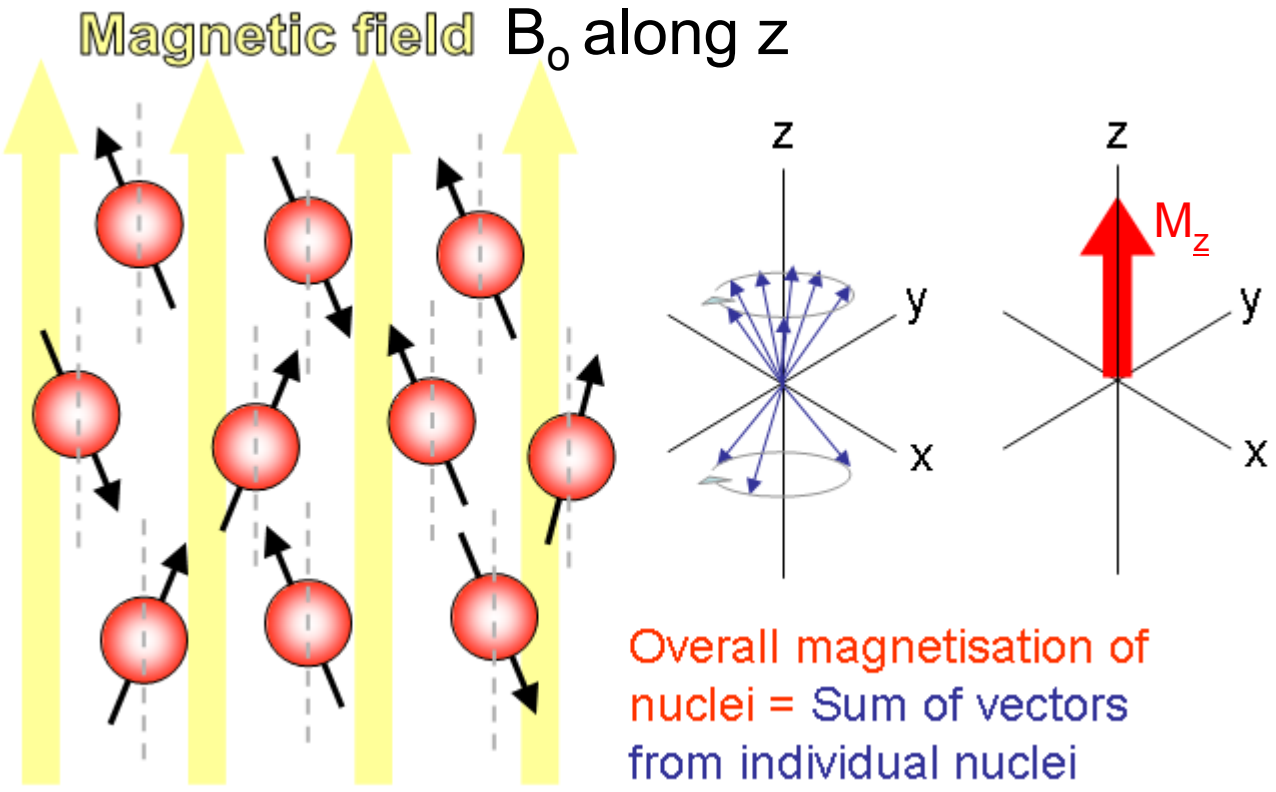


The Concept of Contrast

- We use different MRI protocols that are dominated by different contrasts.
- Contrasts influence the brightness of a voxel.
- For example, water (CSF) is relatively dark in a T1-weighted scan, but relatively bright in a T2 scan.

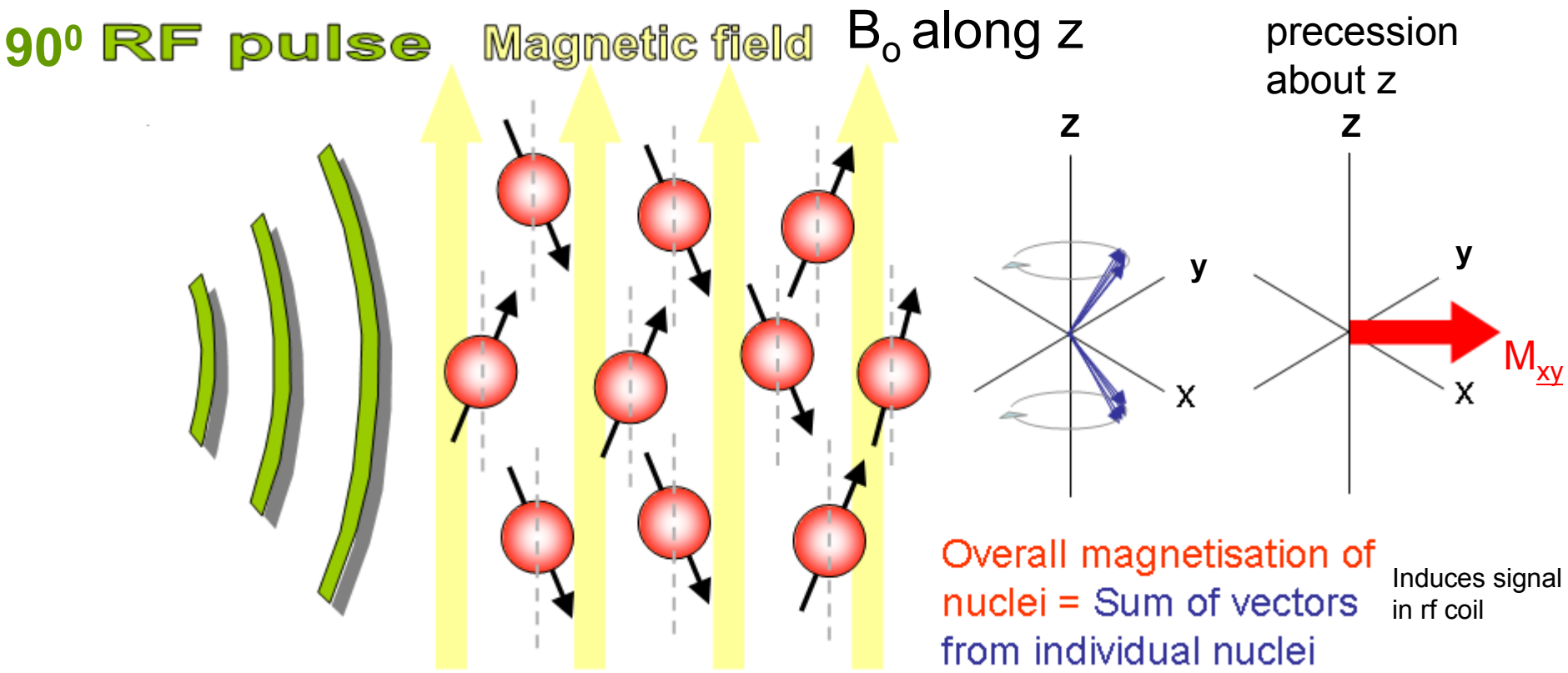


Sample in magnetic field



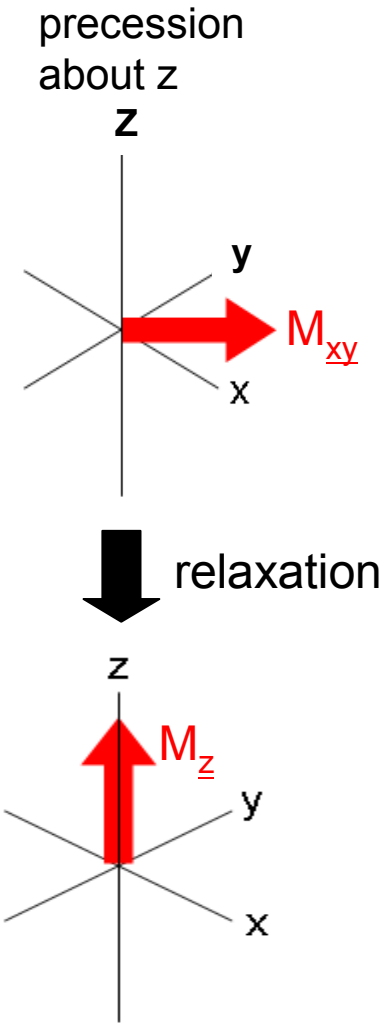
Magnetisation, M, along z

Excitation (90 degree) pulse

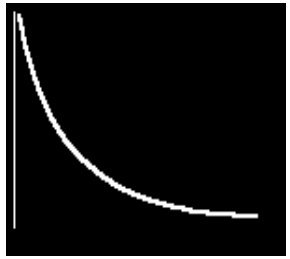


Relaxation: Nothing Lasts Forever

- *M* will go back to being aligned with static field B_0 — this is called *relaxation*
- Part of *M* perpendicular to B_0 shrinks [M_{xy}]
  - This part of *M* is called *transverse magnetization*
  - It provides the detectable RF signal
- Part of *M* parallel to B_0 grows back [M_z]
  - This part of *M* is called *longitudinal magnetization*
  - Not directly detectable, but is converted into transverse magnetization by externally applied B_1



Relaxation Times and Rates



- Times: ‘T’ in exponential laws like $e^{-t/T}$
  - Rates: R = 1/T [so have relaxation like e^{-Rt}]
- T_1: Relaxation of M back to alignment with B_0
  - Usually 500-1000 ms in the brain [lengthens with bigger B_0]
- T_2: Intrinsic decay of the transverse magnetization over a microscopic region (≈ 5-10 micron size)
  - Usually 50-100 ms in the brain [shortens with bigger B_0]
- T_2^*: Overall decay of the observable RF signal over a macroscopic region (millimeter size)
  - Usually about half of T_2 in the brain [i.e., faster relaxation]

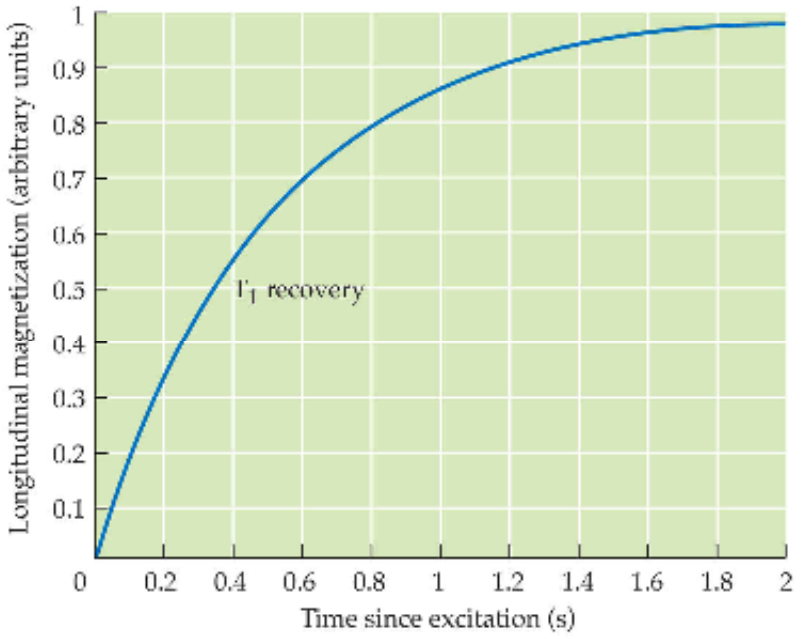
Different tissues have different relaxation times. These relaxation time differences can be used to generate image contrast.

- T_1 - Grey/White matter
- T_2 - Tissue/CSF
- T_2^* - Susceptibility (functional MRI)

Static Contrast Imaging Methods: T_1 and T_2 contrast

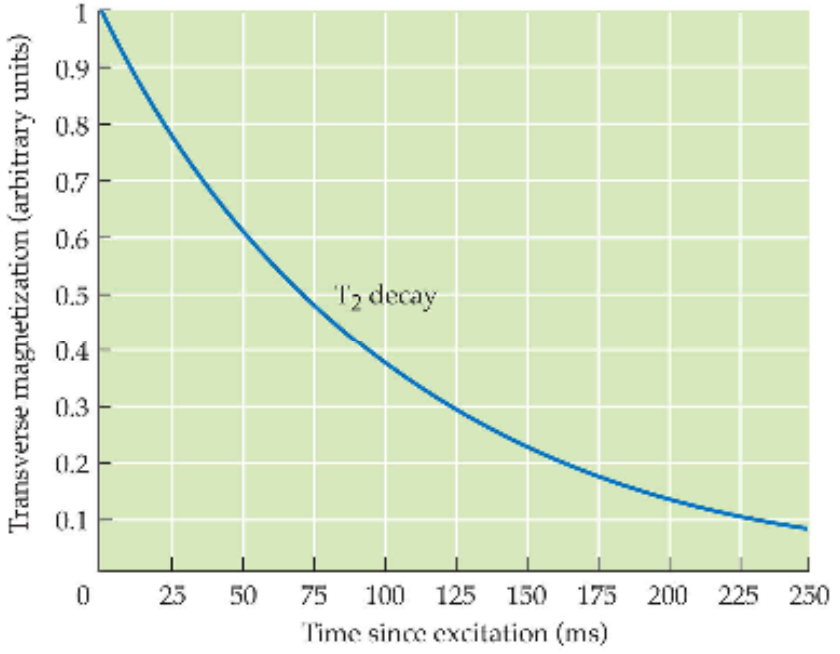
After an initial excitation (90^0 pulse) of fully recovered spin system:

Longitudinal magnetization



$$M_z(t) = M_0\left(1 - e^{-t/T_1}\right)$$

Transverse magnetization



$$M_{xy}(t) = M_0 e^{-t/T_2}$$

T_1 and T_2 Values

- Equilibrium magnetization
  - Depends on field
  - Depends on H_20 content

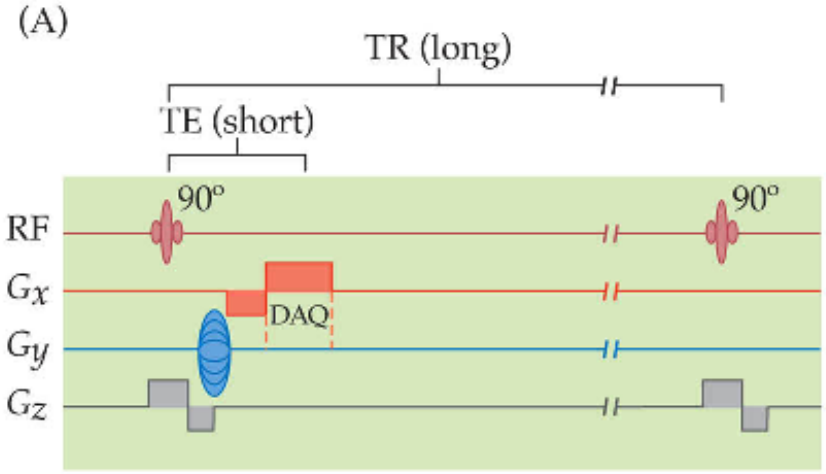
$$M_0 = \frac{N}{V}\frac{\mu_z^2}{k_B T} B_0 \propto p_{H_2O} B_0$$

T_1 and T_2 Values for Various Tissues and Fields					
Material	% H_2O	T_1 (ms)		T_2 (ms)	
		B_0 = 0.5 T	B_0 = 1.5 T	B_0 = 0.5 T	B_0 = 1.5 T
White matter	84.3	500	600	80	74
Grey Matter	70.6	650	900	100	87
CSF	99.0	1800	4000	2000	600

Repetition time, TR

- TR (repetition time) = time interval between successive excitation pulses

- Magnetization is given by $M_{XY} = M_0\left(1 - e^{-\frac{TR}{T1}}\right)\left(e^{-\frac{t}{T2}}\right)$



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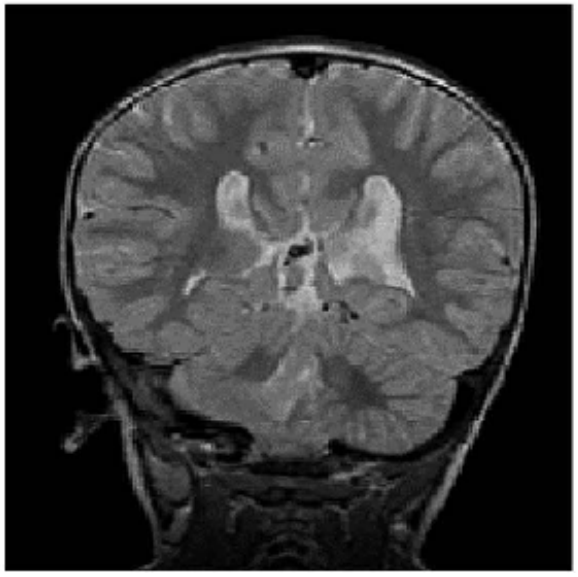
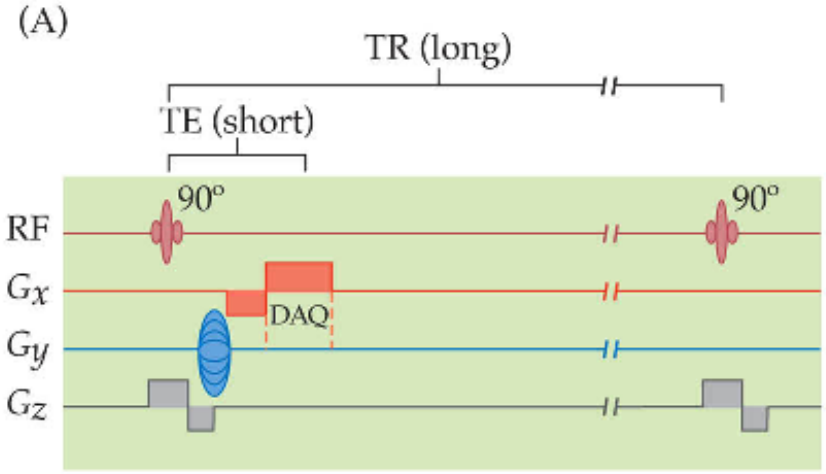


Echo time, TE

- TE (echo time) = time interval between excitation and data acquisition (centre of k-space)

- Magnetization is given by $M_{XY} = M_0\left(1 - e^{-\frac{TR}{T1}}\right)\left(e^{-\frac{TE}{T2}}\right)$



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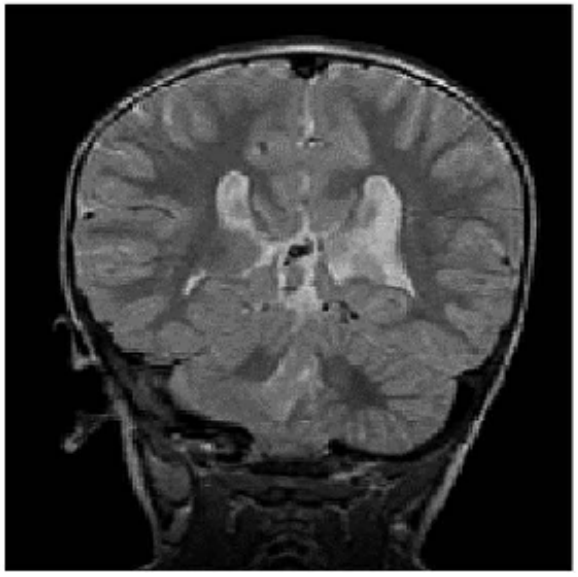


Static Contrasts

1. Weighted by the Proton Density
2. Weighted by the Longitudinal Relaxation Time (T_1)
3. Weighted by the Transverse Relaxation Times (T_2 and T_2^*)

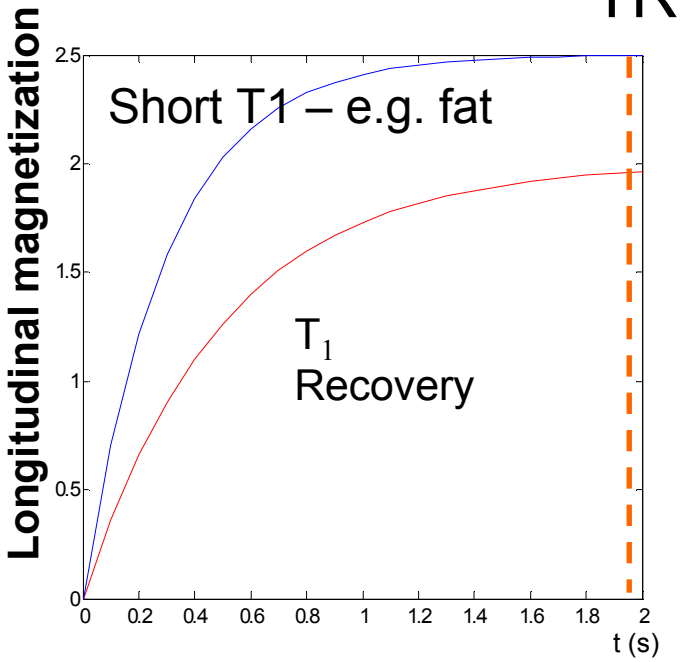
Proton Density (PD) Contrast

- Contrast based on the number of protons in a voxel.

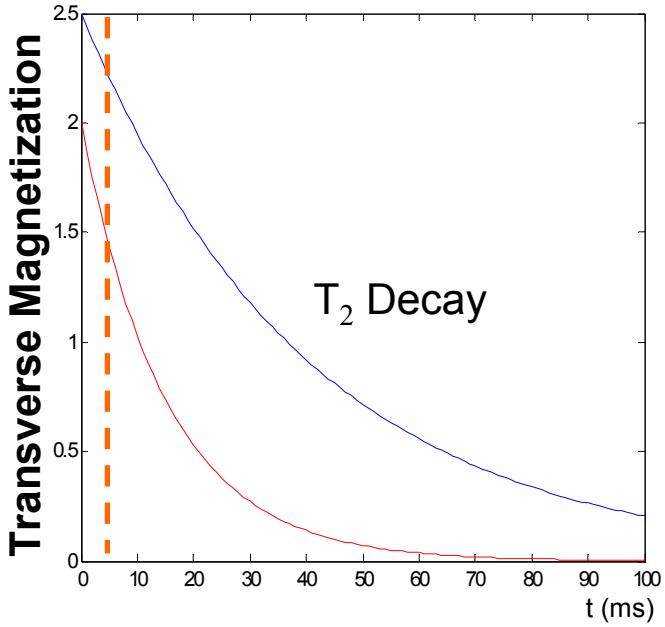
- To maximize PD use pulse sequences that minimize T_1 and T_2 contrast.

Proton Density Contrast
- Effect of TR and TE

TR



TE

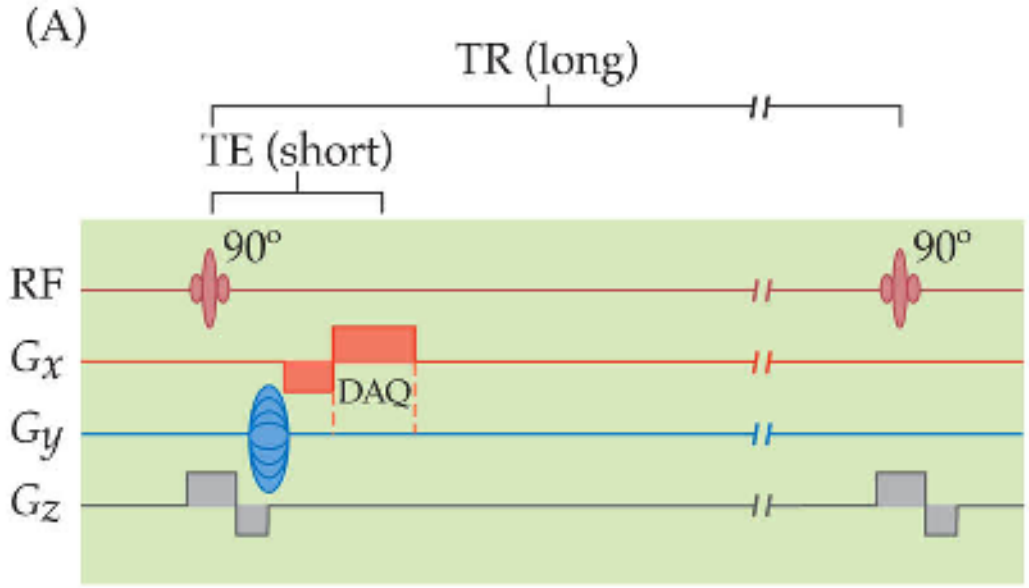


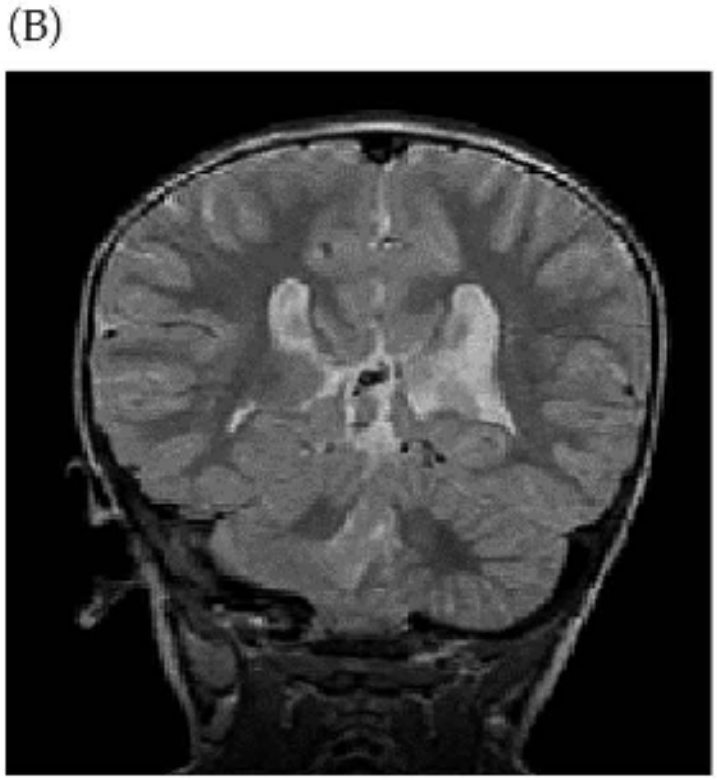
Use very long TR

Use very short TE

Practically use a TR>T_1 and a TE<T_2

Proton Density Contrast

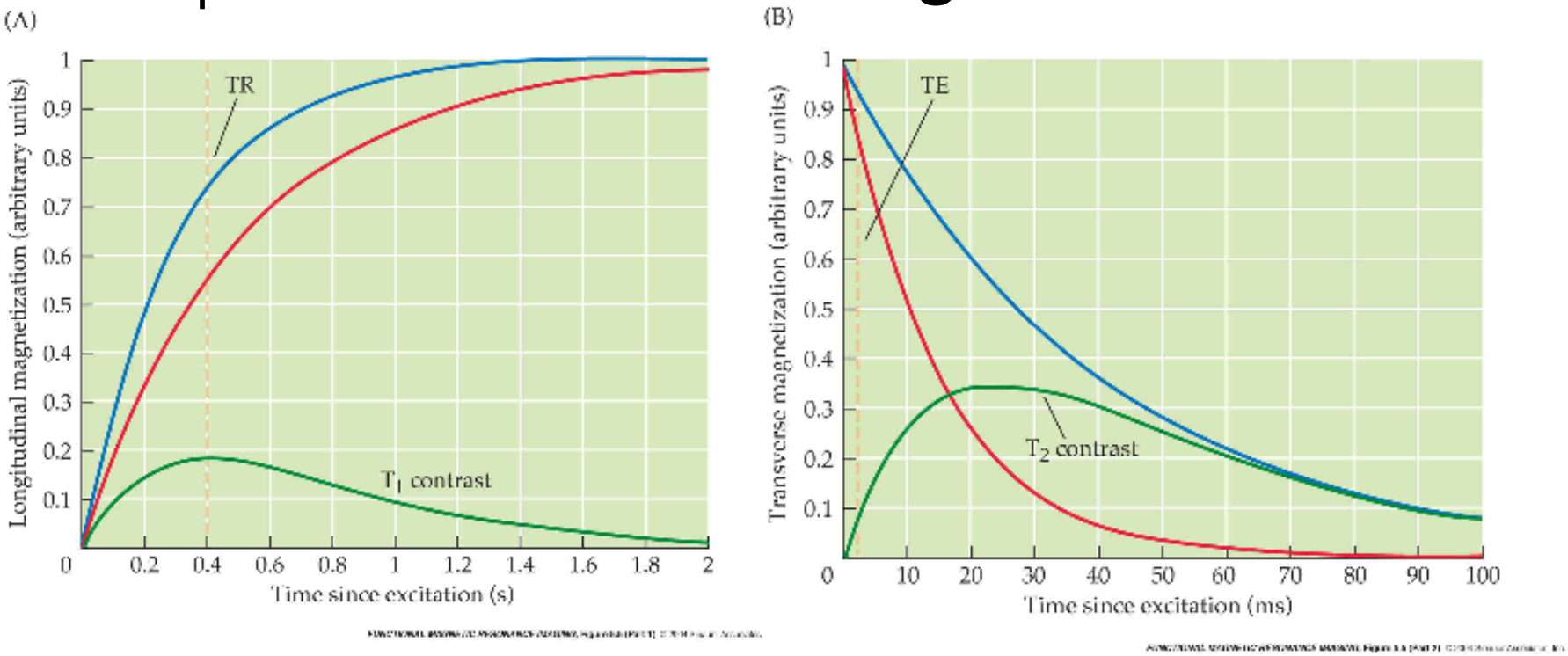




T_1 Contrast

- Most common contrast for structural images.
- T_1-weighted or T_1-dependent.

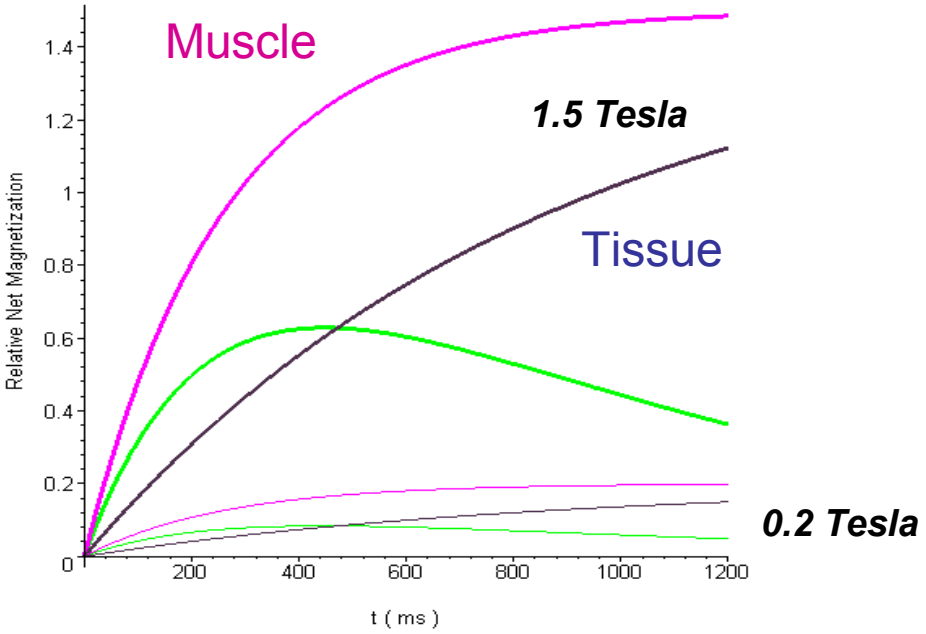
T_1 Contrast –selecting TR and TE

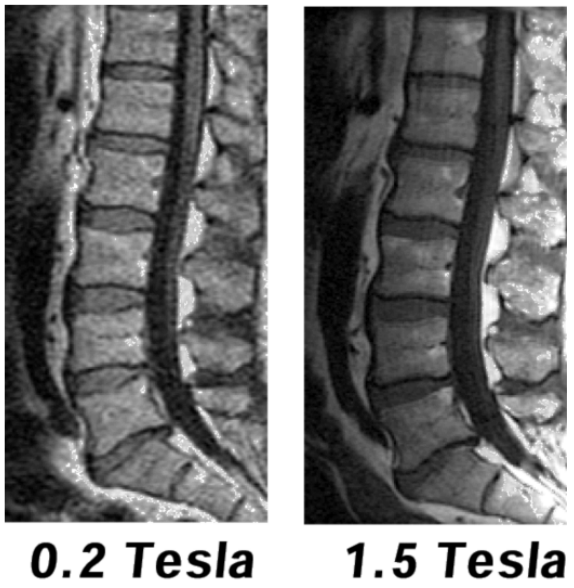


- For exclusive T_1 contrast we must have a **very short TE to minimize T_2 contrast.**

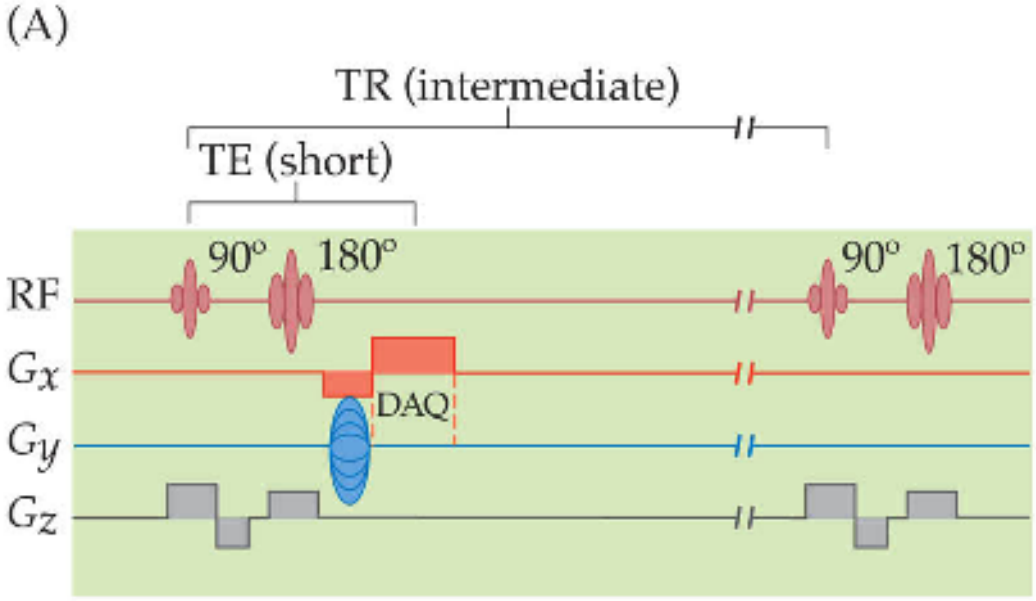
T_1 Contrast – Effect of field strength

- Increased field strength
  - Net magnetization in material is greater
  - Increased contrast means signal is increased
  - Image[1] resolution is better





T_1 Contrast pulse sequence



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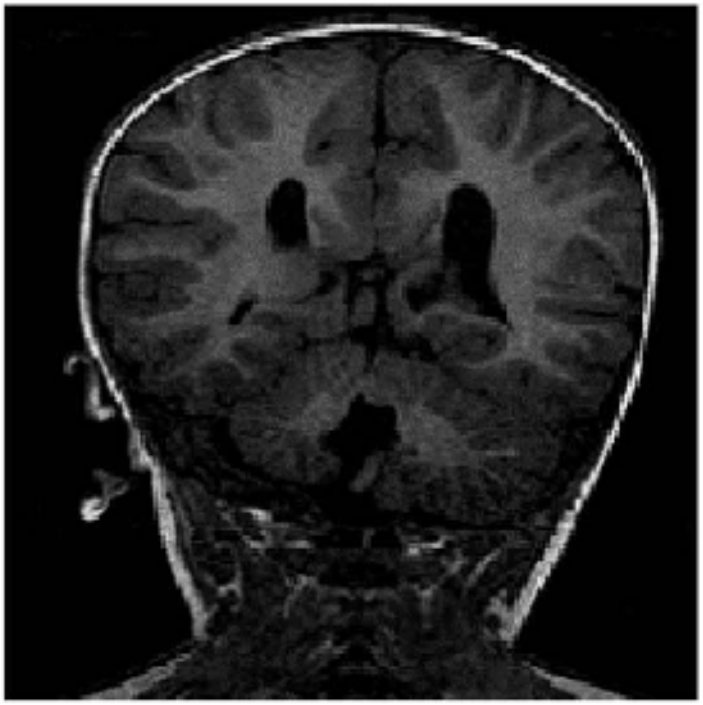
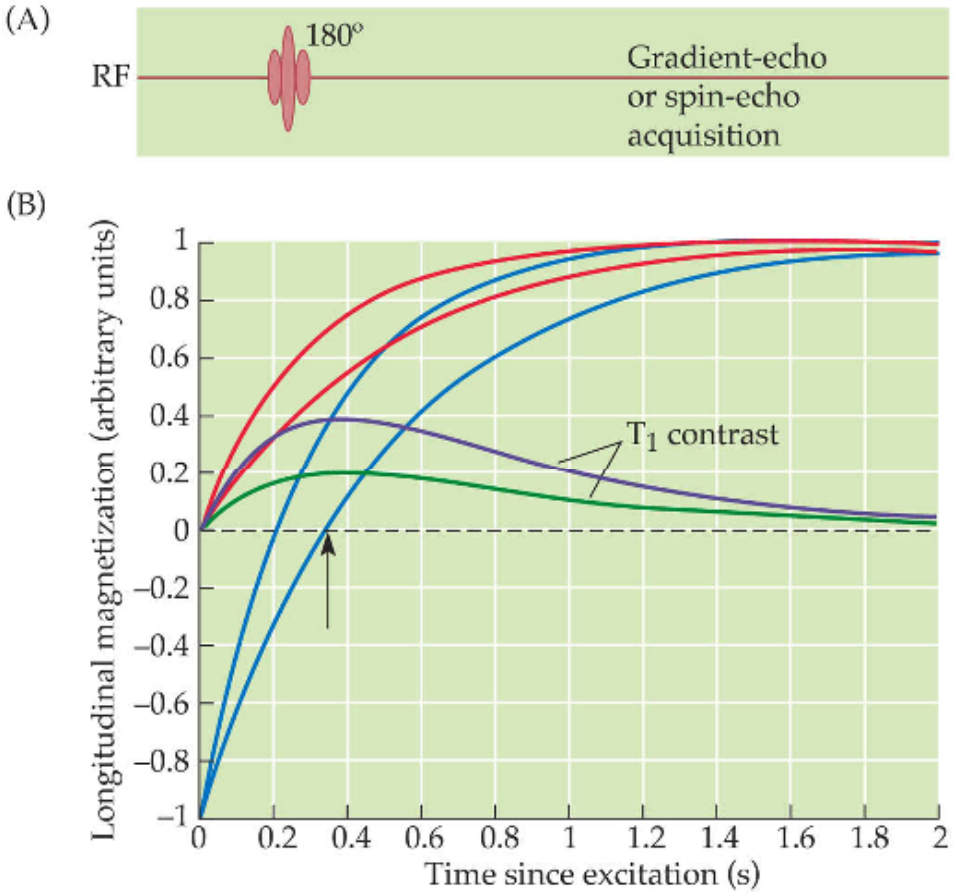


Inversion Recovery to Boost T_1 Contrast

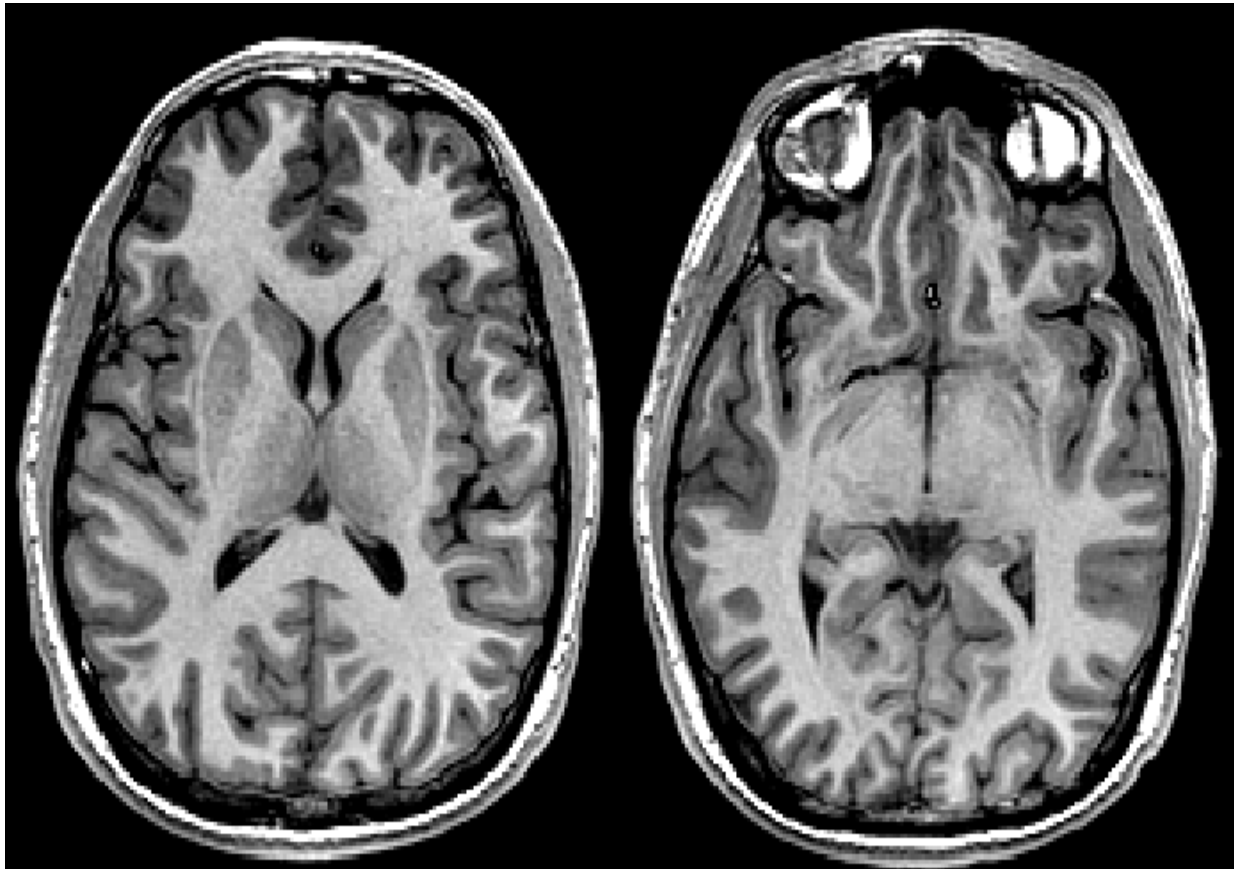
- Sequence begins with a 180^0 inversion pulse rather than a 90^0 pulse



Effectively doubles dynamic range of the signal.
Also allows selective elimination of MR signal of a given tissue type.

FUNCTIONAL MAGNETIC RESONANCE IMAGING, Figure 5.7 © 2004 Sinauer Associates, Inc.

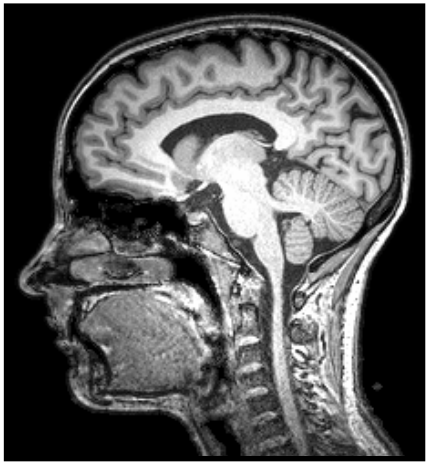
IR-Prepared T_1 Contrast



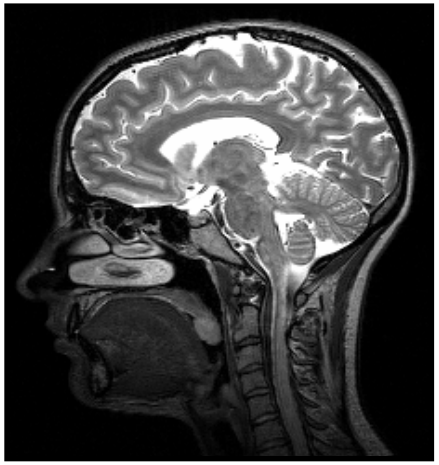
T_2 Contrast

- Images created have maximal signal in fluid-filled regions.
- Important for many clinical studies, e.g. detection of tumours, and anatomical reference image.
- Often used in conjunction with T_1 images.
- T_2-weighted or T_2-dependent.

T1 Weighted Image (T1WI)
(Gray Matter – White Matter)

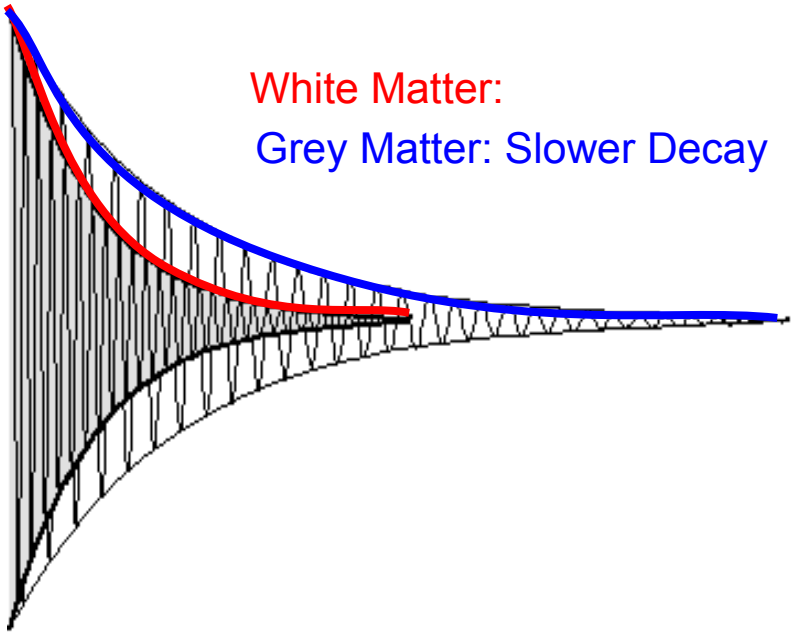


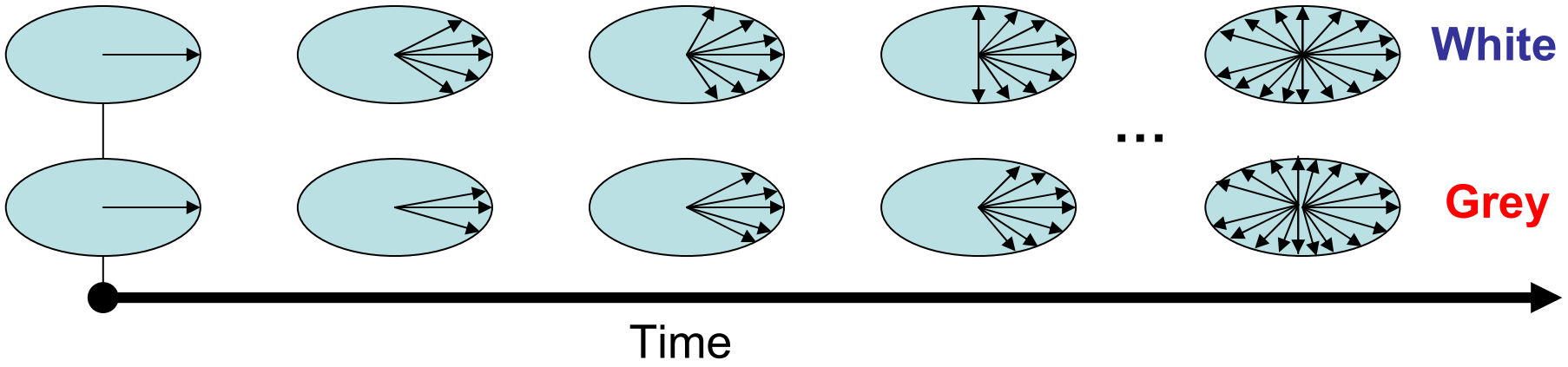
T2 Weighted Image (T2WI)
(Gray Matter – CSF Contrast)



T_2 Contrast

1. Signals from all tissue decays with time.
2. Signal decays faster in some tissues than others.
3. Optimal contrast between tissue when they emit relatively different signals.



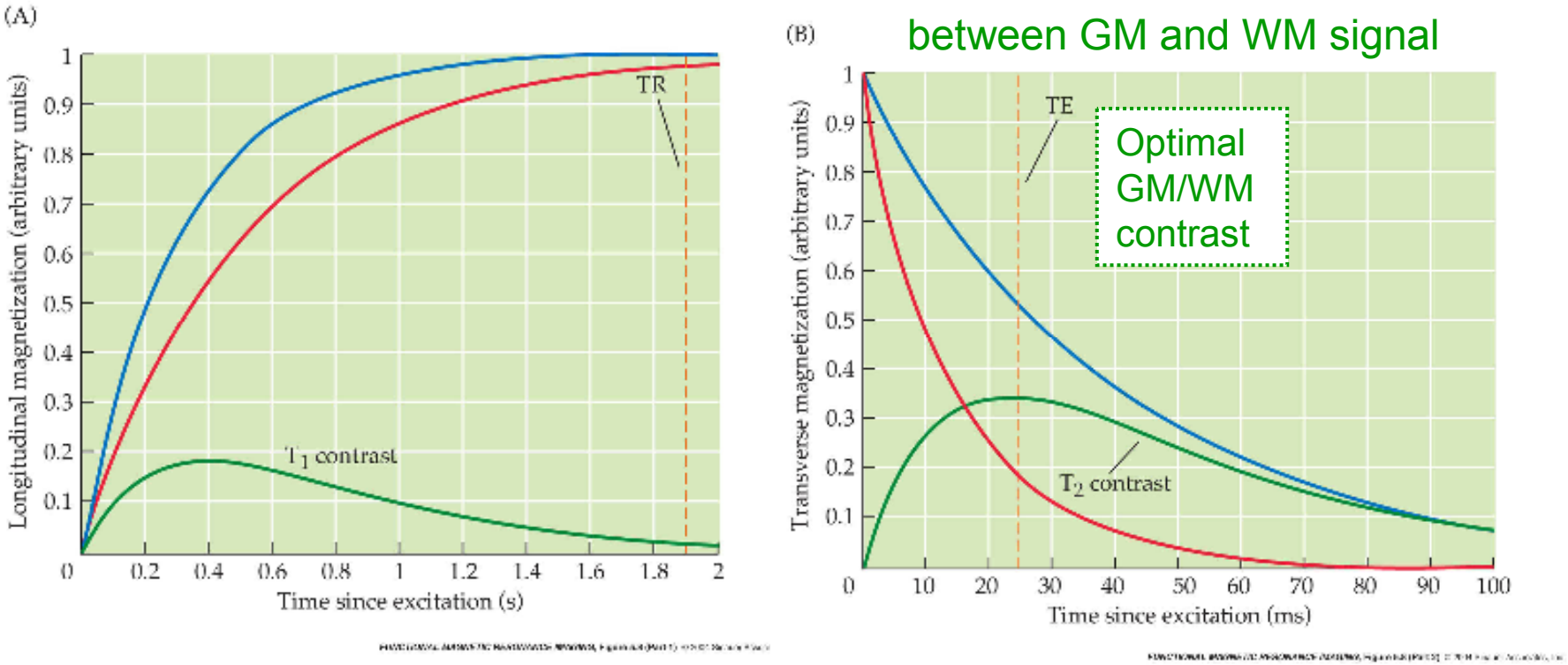


White Matter

Grey Matter

T_2 Contrast

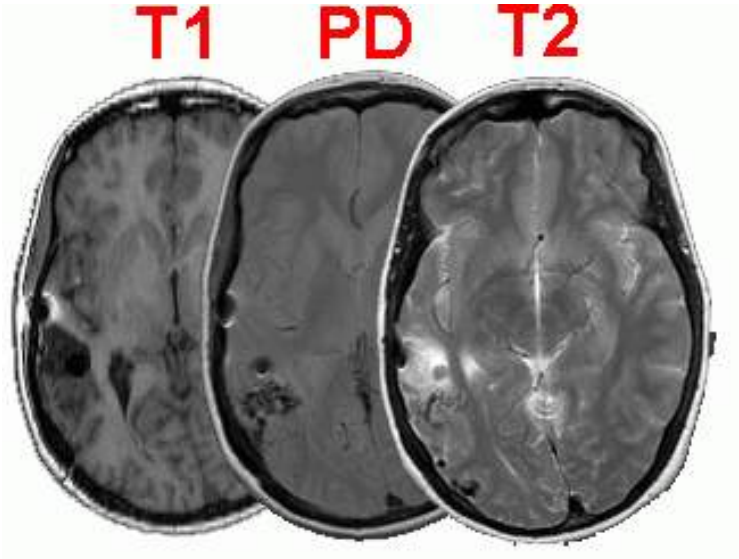
Contrast: difference between GM and WM signal



- For exclusive **T_2 contrast must have very long TR and intermediate TE**

T_1 and T_2 contrasts

- Every scan is influenced by both T_1 and T_2.
- By adjusting TE and TR we can determine which effect dominates:
  - T1-weighted images use short TE and short/intermediate TR.
    - Fat bright (fast recovery), water dark (slow recovery)
  - T2-weighted images use long TE and long TR: they are dominated by the T2
    - Fat dark (rapid dephasing), water bright (slow dephasing).
  - Proton density images use short TE and long TR: reflect hydrogen (water) concentration.

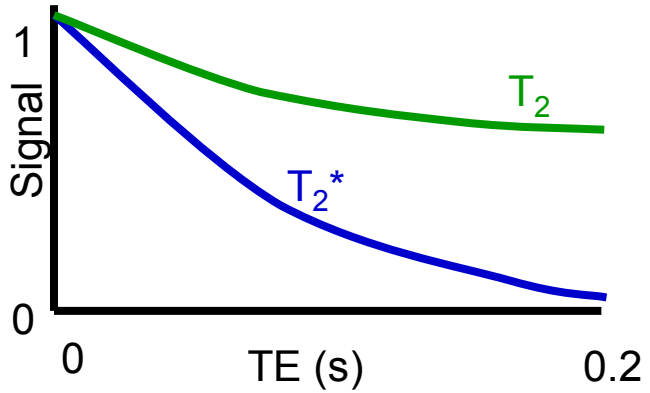


T_2 vs T_2^*

- T_2 only one reason for dephasing:
  - Pure T_2 dephasing is intrinsic to sample (e.g. different T_2 of CSF and fat).
  - T_2^* dephasing includes true T_2 as well as field inhomogeneity (T_{2M}) and tissue susceptibility (T_{2MS}).
    - Due to these artifacts, Larmor frequency varies between locations.

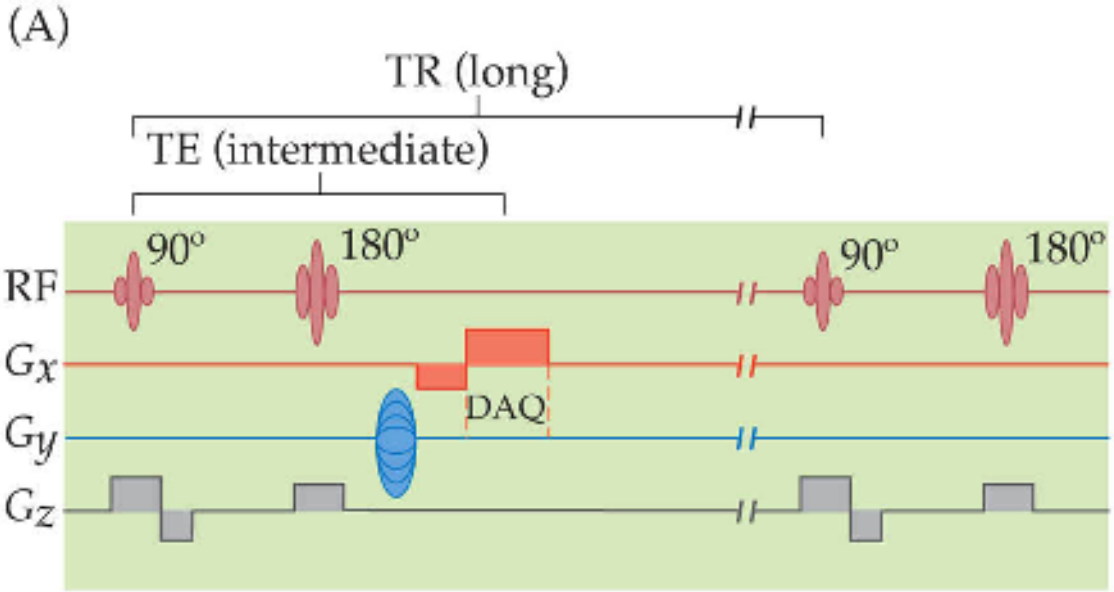
$$\frac{1}{T_2^*} = \frac{1}{T_2} + \frac{1}{T_{2M}} + \frac{1}{T_{2MS}}$$

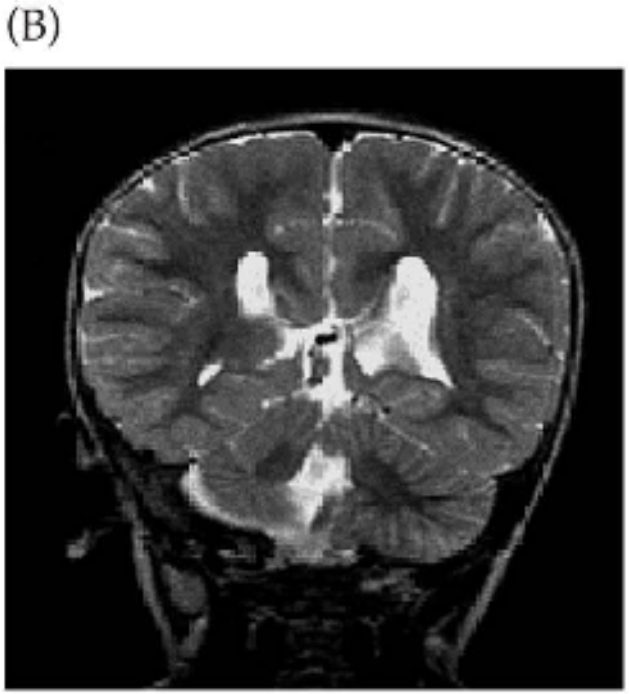
- T_2^* leads to rapid loss of signal:



T_2 Contrast

- T_2 weighted images can only be generated using a **spin echo pulse sequence**





- The 180^0 pulse reverses the loss of phase coherence experienced by spins, spin-echo is insensitive to static magnetic field inhomogogeneities (T_2* effects).

Restoring phase coherence using a 180^0 pulse.