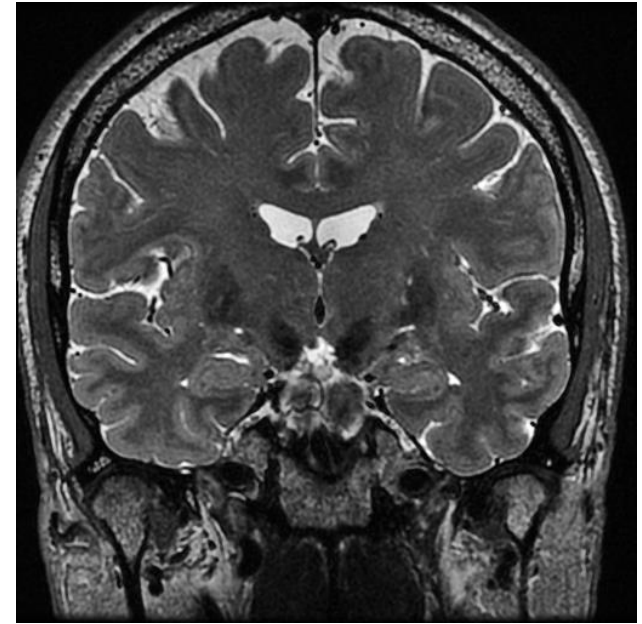
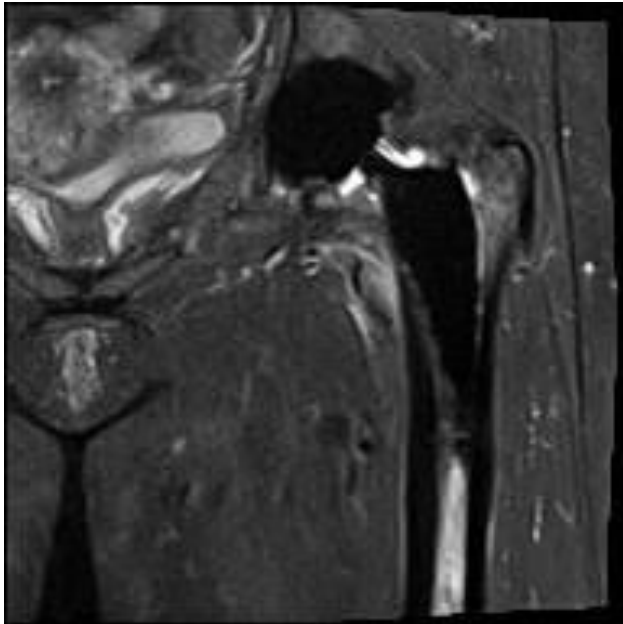


Magnetic Resonance Imaging

F.R.C.R. Physics Lectures



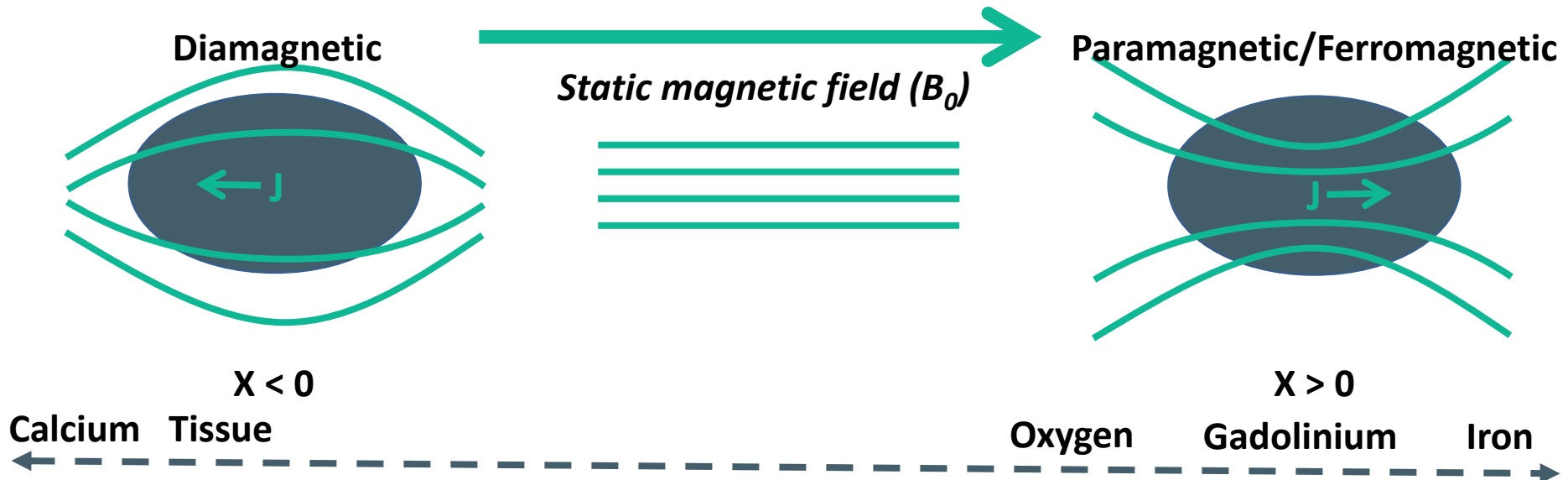
Lawrence Kenning PhD

7.2 Basic Contrast Mechanisms

- *Magnetic Materials*
- *Spin Echo*
- T_1 . Understand concept of MR signal saturation
- T_2 and T_2^*
- Impact of relaxivity of gadolinium-based contrast agents on T_1 -weighted and T_2^* weighted images
- Difference between a contrast-weighted MR image and a quantitative image (map)
- Extension of T_2^* -weighted MRI to susceptibility-weighted imaging (SWI)

Susceptibility (χ – “chi”)

Susceptibility is defined as the magnitude of the internal polarization (J) divided by the strength of the external field (B): $\chi = J / B_0$



- Nearly all biological tissues are weakly **diamagnetic**
- Some tissues contain focal accumulations of metals such as iron, gadolinium, copper, or manganese that concentrate the magnetic field and are therefore **paramagnetic**
- A few tissues also contain chunky iron-based protein conglomerates (ferritin and hemosiderin) that are **superparamagnetic**.

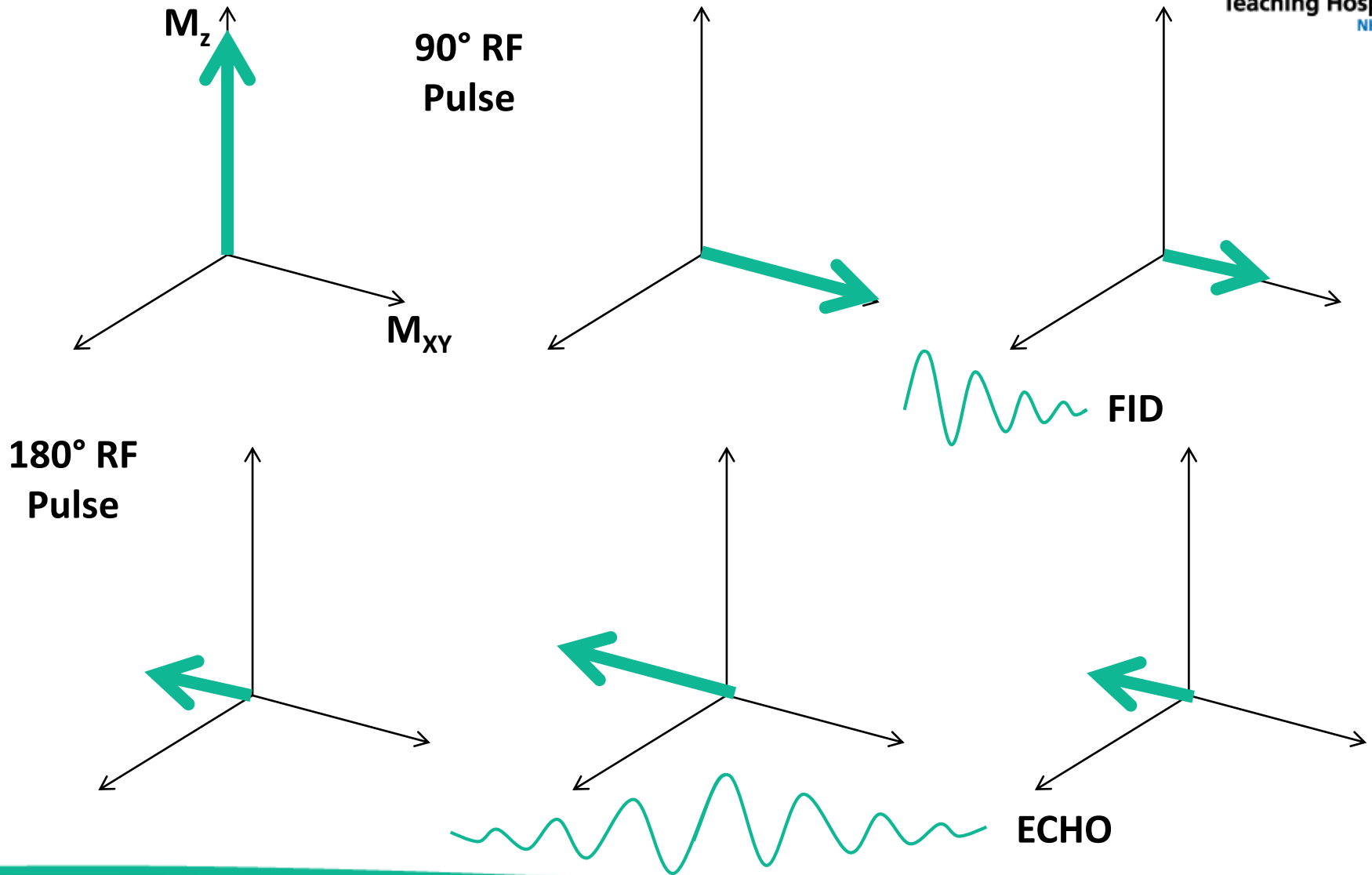
- In the presence of an externally applied magnetic field:
- **Ferromagnetic** materials
 - Strongly attracted to magnetic fields
 - Induced magnetisation may persist after removal of field
 - E.g. iron, nickel, cobalt
- **Paramagnetic** materials
 - Weakly attracted to magnetic field,
 - No permanent magnetism persisting after field removal
 - E.g. magnesium, molybdenum, lithium, **gadolinium contrast**
- **Diamagnetic** materials
 - Repelled by magnetic field



- Spin echo describes the excitation of the magnetised protons in a sample with a **90° RF pulse** and production of a FID, followed by a refocusing **180° RF pulse** to produce an echo
- The 90° pulse converts M_z into M_{xy} and creates coherent transverse magnetisation that immediately begins to decay at a rate described by T_2^* relaxation (loss of phase coherence)
- The 180° RF pulse applied at $TE/2$ inverts the spins and induces phase coherence at TE
- Inversion of the spins causes the protons to experience external magnetic field variations opposite of that prior to $TE/2$, resulting in the cancellation of the extrinsic inhomogeneities and associated dephasing effects

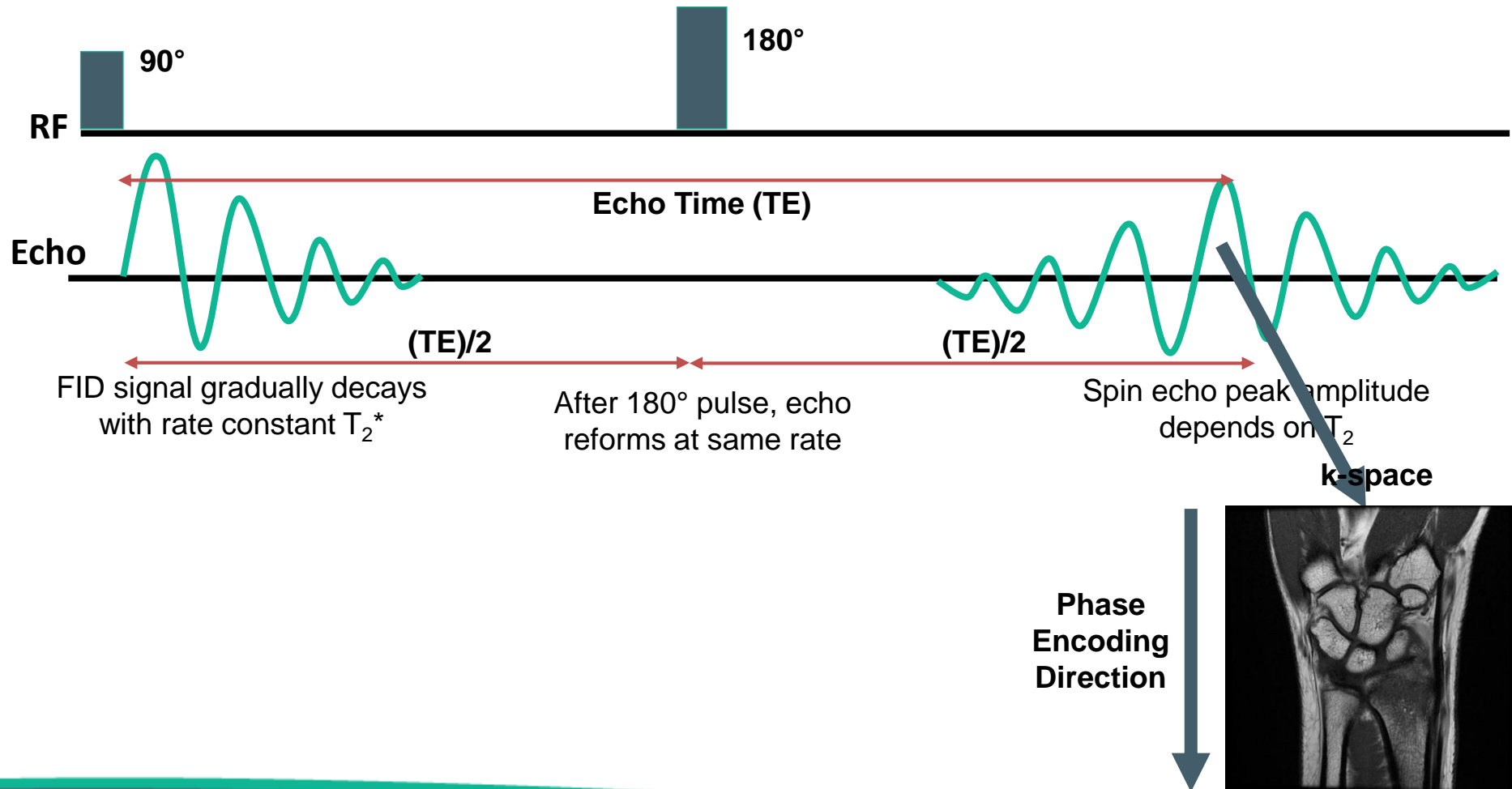
- Subsequent 180° RF pulses during the TR interval produce corresponding echoes with peak amplitudes that are reduced by intrinsic T_2 decay of the tissues, and are immune from extrinsic inhomogeneities
- Digital sampling and acquisition of the signal occurs in a time window symmetric about TE, during the evolution and decay of each echo
- **Spin Echo sequences can produce T_1 , T_2 and P.D. weightings**

Spin Echo (SE) Pulse Sequences



Spin Echo (SE) Pulse Sequences

- Spin Echo (SE)
- Simple pulse sequence



Spin Echo Image acquisition

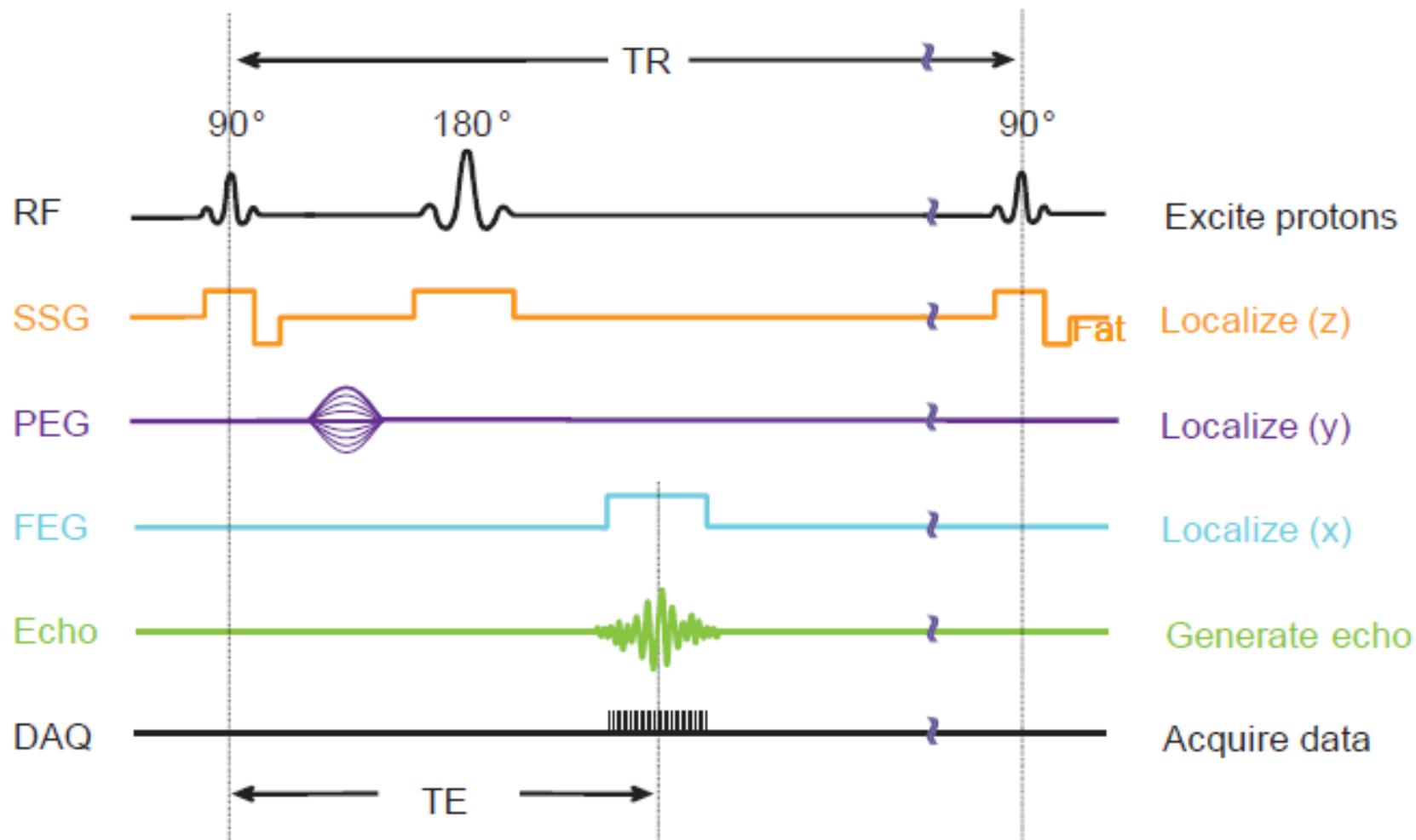
- **Narrow band RF excitation** pulse simultaneously applied with **the slice select gradient** causing a specific slab of tissue to be excited
- **Transverse magnetisation (M_{xy}) is produced** with amplitude dependence on the saturation of the protons and the angle of excitation
- **Phase encoding gradient is applied briefly**, introducing a phase difference among the protons along the phase encode direction

Spin Echo

- A **refocusing 180-degree RF pulse** is delivered at $TE/2$ to invert and re-establish the phase coherence of the transverse magnetisation at time TE
- During the echo formation, the **frequency encoding gradient is applied**, generating spatially dependent changes in the precessional frequencies of the protons

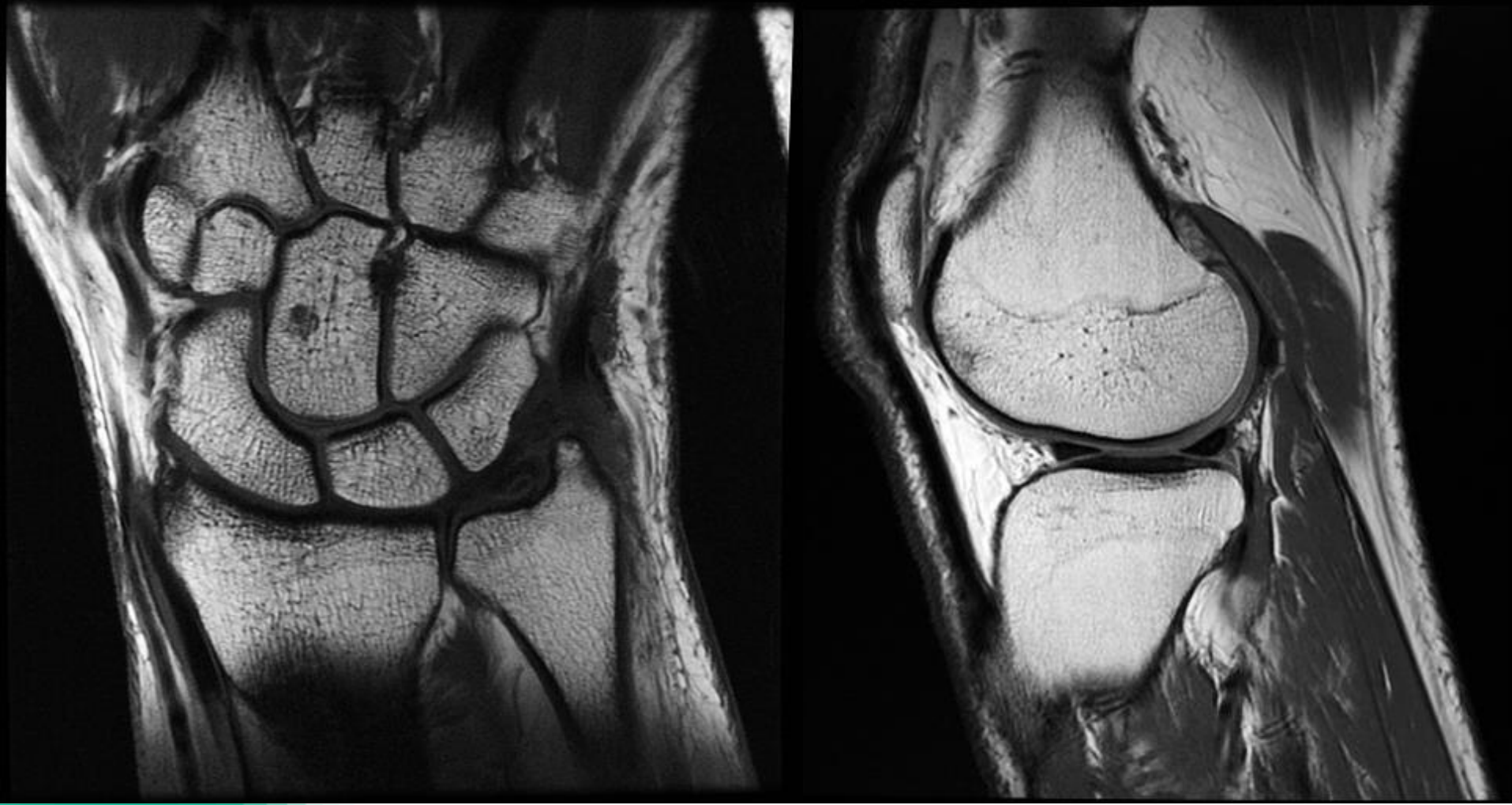
- **Data sampling and acquisition** of the signal occurs simultaneous to the **frequency encoding gradient**
- Data is deposited in the k-space matrix at a row location determined by the strength of the phase encoding gradient
- For each TR, an incremental change of the phase encoding gradient strength sequentially fills each row
- Following the **complete filling of k-space**, an **inverse Fourier transform** decodes the frequency domain variations in phase for each of the columns of k-space to produce the spatial domain representation - an image!

Spin Echo Sequence



- SE sequences are generally:
 - High SNR
 - Resolute
 - Lengthy
 - Less susceptible to metallic artefacts

Spin Echo (SE) Pulse Sequences





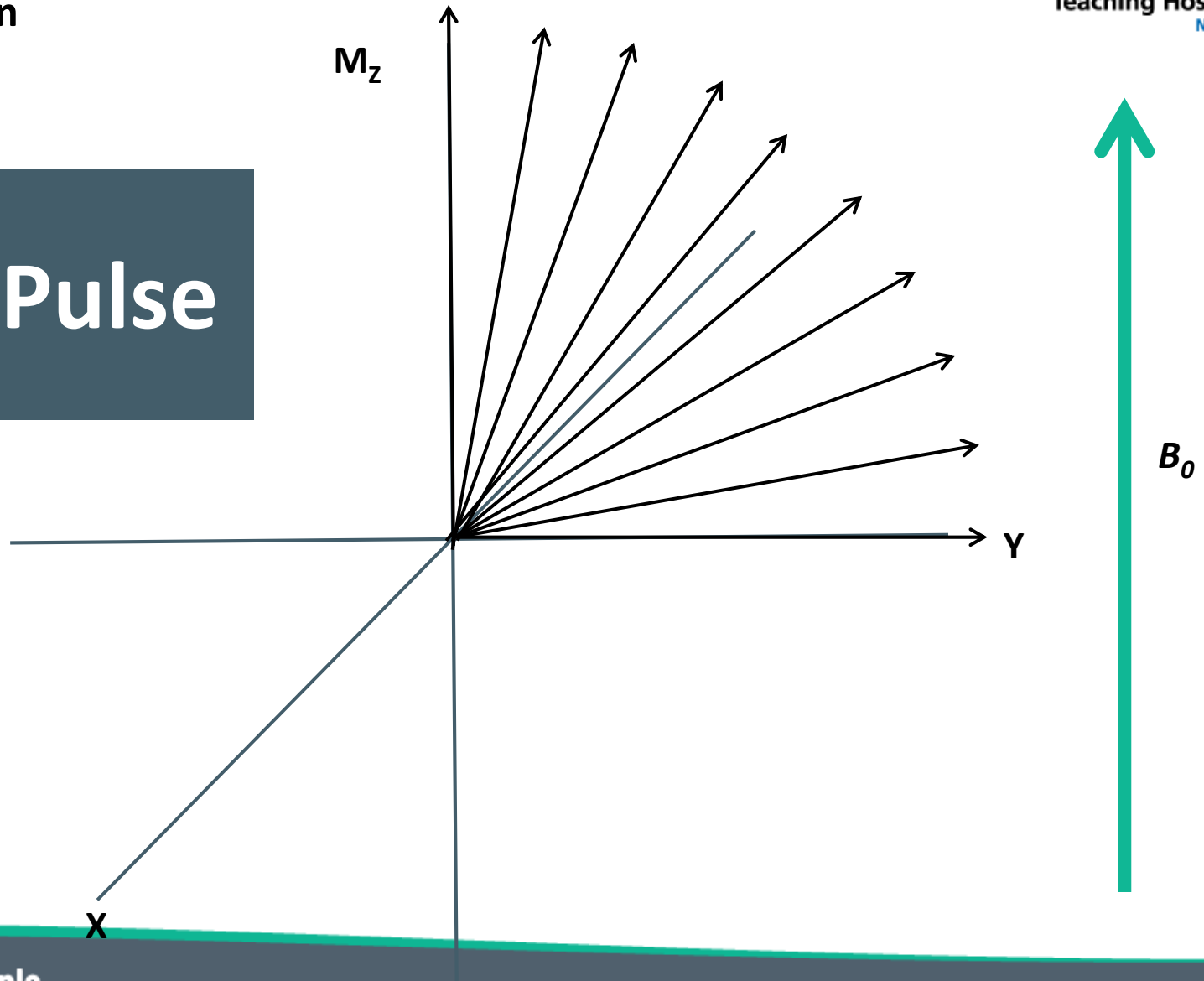
T₁ Relaxation (spin-lattice relaxation)

- Following a B₁ excitation pulse, longitudinal magnetisation begins to recover immediately
- *Spin-lattice relaxation* is the term describing the release of energy back to the *lattice* (the molecular arrangement and structure of the hydration layer), and the regrowth of M_z
- T₁ is the time needed for the recovery of 63% of M_z after a 90-degree pulse

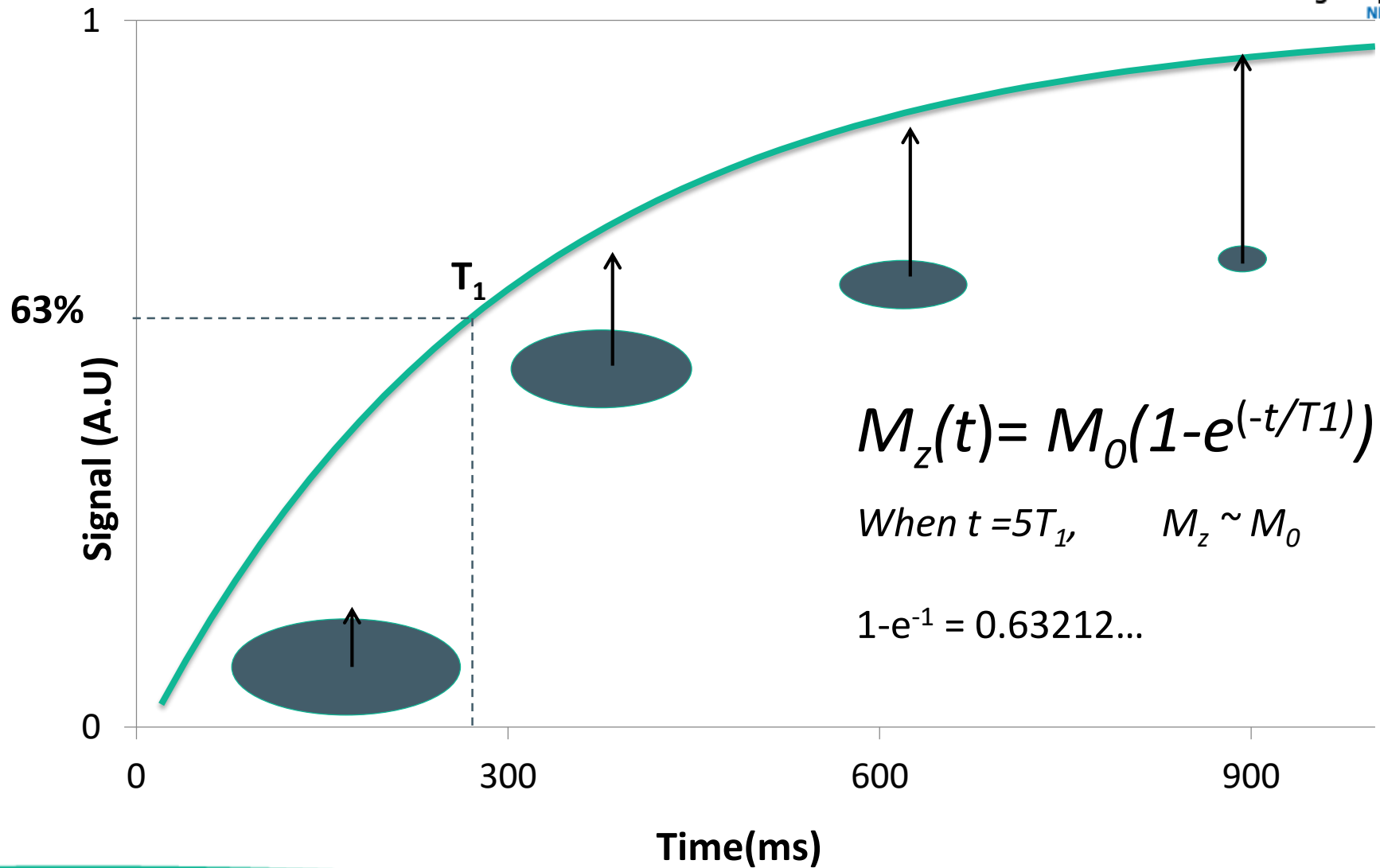
T₁. Understand concept of MR signal saturation

T₁ Relaxation

90° Pulse

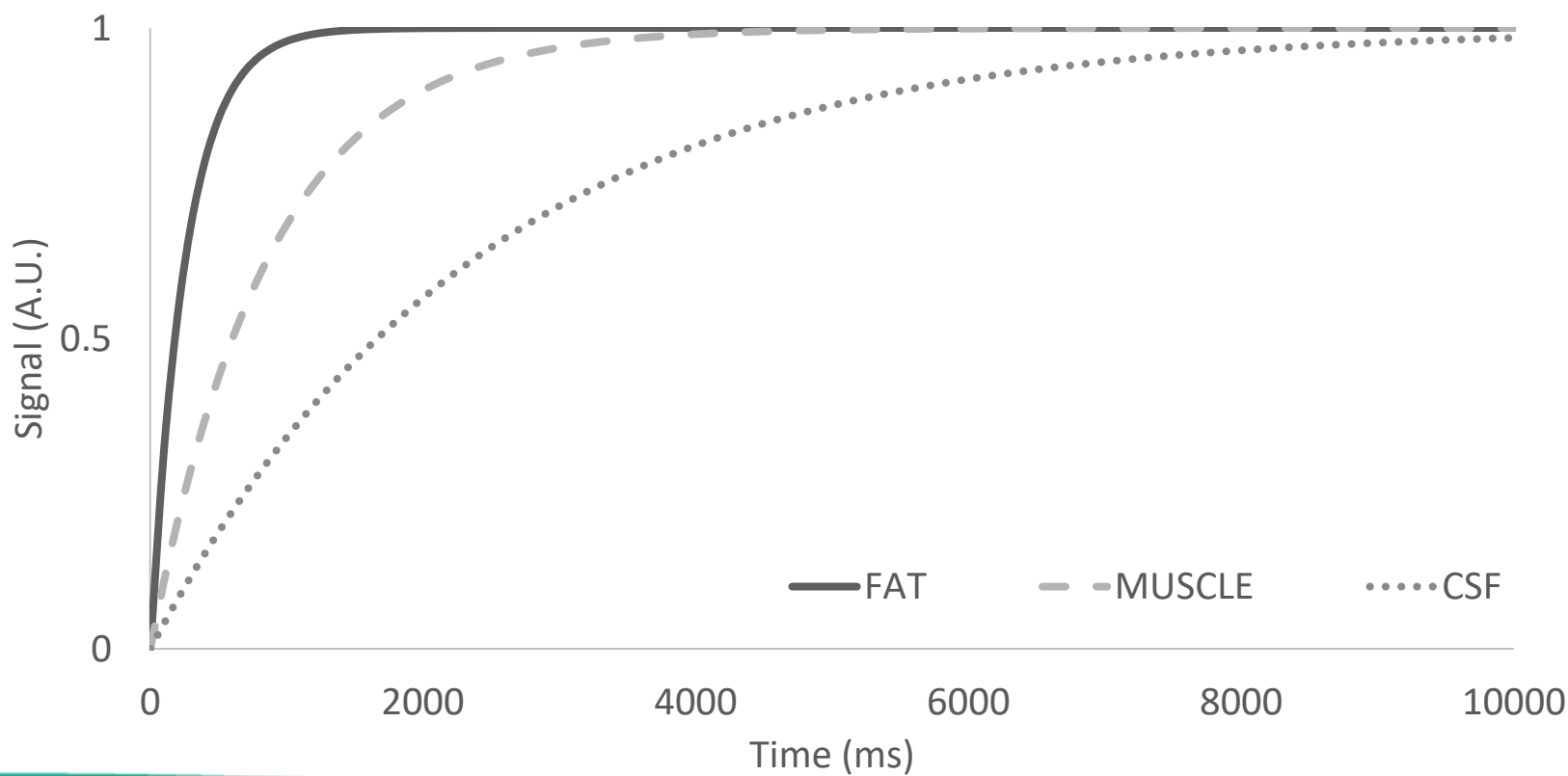


T₁. Understand concept of MR signal saturation



T₁. Understand concept of MR signal saturation

Tissue	T ₁ 1.5T
Fat	260
Muscle	870
CSF	2400

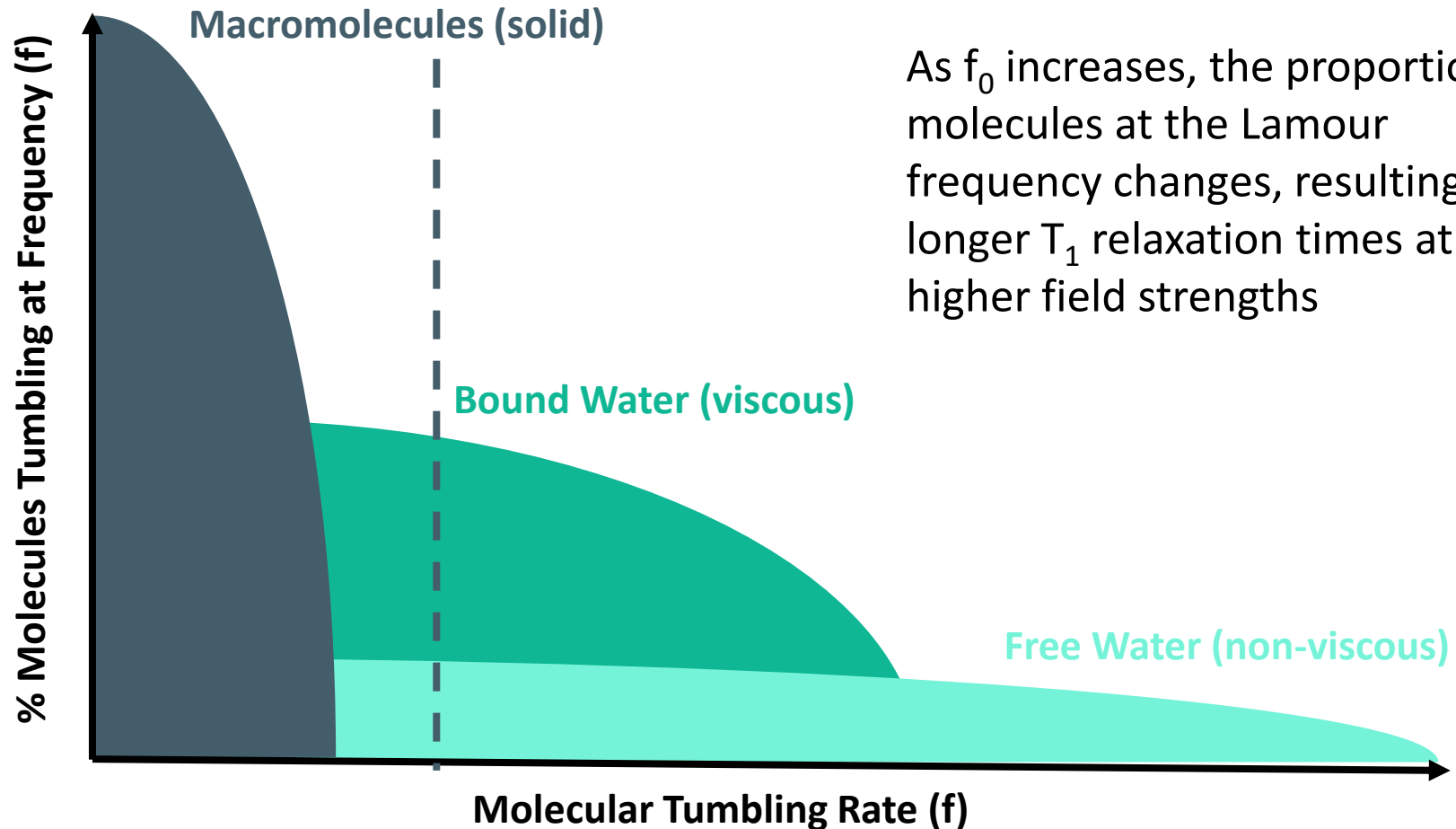


T₁. Understand concept of MR signal saturation



T₁. Understand concept of MR signal saturation

Field Strength Dependence of T₁



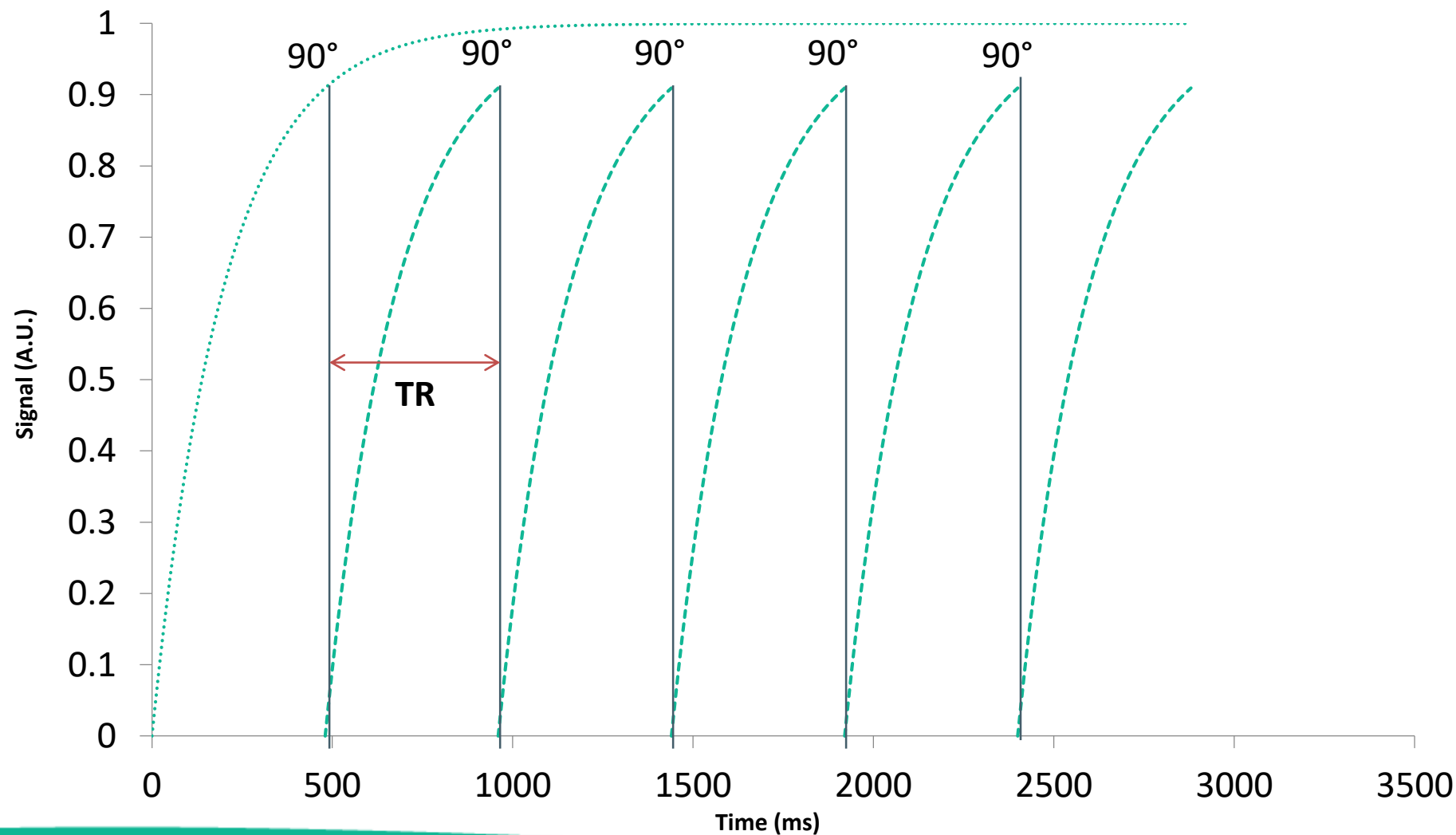
As f_0 increases, the proportion of molecules at the Larmor frequency changes, resulting in a longer T₁ relaxation times at higher field strengths

Time of Repetition (TR)

- Acquiring an MR image requires the repetition of a sequence in order to sample the volume of interest and periodically build the complete dataset
- The time of repetition (TR) is the period between B₁ excitation pulses.
- During the TR interval, T₂ decay and T₁ recovery occur in the tissues
- TR values range from extremely short (milliseconds) to extremely long (10,000 ms) time periods, determined by the type of sequence employed
- TR is a parameter chosen by the scanner operator (often Radiographer)

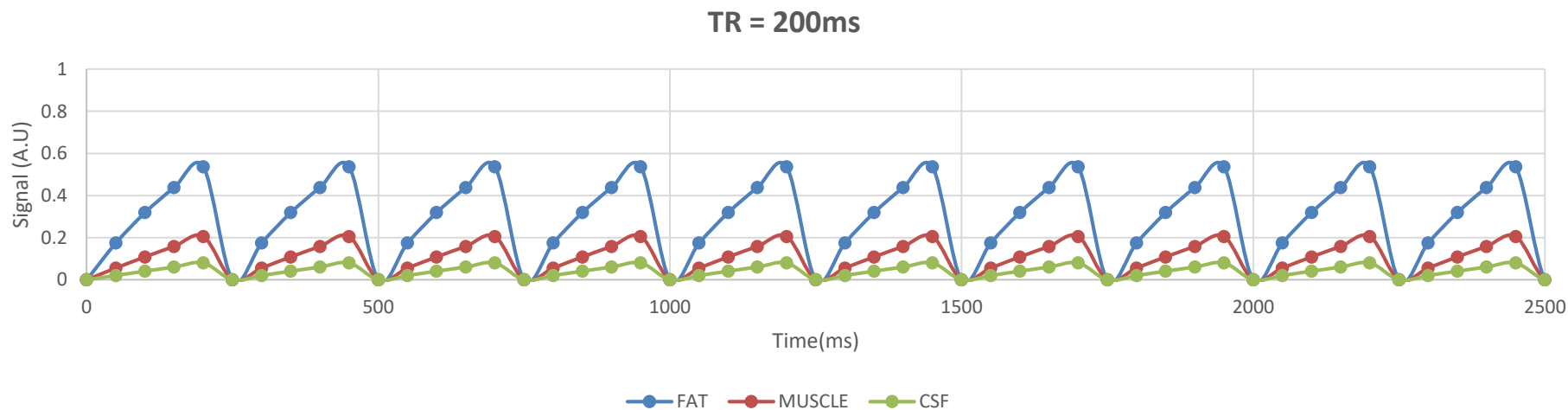
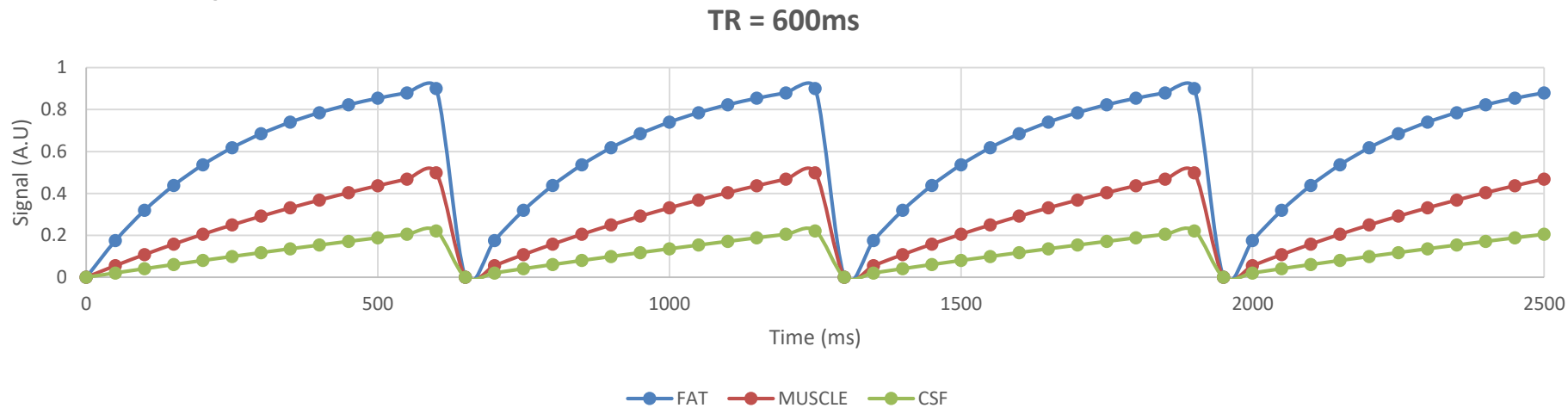
T₁. Understand concept of MR signal saturation

Time of Repetition



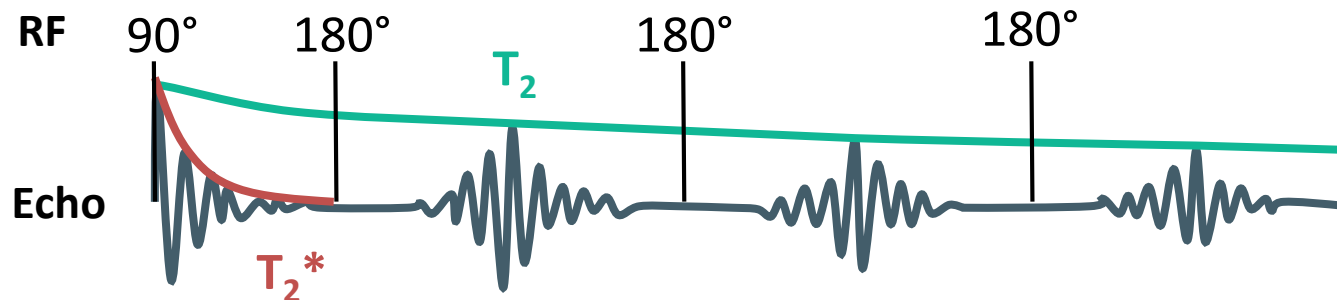
T₁. Understand concept of MR signal saturation

Time of Repetition



T_2 Relaxation (spin-spin relaxation)

- T_2 decay is the process whereby spins begin to dephase, occurring **simultaneously with T_1 relaxation**.
- Due to individual spins observing local differences in the magnetic field **caused by interactions between spins**.
- Spins dephase much quicker than the 'true' T_2 due to inhomogeneities in the static magnetic field (B_0) causing the signal decay to be characterised as T_2^*



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

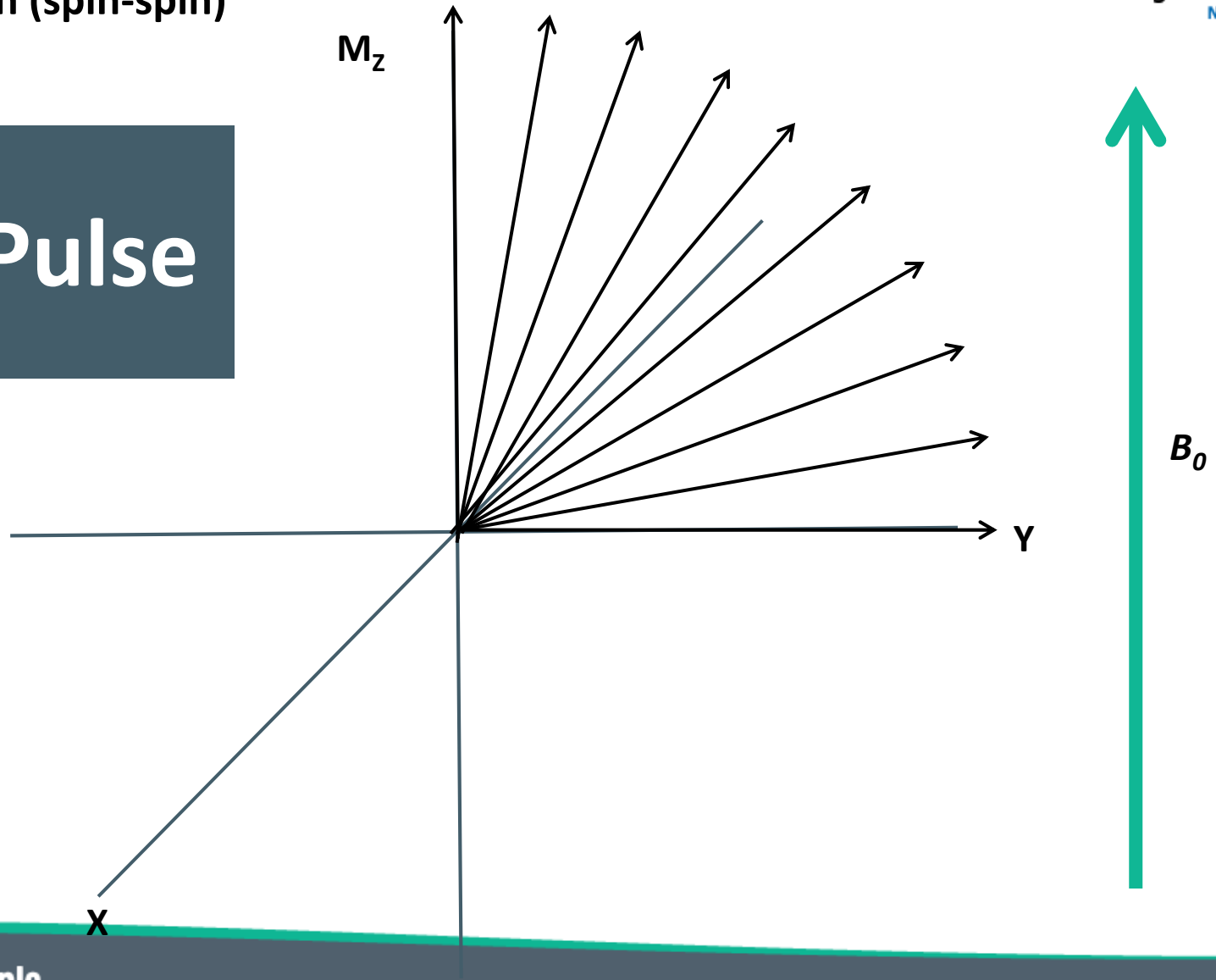
T_2' represents:

- imperfections in the field
- variations in B_0 field inhomogeneities & magnetic susceptibility
 - Susceptibility is a property of matter which determines how easily it becomes magnetised when placed in an external field
 - Susceptibility artefacts are signal voids present due to differences in susceptibility between objects and tissue or air/tissue interface
- T_2 - spin-spin relaxation which is tissue specific

T_2 and T_2^*

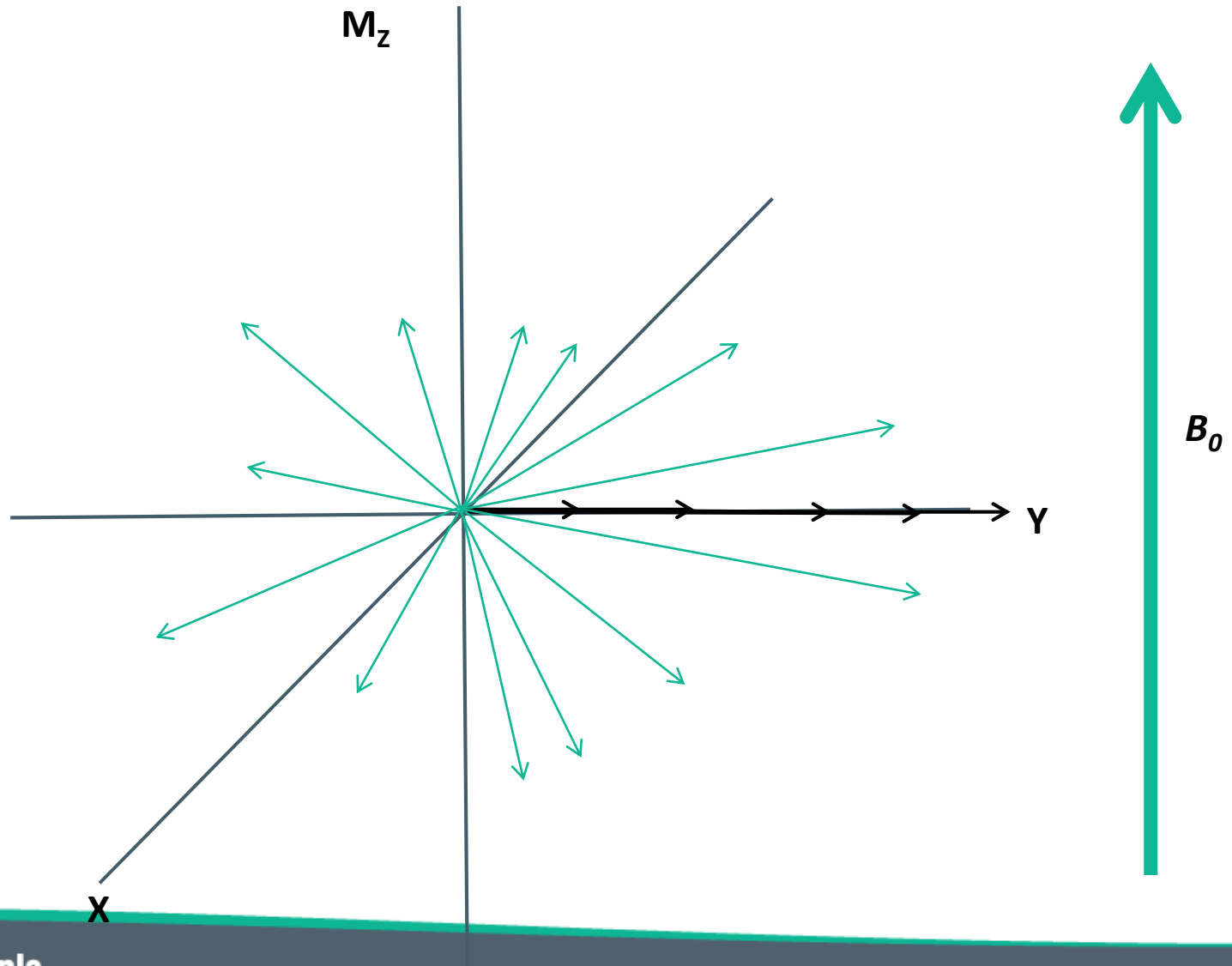
T_2 Relaxation (spin-spin)

90° Pulse

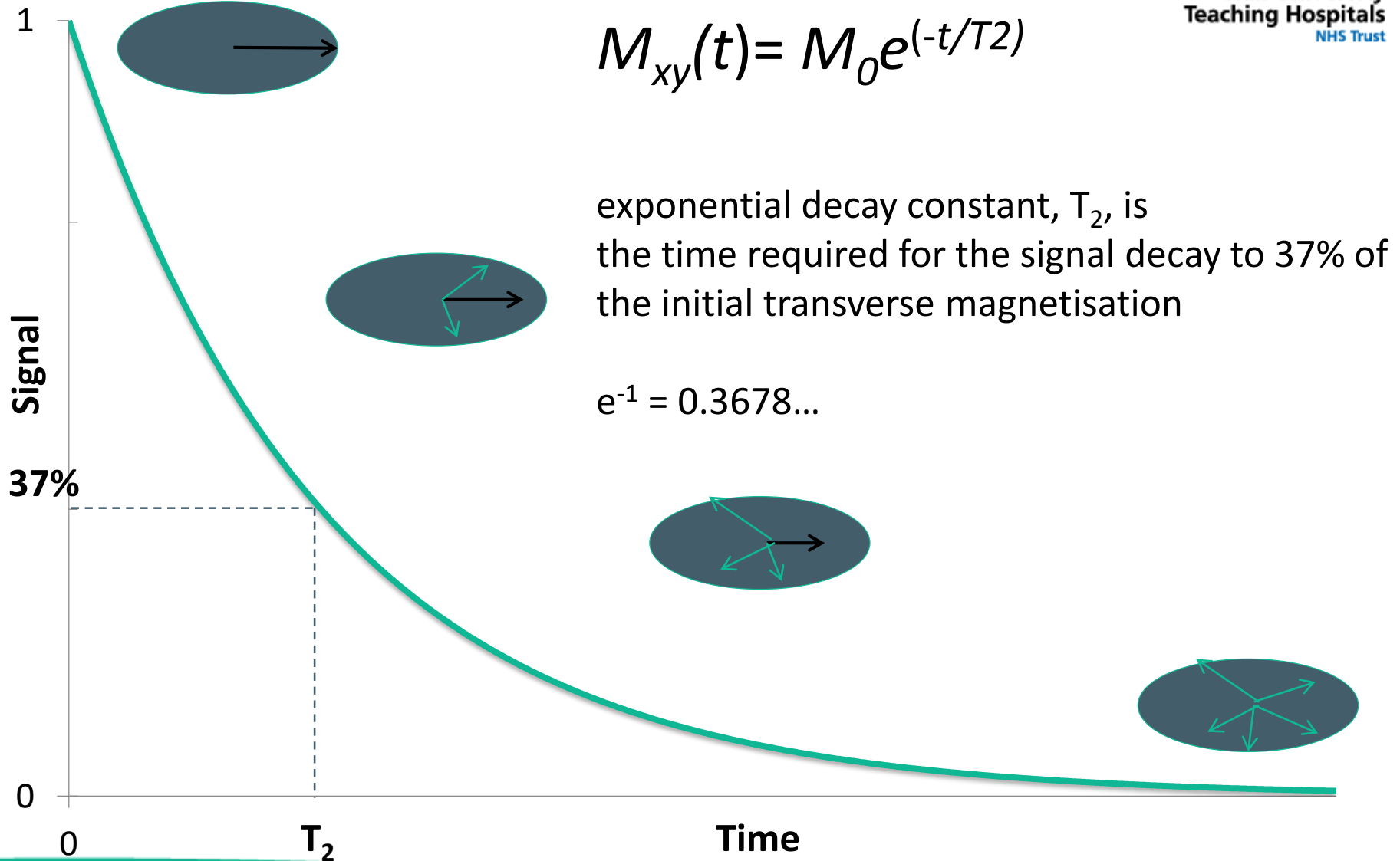


T_2 and T_2^*

T_2 Relaxation (spin-spin)

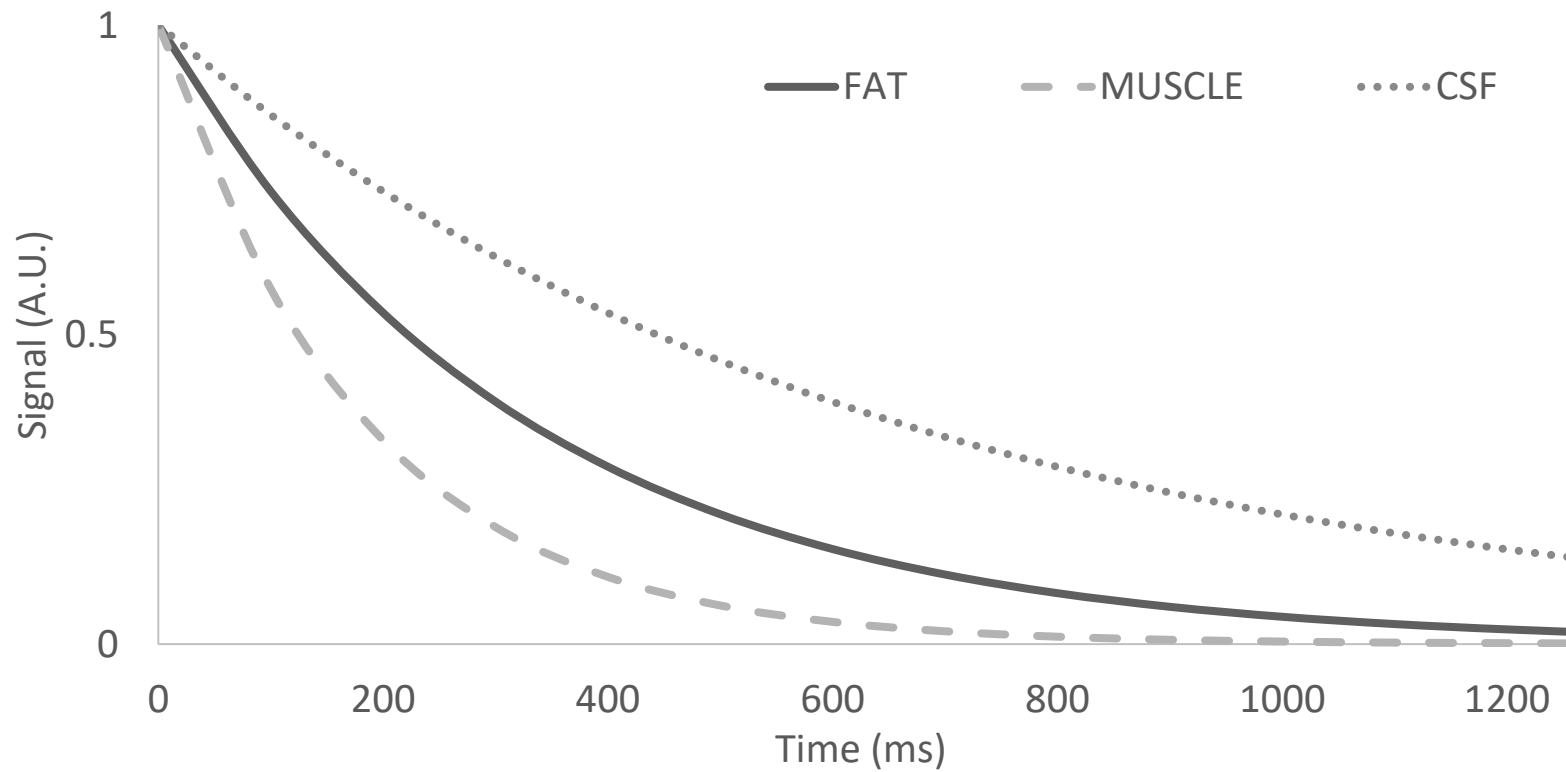


T_2 and T_2^*

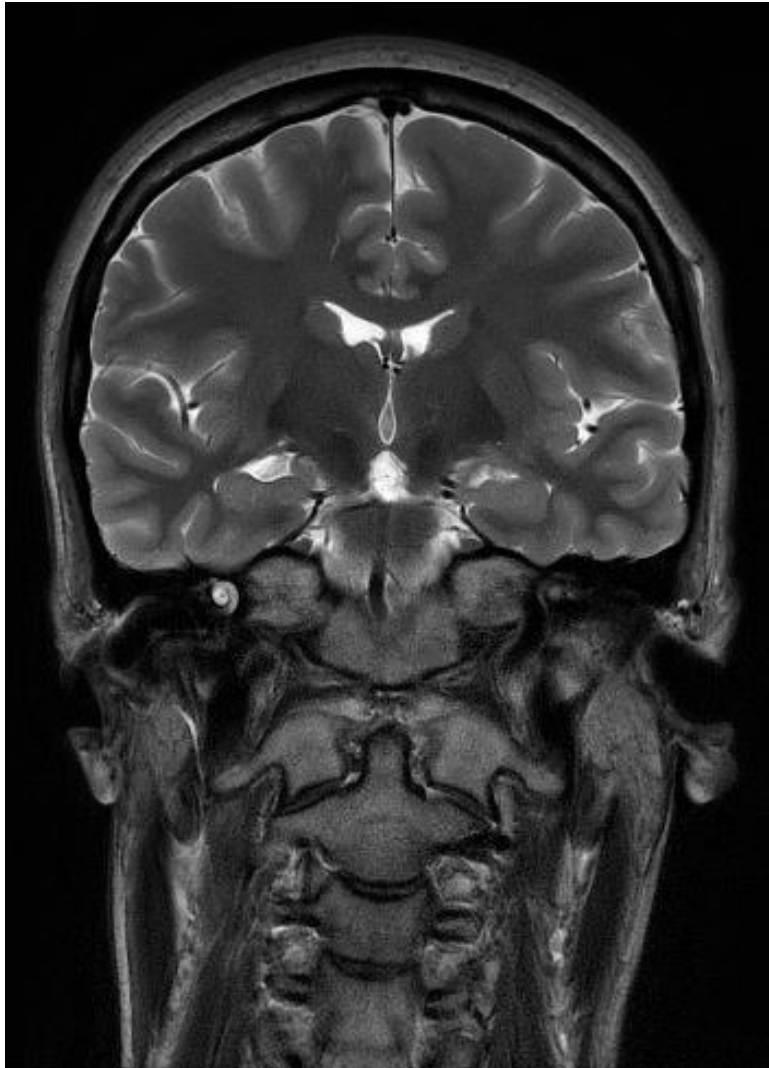


T_2 and T_2^*

Tissue	T_2 Relaxation Time (ms) (1.5T)
Fat	80
Muscle	45
CSF	160

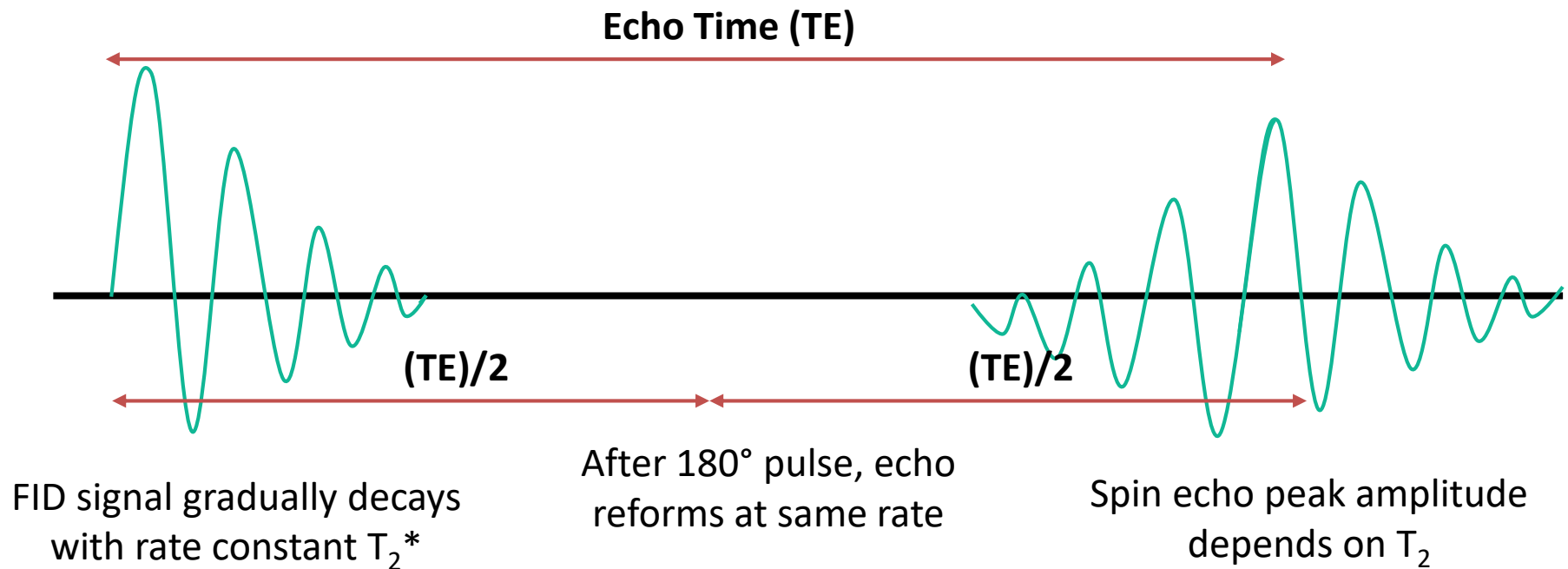


T_2 and T_2^*



Time of Echo (TE)

- Excitation of spins with the B_1 RF pulse creates the M_{xy} FID signal
- To separate the RF energy deposition and returning signal, an “echo” is induced to appear at a later time, with the application of a 180-degree RF inversion pulse.
- This can also be achieved with a gradient field and subsequent polarity reversal
- The TE is the time between the excitation pulse and the appearance of the peak amplitude of an induced echo, which is determined by applying a 180-degree RF inversion pulse or gradient polarity reversal at a time equal to $TE/2$
- TE is a parameter chosen by the scanner operator (often Radiographer)



Tissue	T_1 1.5T (ms)	T_2 1.5T (ms)
Fat	260	80
Liver	500	40
Muscle	870	45
White Matter	780	90
Grey Matter	900	100
CSF	2400	160

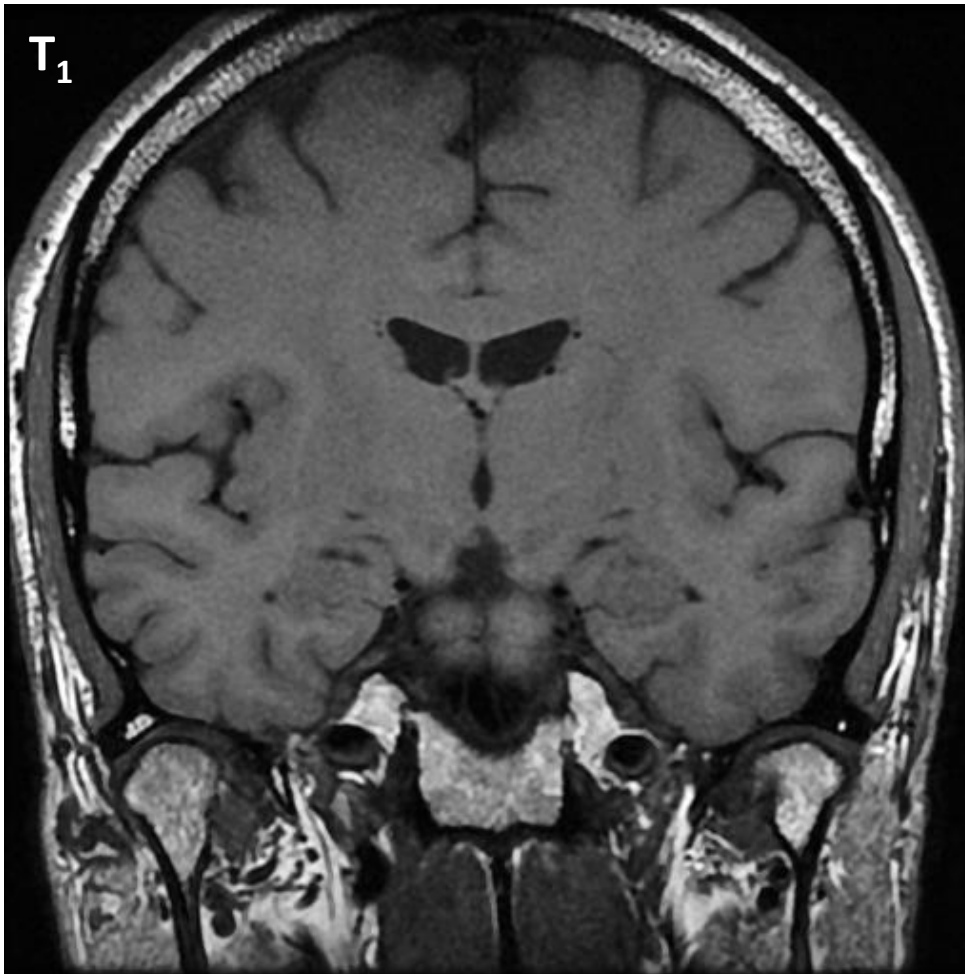
- Return to equilibrium (T_1) always occurs over a longer time period than T_2 relaxation
- $T_1 \gg T_2$

T_1 Weighting

- “ T_1 -weighted” sequences are designed to produce contrast primarily based on the T_1 characteristics of tissues (differences), with reduced emphasis of T_2 and proton density contributions to the signal
- Use a relatively short TR (350-700ms) to maximise the differences in longitudinal magnetisation recovery during the return to equilibrium, and a short TE (<30ms) to minimize T_2 decay during signal acquisition

T_1 Weighting

- To minimise T_2 decay and to maintain the differences in signal amplitude due to T_1 recovery, the TE time is kept short
- White and grey matter have intermediate T_1 values with intermediate signal amplitude, and CSF, with a long T_1 , has the lowest signal amplitude
- Short echo times preserve the T_1 signal differences by minimising transverse (T_2) decay
- **T_1 -weighted SE contrast therefore requires a short TR and a short TE**



T₁ Weighted Imaging

CSF – Dark

Grey Matter – Intermediate

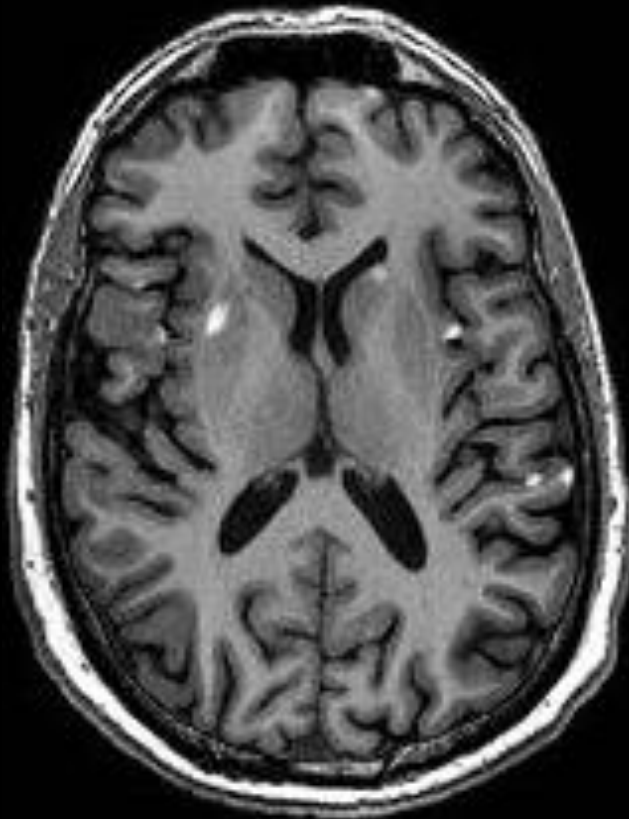
White Matter – Intermediate- Bright

Fat – Bright

Bone - Dark

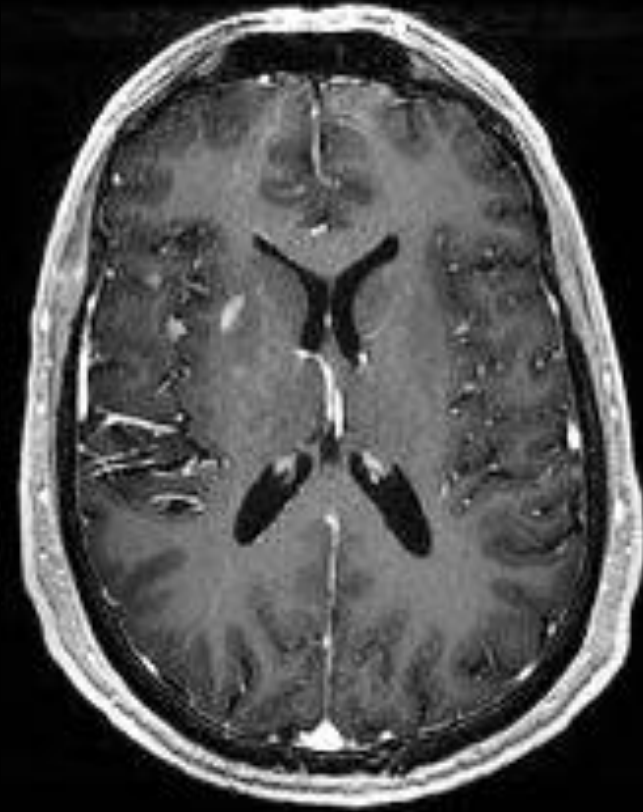
Tissue	T ₁ 1.5T (ms)
Fat	260
Liver	500
Muscle	870
White Matter	780
Grey Matter	900
CSF	2400

3D T_1 IR-FSPGR



$v^$

3D T_1 IR-FSPGR +C

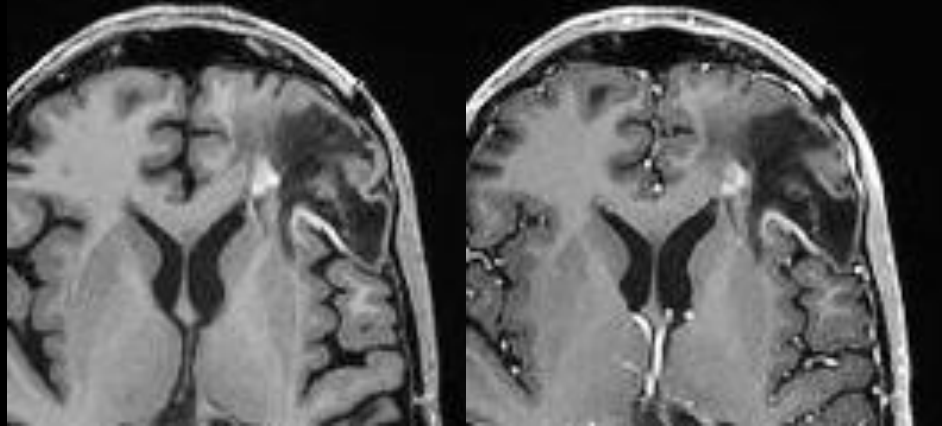


$v^$

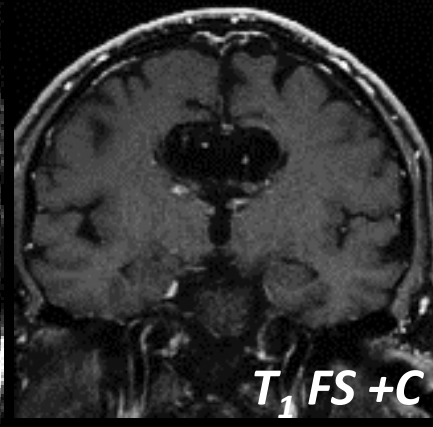
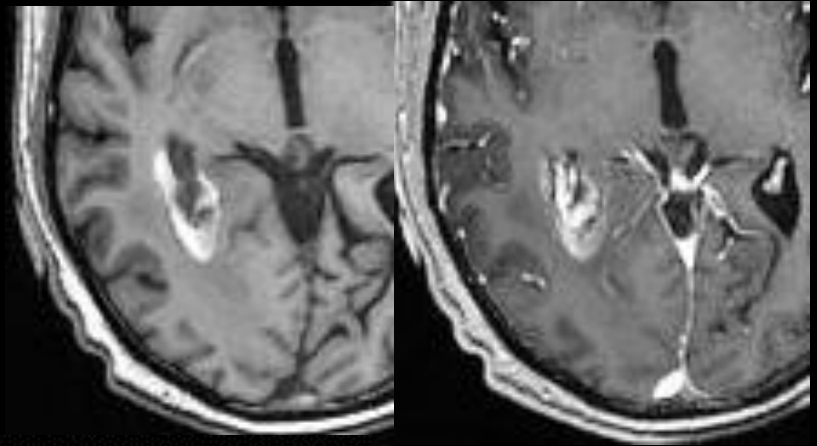
Short T_1 species prior to gadolinium contrast include:

- Fat
- Melanin
- Calcification
- Methaemoglobin
- Proteinaceous fluid

Calcification



Methaemoglobin

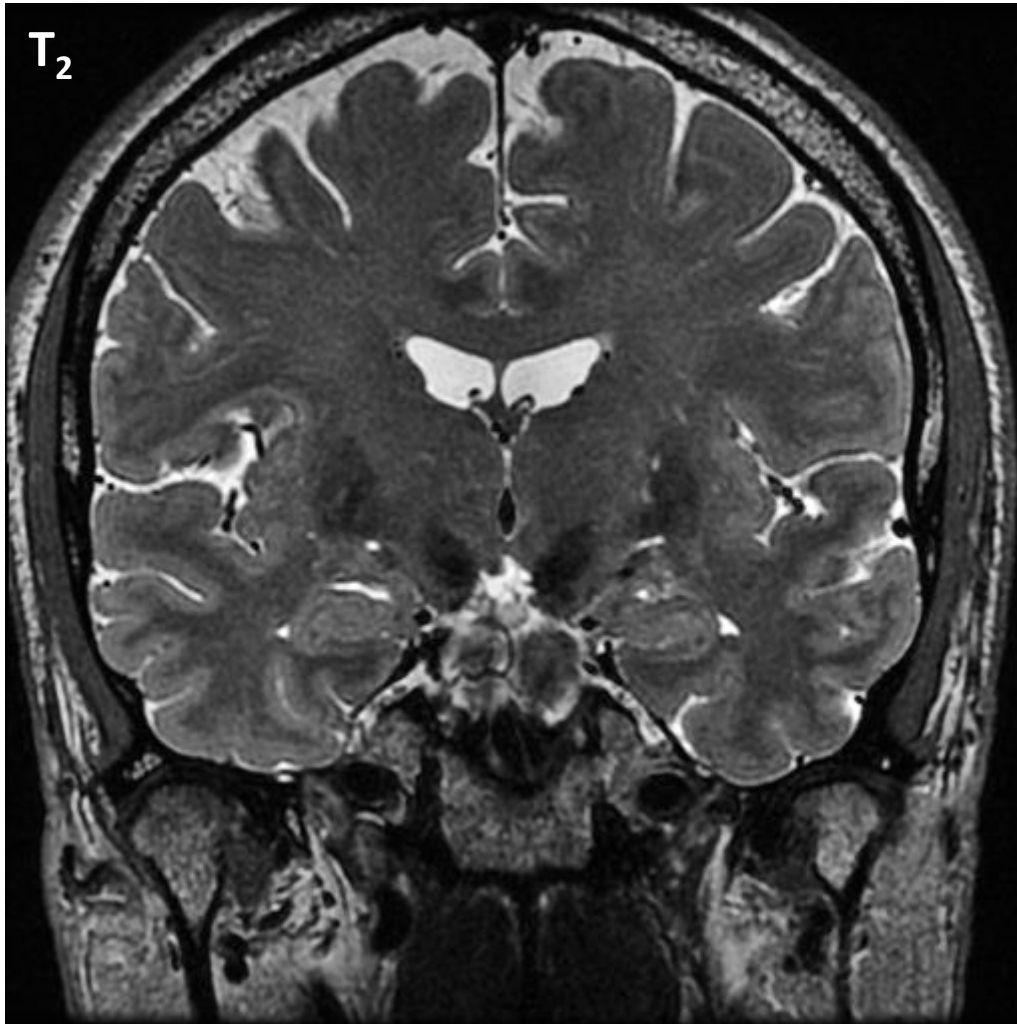


Fat

T_1 FS + C

T_2 Weighting

- Use a long TR ($>2500\text{ms}$) to minimise the differences in longitudinal magnetisation (T_1) recovery during the return to equilibrium, and a long TE ($\sim 100\text{ms}$) to maximise differences in T_2 decay during signal acquisition
- As TE is increases, more T_2 -weighted contrast is achieved, but at the expense of less M_{xy} signal and greater image noise
- **T_2 -weighted SE contrast requires a long TR and a long TE**



T₂ Weighted Imaging

CSF – Bright

Grey Matter – Intermediate-Bright

White Matter – Intermediate

Fat - Bright

Bone - Dark

Tissue	T ₂ 1.5T (ms)
Fat	80
Liver	40
Muscle	45
White Matter	90
Grey Matter	100
CSF	160

Proton Density Weighting

- Proton density contrast weighting relies mainly on differences in the number of magnetised protons per unit volume of tissue
- At equilibrium, tissues with a large proton density, such as lipids, fats and CSF, have a corresponding large M_z compared to other soft tissues
- Contrast based on proton density differences is achieved by reducing the contributions of T_1 recovery and T_2 decay
- T_1 differences are reduced by selecting a long TR value to allow substantial recovery of M_z
- T_2 differences of the tissues are reduced by selecting a short TE value
- **PD-weighted SE contrast therefore requires a long TR and a short TE**

P.D.



P.D. Weighted Imaging

Fat - Bright

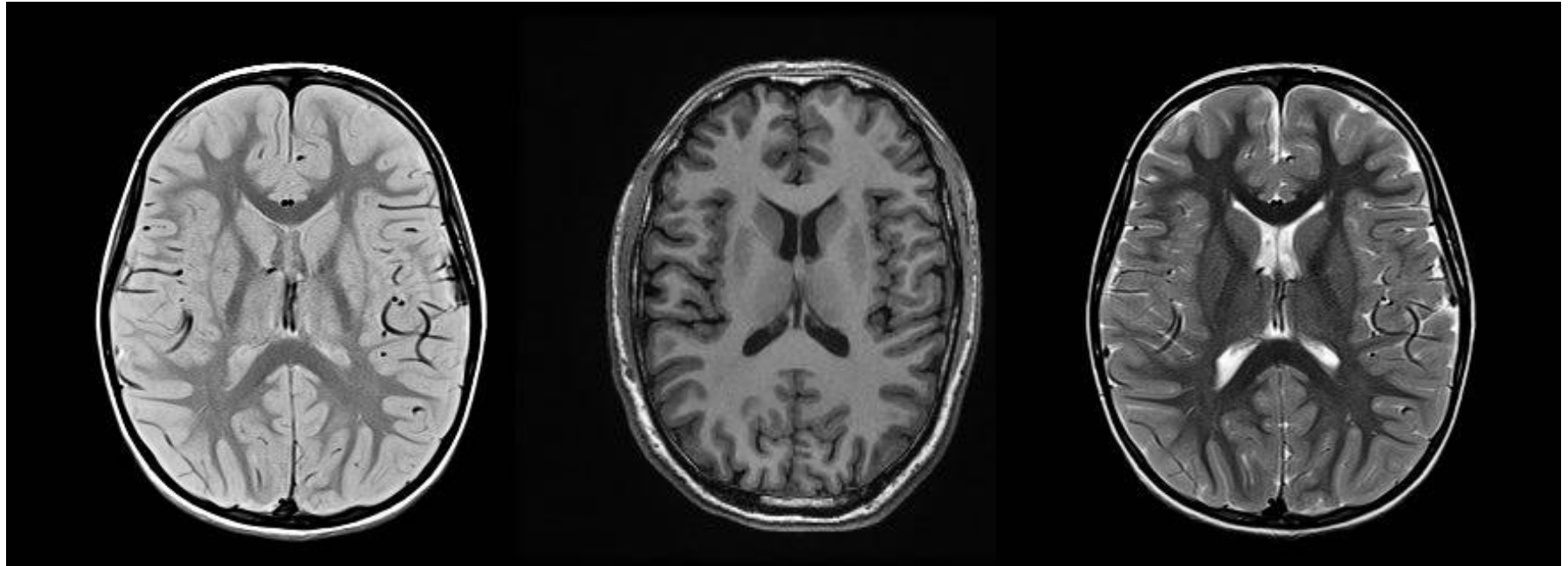
Fluid – Bright

Muscle – Intermediate

Cortical Bone - Dark

Spin Echo sequences can produce: T_1 , T_2 and P.D. weightings

$$\text{signal intensity} \propto \rho (1 - e^{-TR/T_1}) e^{-TE/T_2}$$



Proton Density

T_1 Weighted

T_2 Weighted

Short TE
Long TR

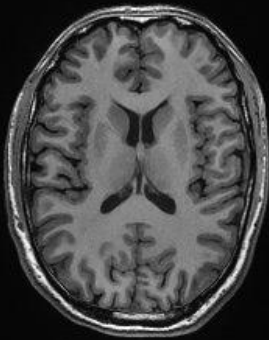

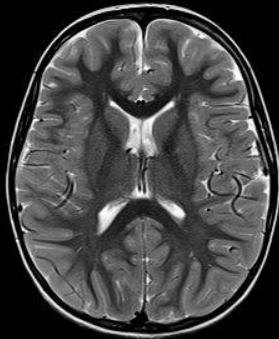
Short TE
Short TR

Long TE
Long TR

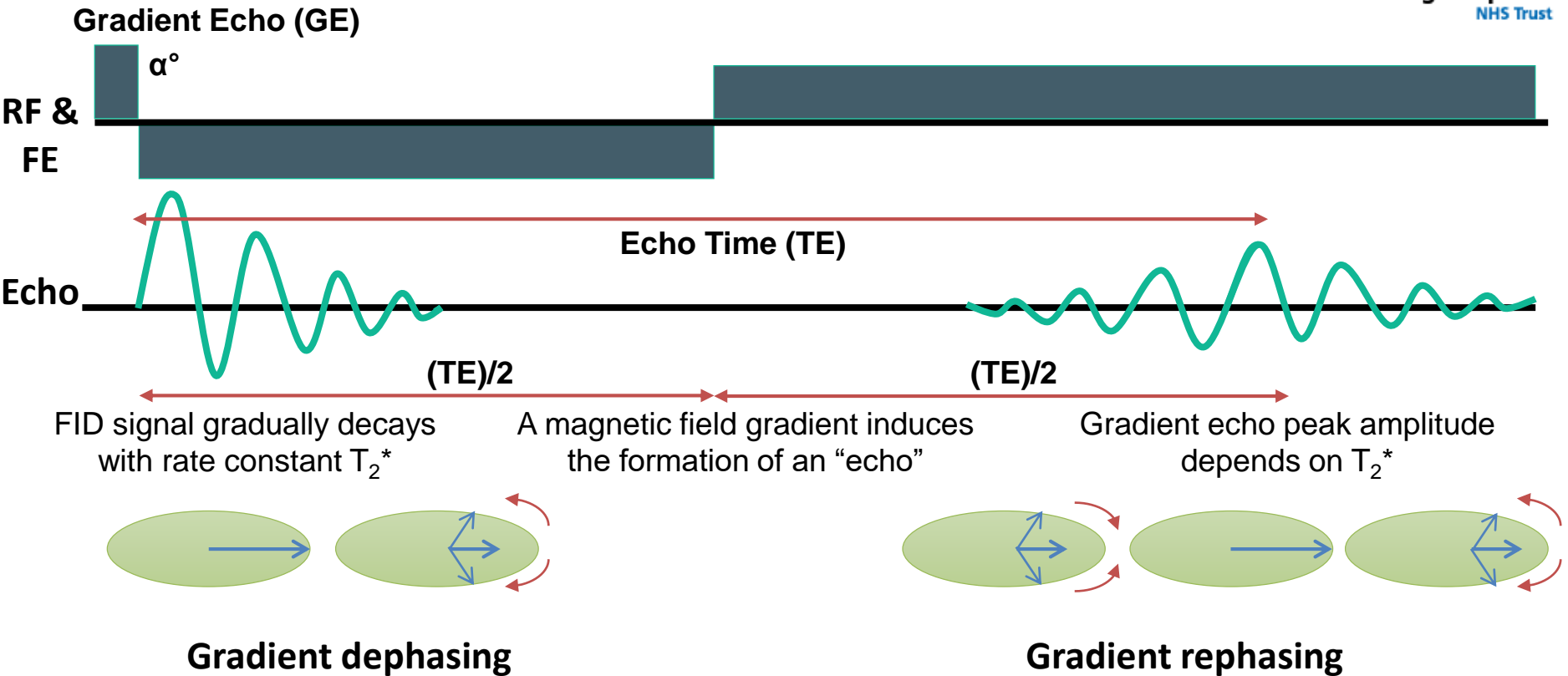
Tissue contrast can be manipulated by changing repetition time (TR) and echo time (TE)

Repetition Time (TR)
= time between 90° pulses

Echo Time (TE)
= 2 x time between 90° and 180° pulses

	Short TR		Long TR	
Short TE				
Long TE				

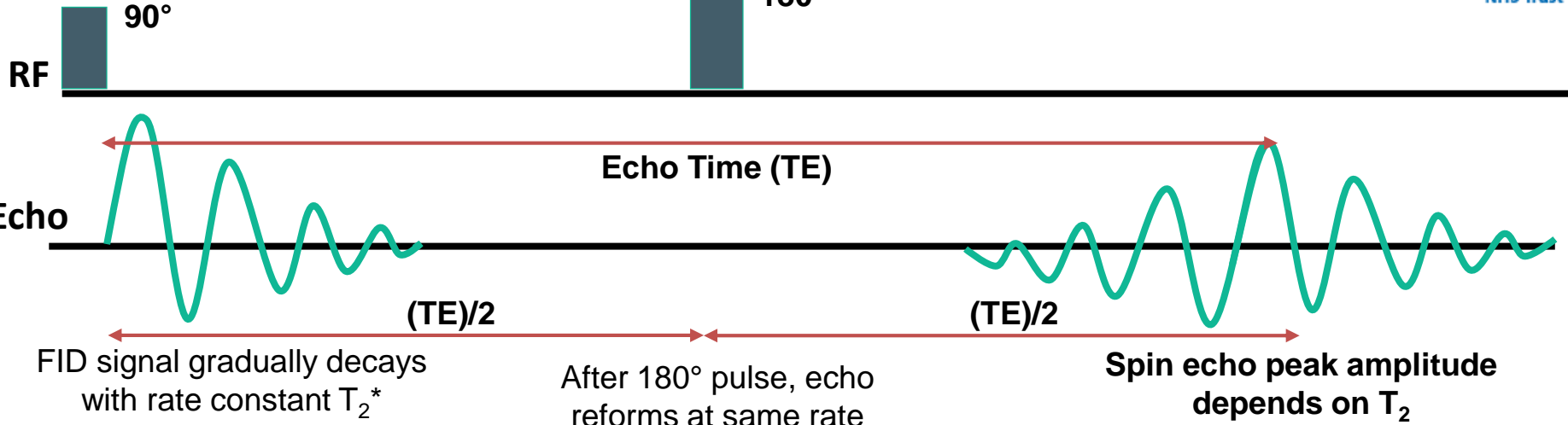
- Gradient echo (GE/GRE) sequences can utilise a range of flip angles (α)
- Magnetic field gradients are then applied in one direction and then reversed to induce an echo
- The magnetic field gradient replaces 180° pulse used by spin echo sequences
- For a FID signal generated under a linear gradient (frequency encoding gradient), the transverse magnetisation dephases rapidly as the gradient is applied
- After a predetermined time, near instantaneous reversal of the GE polarity will rephase the protons and produce a GE that occurs when the opposite gradient polarity of equal strength has been applied for the same time as the initial gradient
- **Gradient Echo sequences can produce T_1 , T_2^* and P.D. weightings**



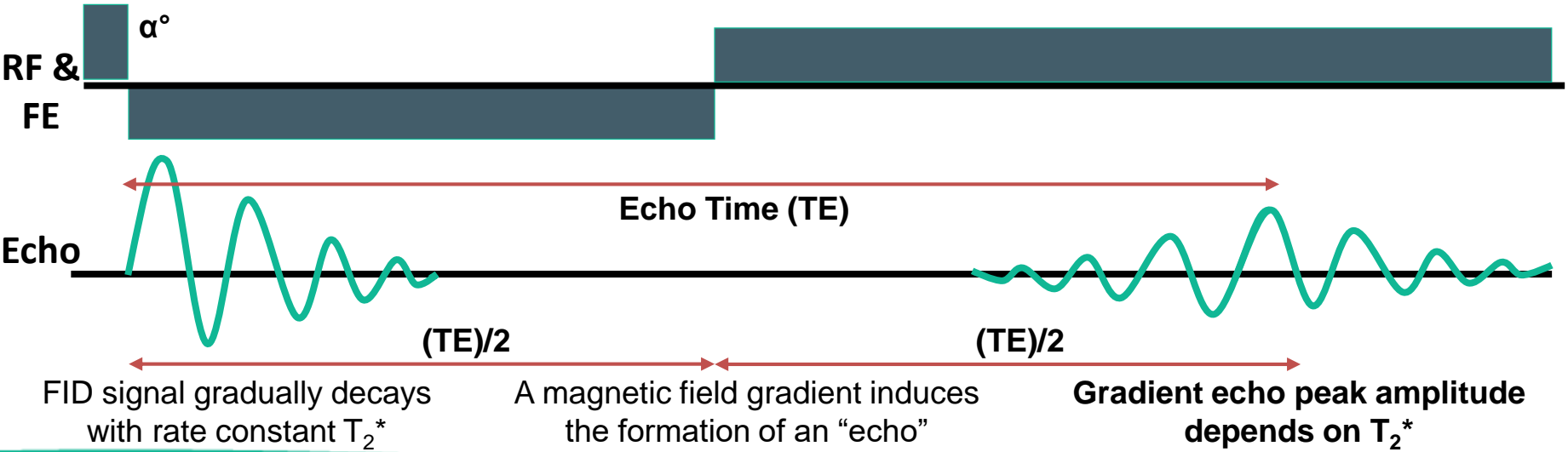
- Frequency encoding gradient is initially applied negatively to speed up the dephasing of the FID. Then its polarity is reversed producing rephasing of the gradient echo

T_2 and T_2^*

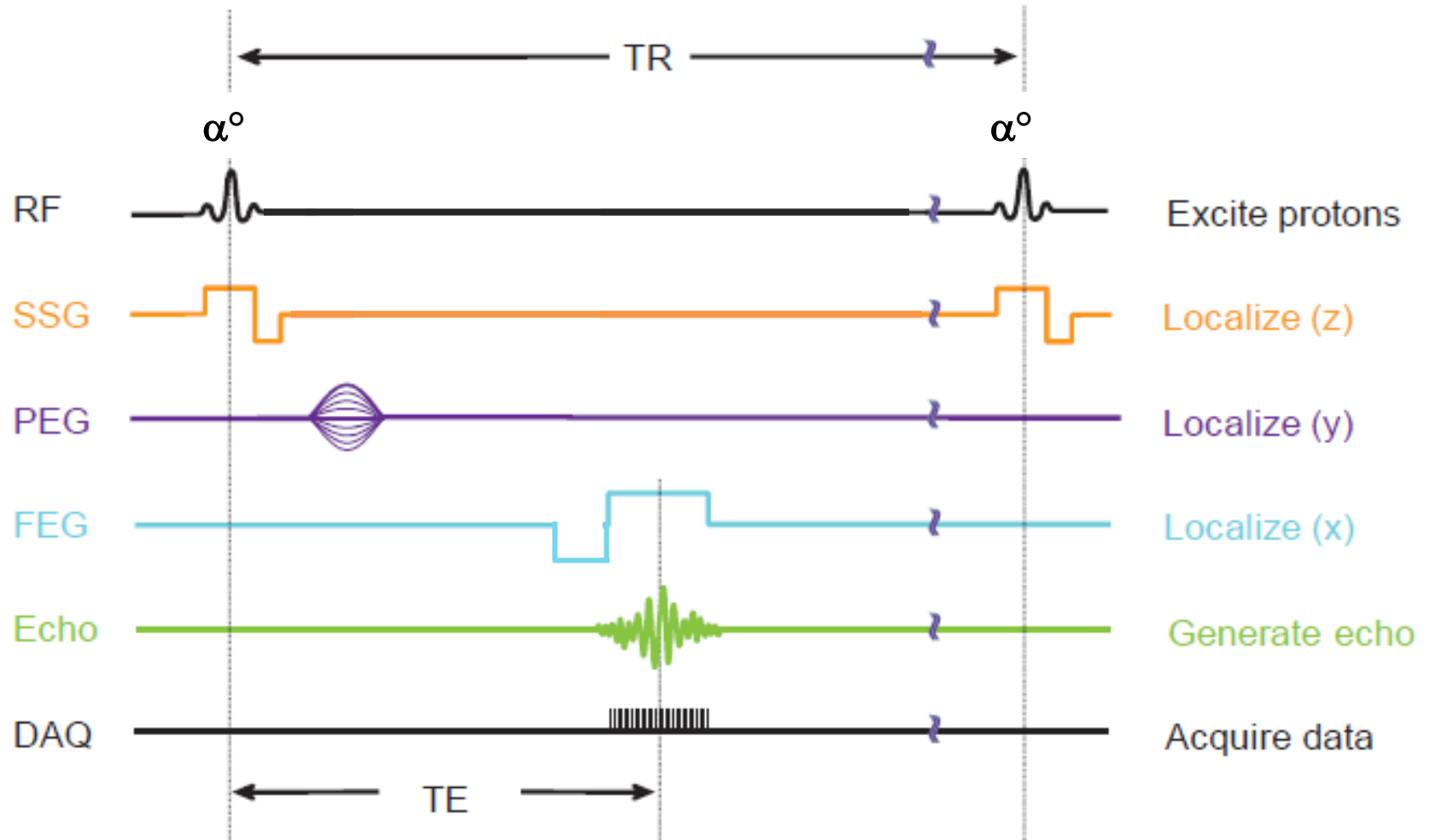
Spin Echo (SE)



Gradient Echo (GE)



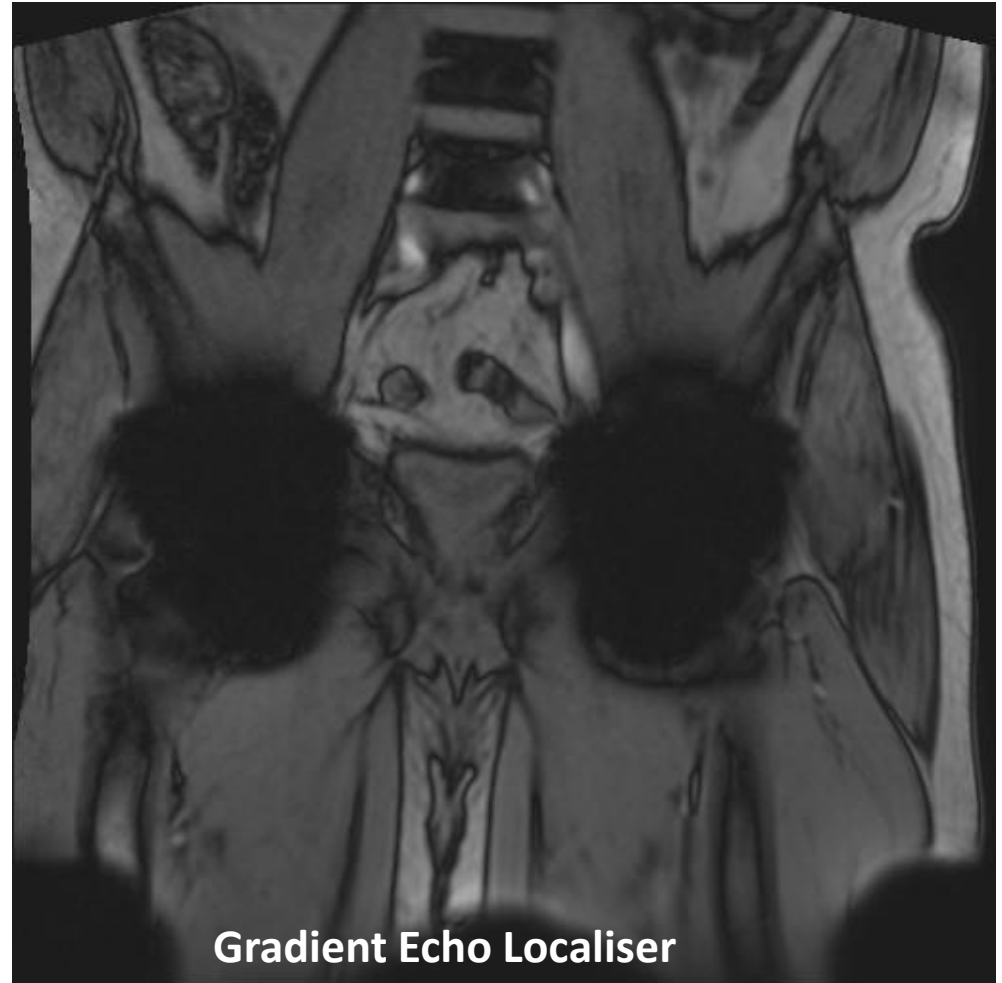
Gradient Echo Sequence



T_2 and T_2^*

T_2/T_2^*

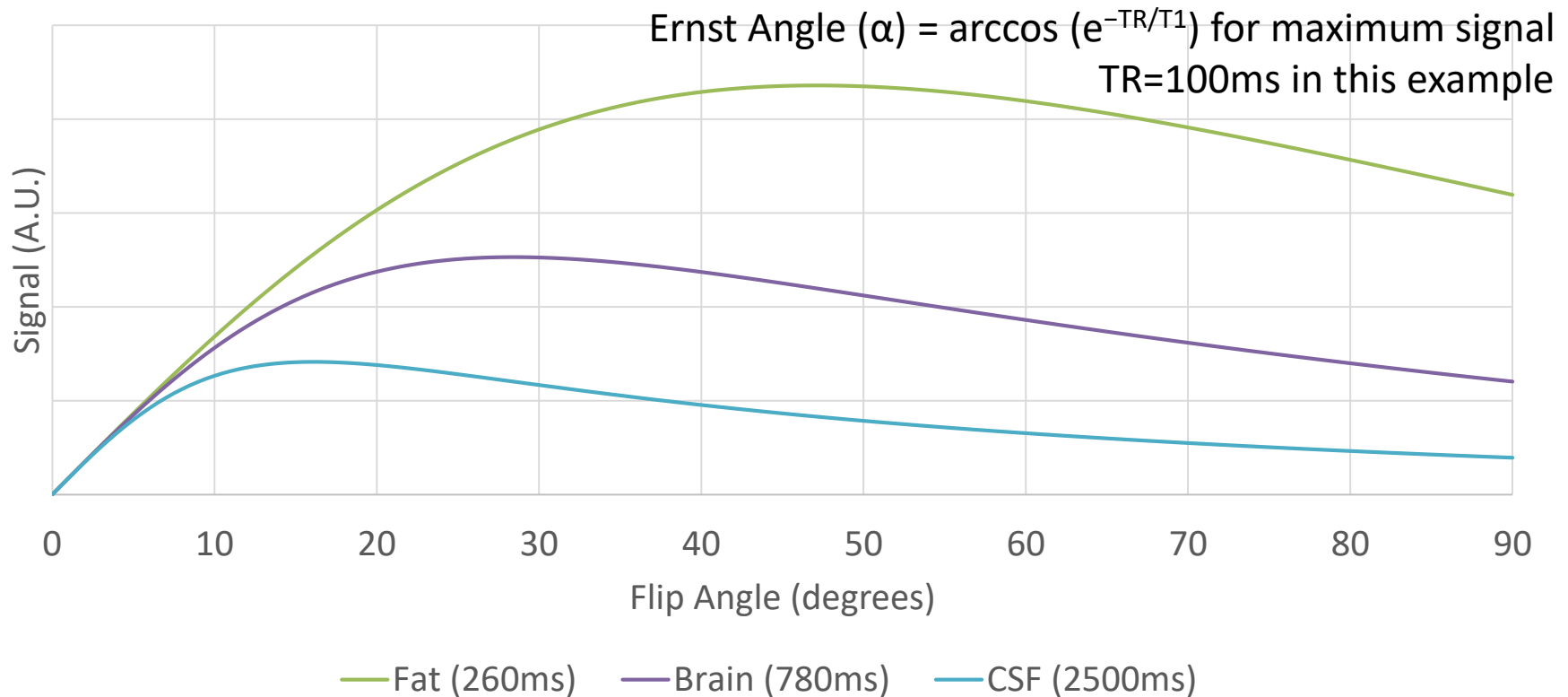
- In the absence of a 180° rephasing pulse, field inhomogeneities are maintained and images are T_2^* (not T_2) weighted
- GE sequences are thus more sensitive to magnetic susceptibility artefacts than spin echo sequences



Gradient Echo Image Contrast

- Flip angle (α):
 - Small α → reduced T₁ weighting
 - Large α → increased T₁ weighting
 - ** Small flip angles minimise T₁-weighting because the longitudinal magnetisation (M_z) of tissues are less well differentiated*
- TE:
 - Short TE → reduced T₂* weighting
 - Long TE → increased T₂* weighting.
- TR:
 - Short TR → reduced T₁ weighting
 - Long TR → increased T₁ weighting

Gradient Echo Image Contrast

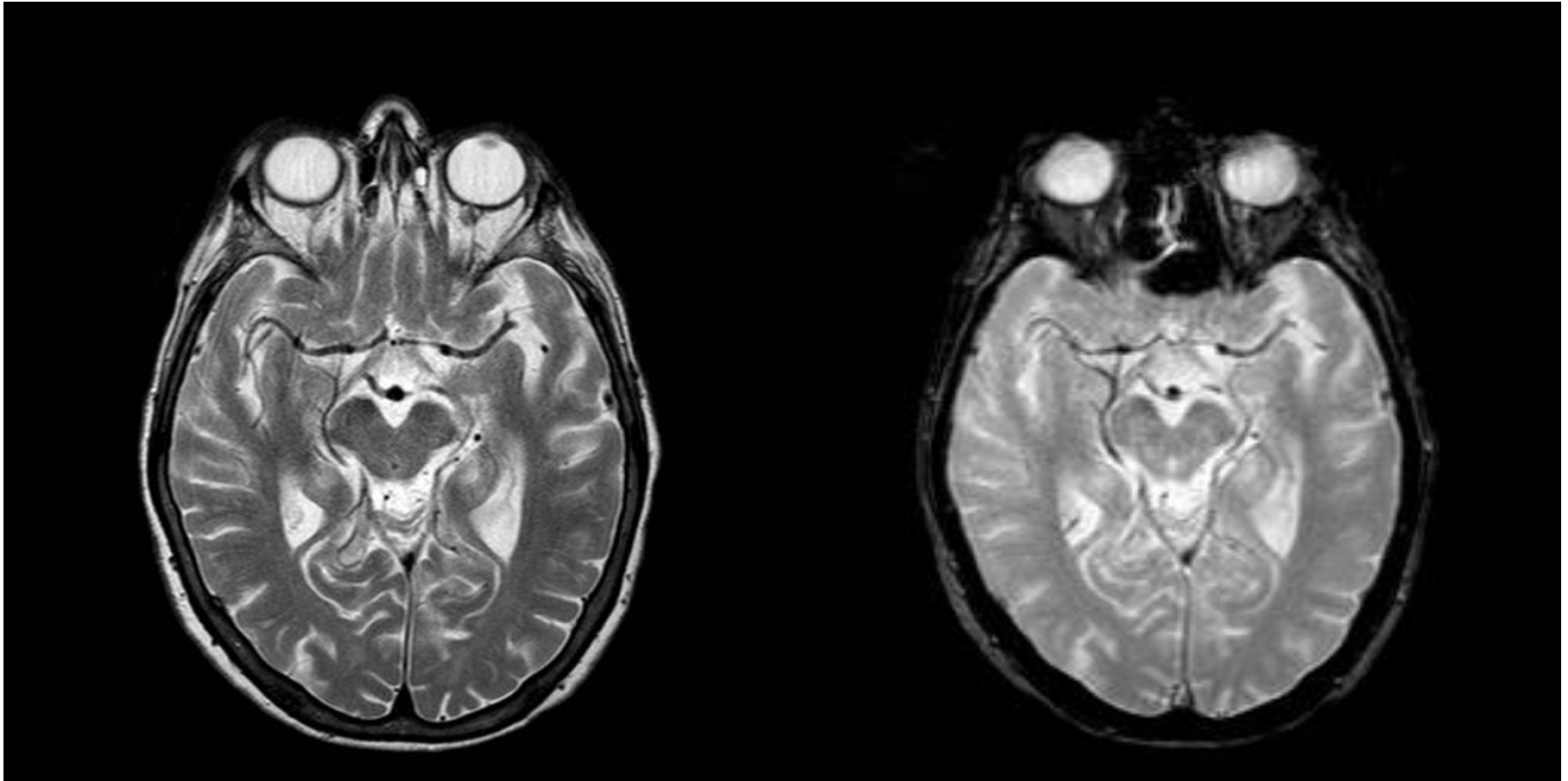


Flip angle:

T_1 weighting	Flip=high	TR=short	TE=short
T_2^* weighting	Flip=low	TR=long	TE=long
P.D weighting	Flip=low	TR=long	TE=short

T_2 and T_2^*

T_2^* Weighted Imaging

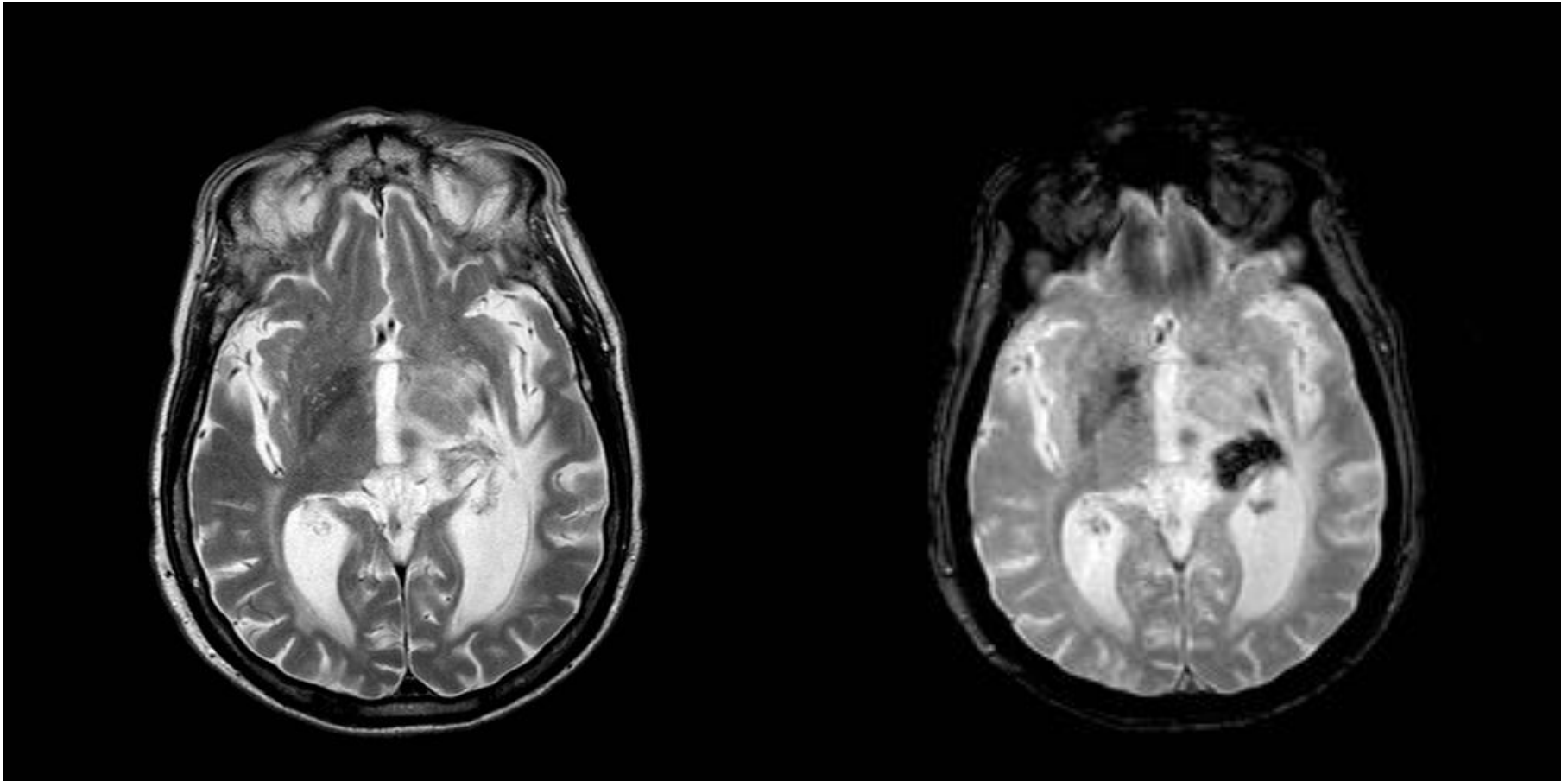


Spin Echo T_2

Gradient Echo T_2^*

T_2 and T_2^*

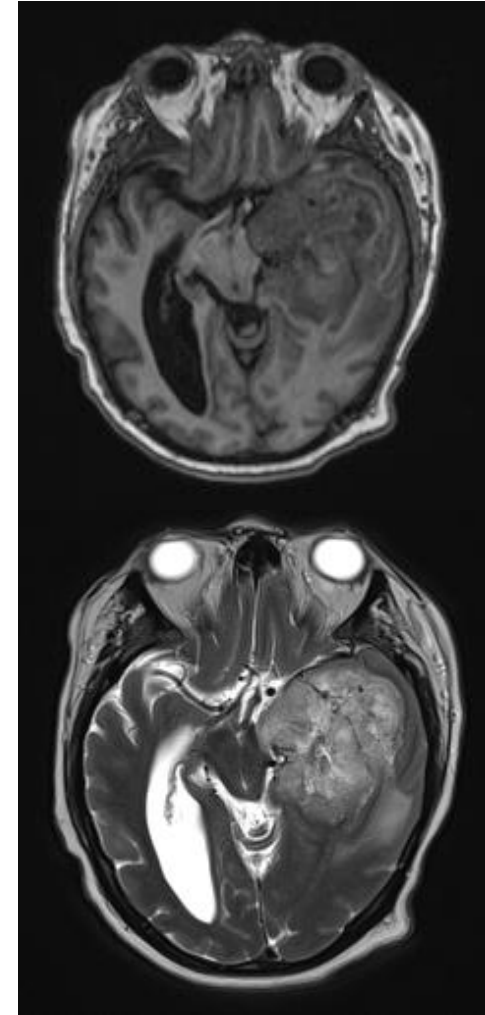
T_2^* Weighted Imaging



Spin Echo T_2

Gradient Echo T_2^*

- Tissue contrast observed from conventional T_1 or T_2 weighted images may not be sufficient to delineate the disease or identify higher grade transformation
- By using a contrast agent, it is possible to further enhance the imaging characteristics of tissue
- Contrast agents are administered intravenously into the body



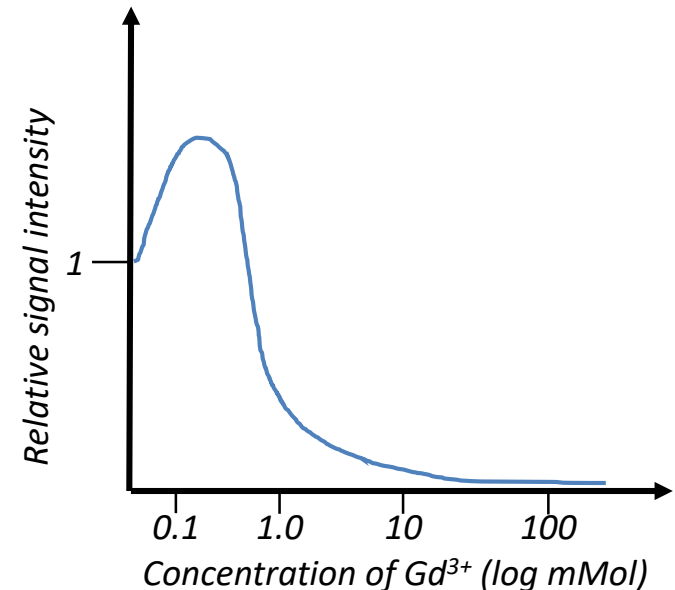
- In MRI, gadolinium based contrast agents (GBCA) are used
 - CT – iodinate contrast agents
- Most gadolinium (Gd) paramagnetic contrast agents have five unpaired electrons, each with their own magnetic moments, able to affect both T_1 and T_2 relaxation times
- This is made possible by the local paramagnetic susceptibility that occurs in the vessels/tissues where it accumulates
 - Unpaired electrons interact with neighbouring water molecules
- The T_1 shortening effect that occurs, leads to an increase in signal intensity observed on a T_1 weighted image. This is known as “enhancement”
- A T_2 shortening effect can also be observed on T_2 / T_2^* weighted images but with reduced effect

- Gd^{3+} affects both the longitudinal and transverse relaxation rates

$$\frac{1}{T_1} = \frac{1}{T_{10}} + r_1 C \quad \frac{1}{T_2} = \frac{1}{T_{20}} + r_2 C$$

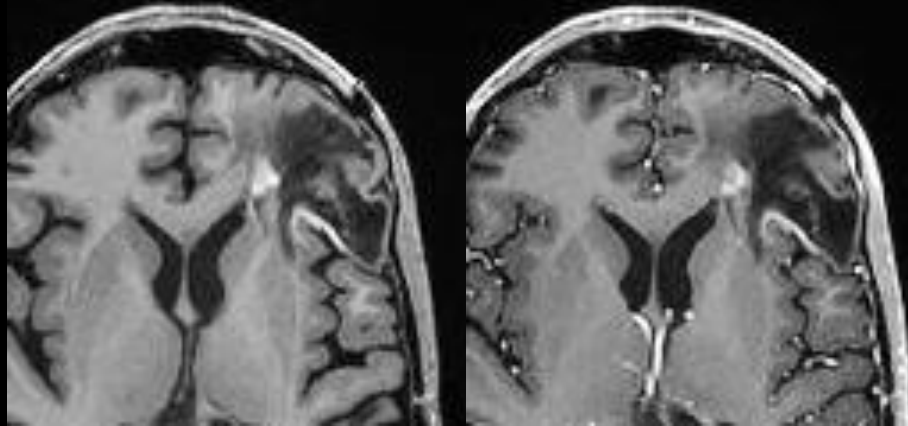
$T_{1(2)}$ are the reduced relaxation times
 $T_{10(20)}$ are the native relaxation times
 $r_{1(2)}$ are the contrast agent relaxivities
 C is the concentration of contrast

- T_1 shortening effect leads to increase in signal on T_1 weighted image
- T_2 shortening effect leads to decrease in signal on T_2^* weighted image
- At high concentration T_2 shortening effect will predominate

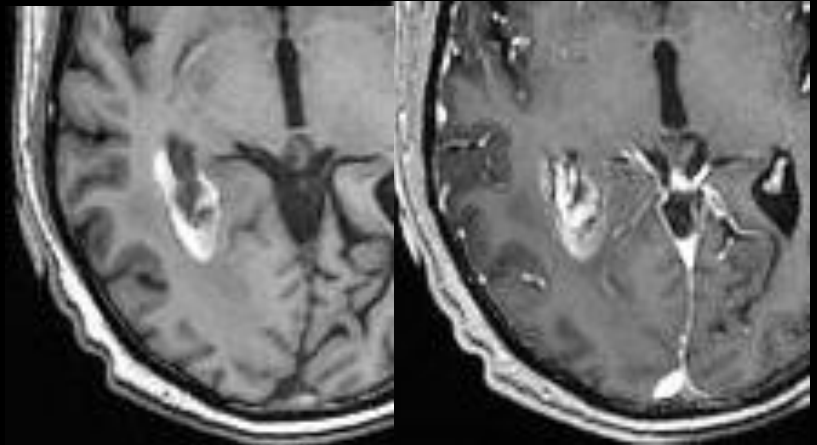


Native T_1 species

Calcification



Methaemoglobin

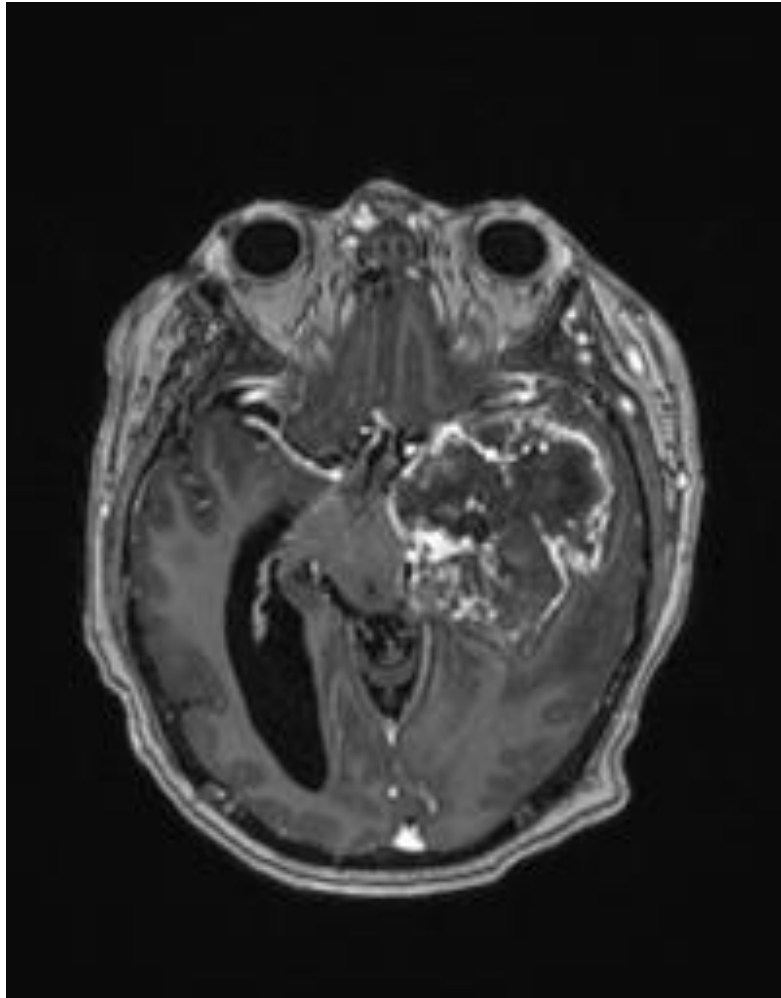


Short T_1 species prior to gadolinium contrast include:

- Fat
- Melanin
- Calcification
- Methaemoglobin
- Proteinaceous fluid

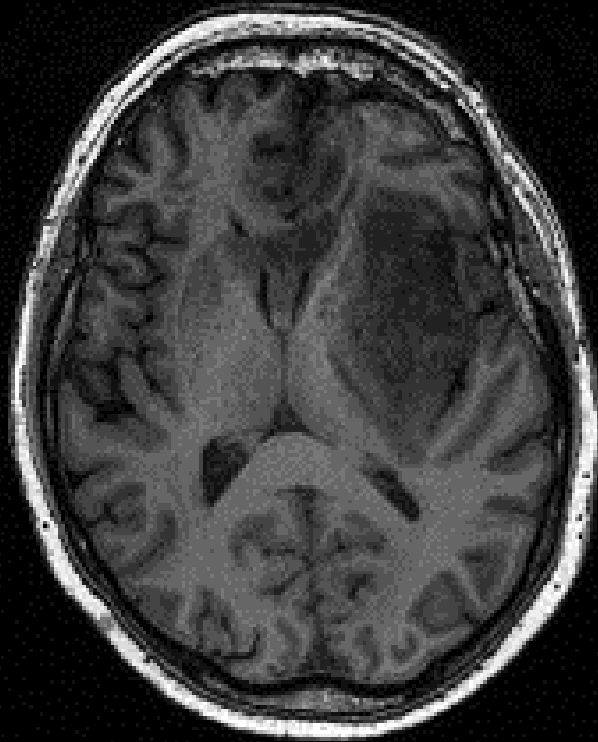


Melanin

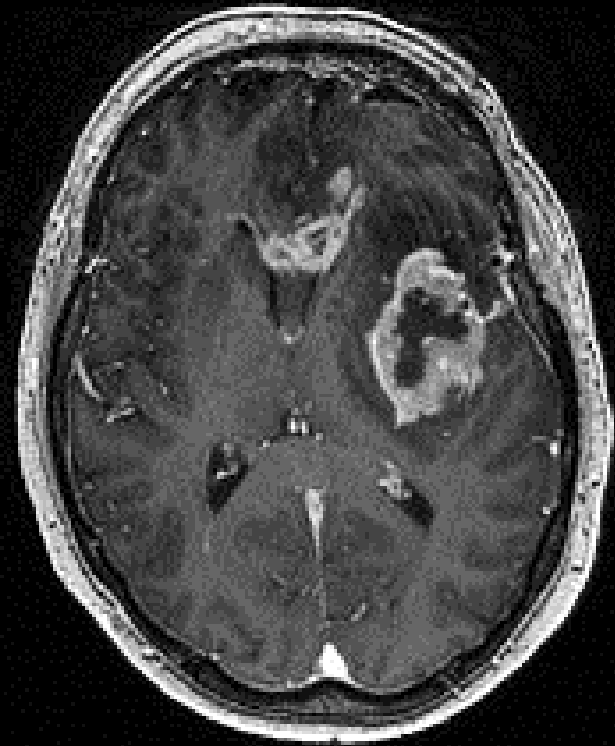


- In neuroimaging post-gadolinium T_1 weighted images give greatest sensitivity for detecting pathological processes that break down the blood-brain barrier (BBB)
- Tumours, infection & inflammation all disrupt BBB
- Gadolinium agents will not pass through healthy BBB

Pre/Post- T_1 Contrast



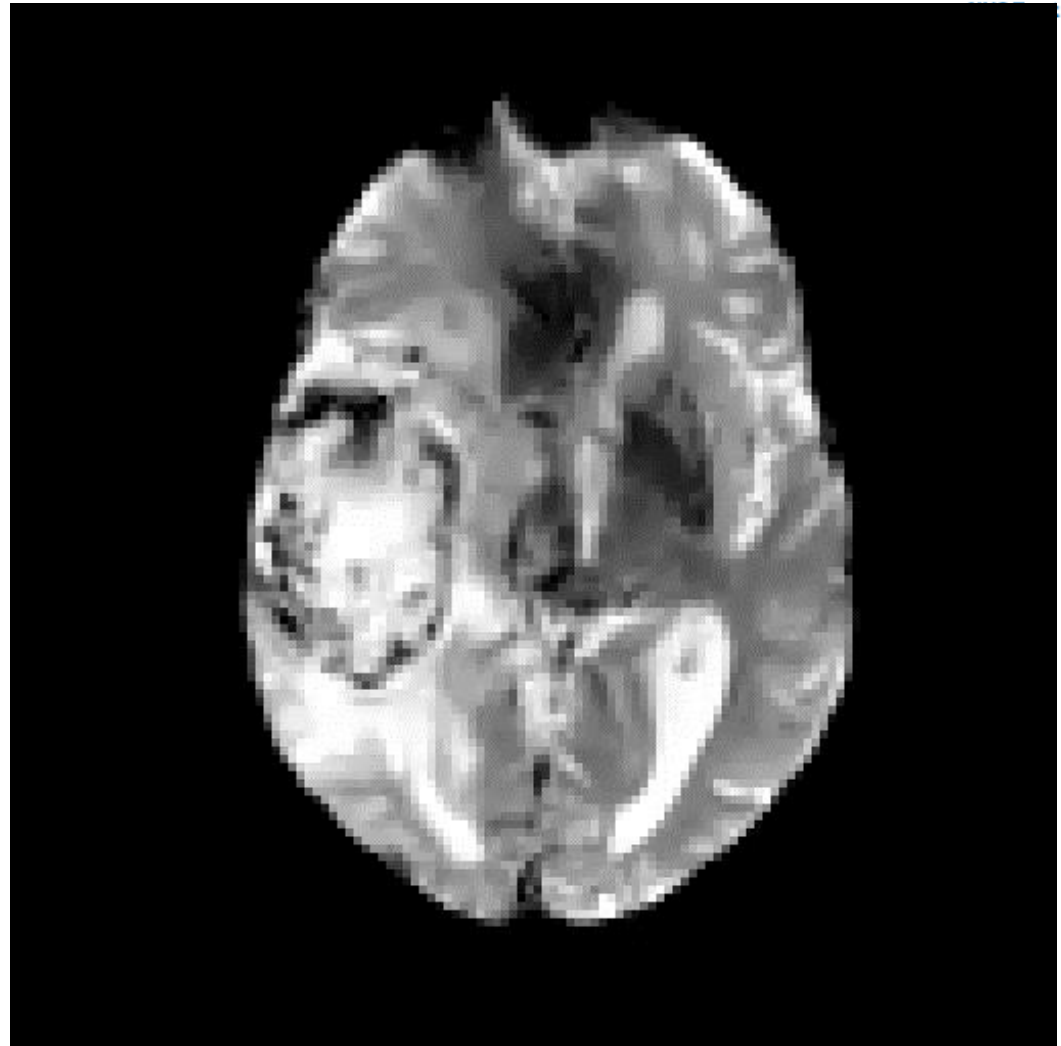
T1 Pre-contrast



T1 Post-contrast

Dynamic susceptibility contrast (DSC) MR perfusion:

- Analyse dynamic signal changes following a bolus of Gd^{3+} contrast agent
- Observe first pass through tissue using a series of T_2 - or T_2^* -weighted MR images
- Susceptibility effect of the paramagnetic contrast agent leads to a signal decrease

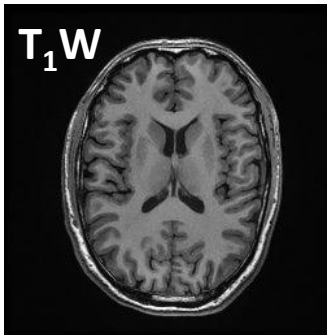
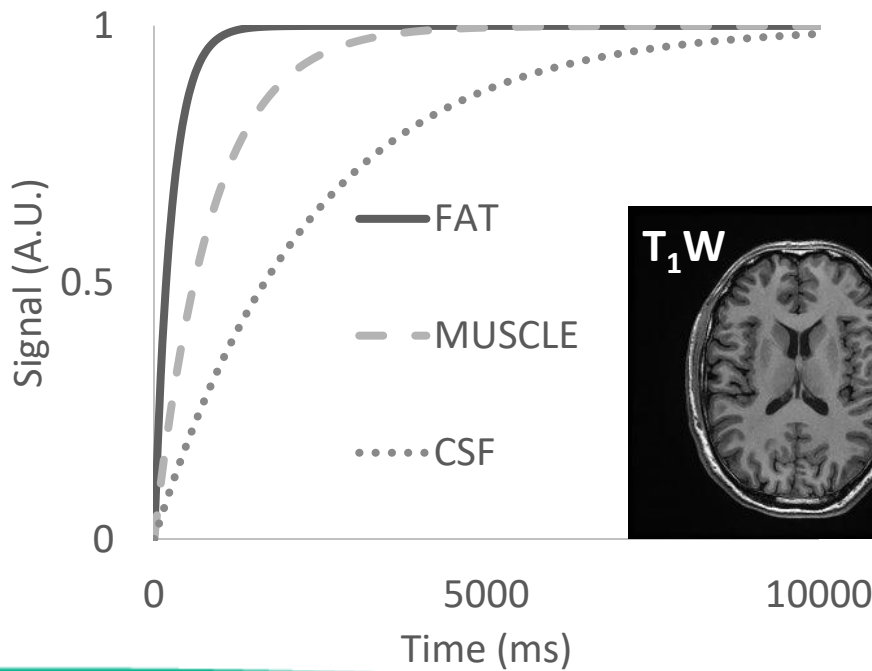


Quantitative magnetic resonance imaging (qMRI)

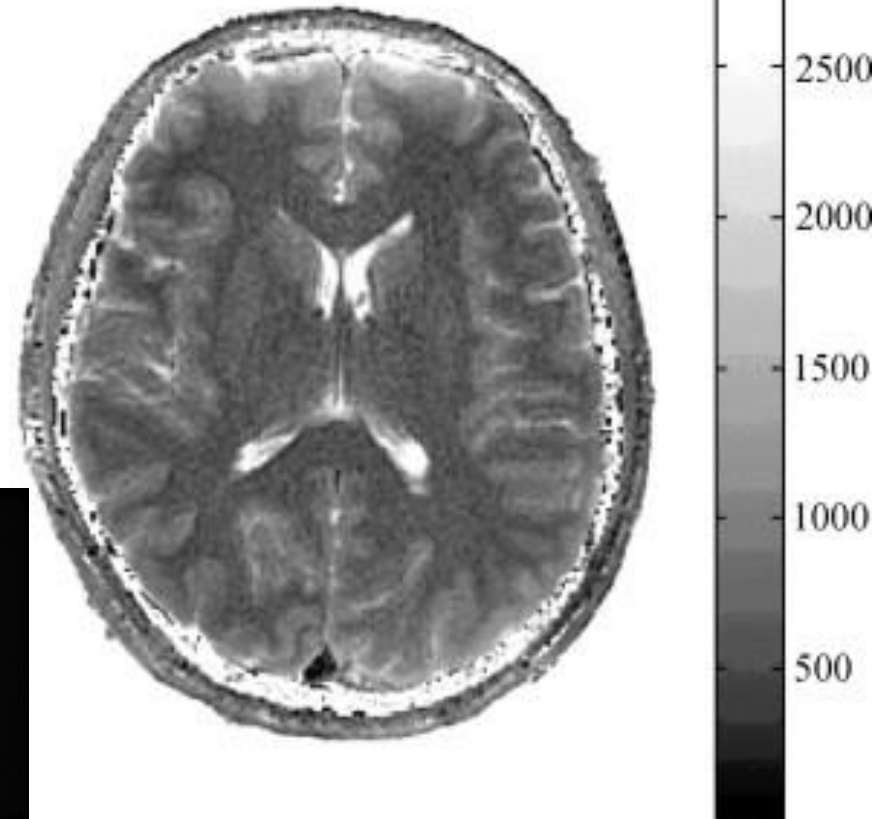
- Most conventional imaging in MRI is “weighted”
- The image contrast in “ T_1 weighted” MRI is predominantly T_1 weighted but contains a small T_2 contribution
- The pixel values stored in the image are also arbitrary and differ between visit and vendor.
- Quantitative magnetic resonance imaging (qMRI) attempts to absolutely quantify 1 parameter (T_1 , T_2 , P.D, fat-fraction, apparent diffusion coefficient) and should be repeatable across all scanners/time points.
- Mapping techniques are limited by time, motion and interpretation
 - Most radiologists are used to looking at T_1 weighted imaging not T_1 maps.

T₁ Maps

Tissue	T ₁ 1.5T
Fat	260
Muscle	870
CSF	2400



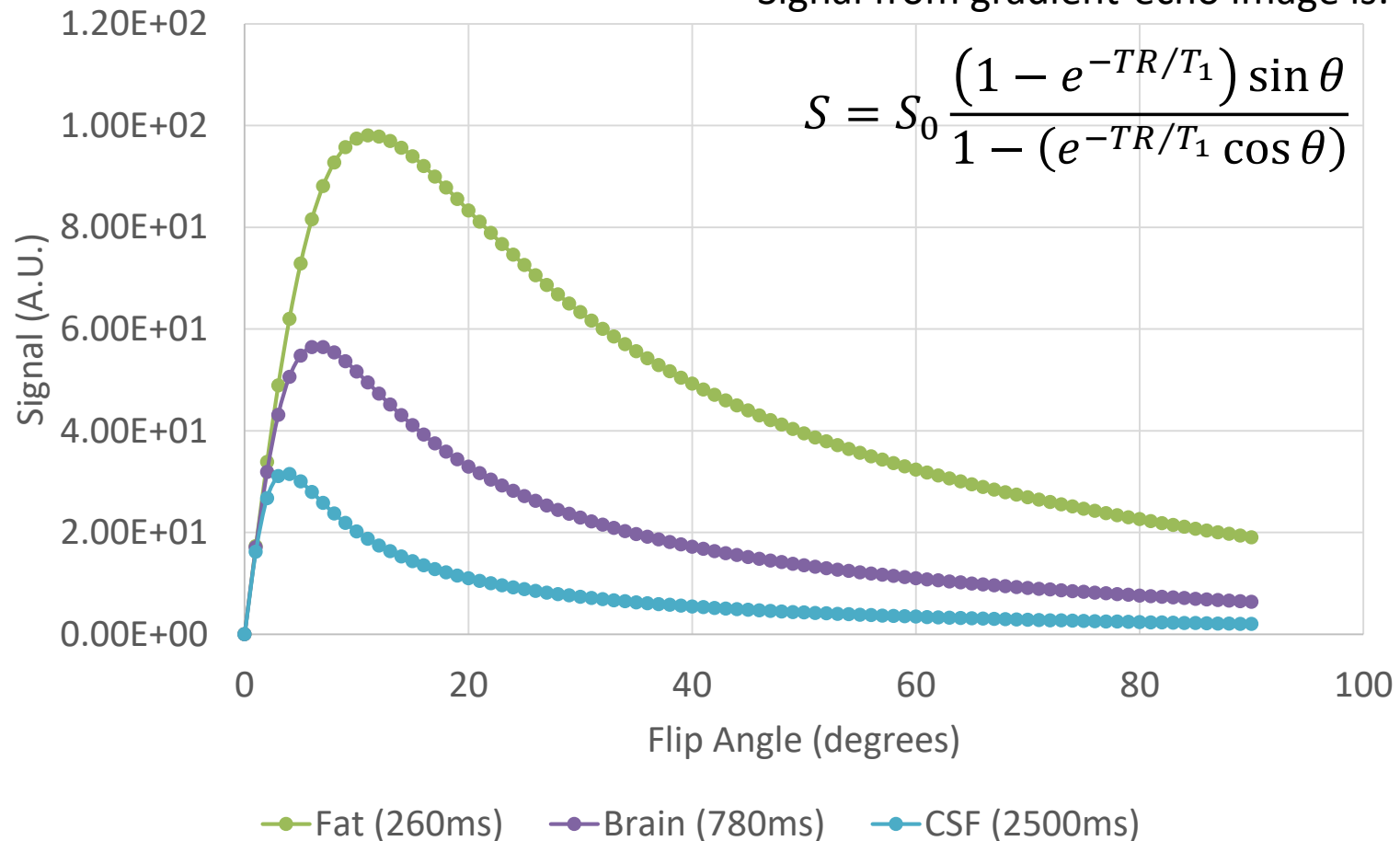
T₁ Map



Rapid spin-lattice relaxation time mapping incorporating flip angle calibration in quantitative magnetic resonance imaging. *Progress in Natural Science* 18(2008)1077–1081

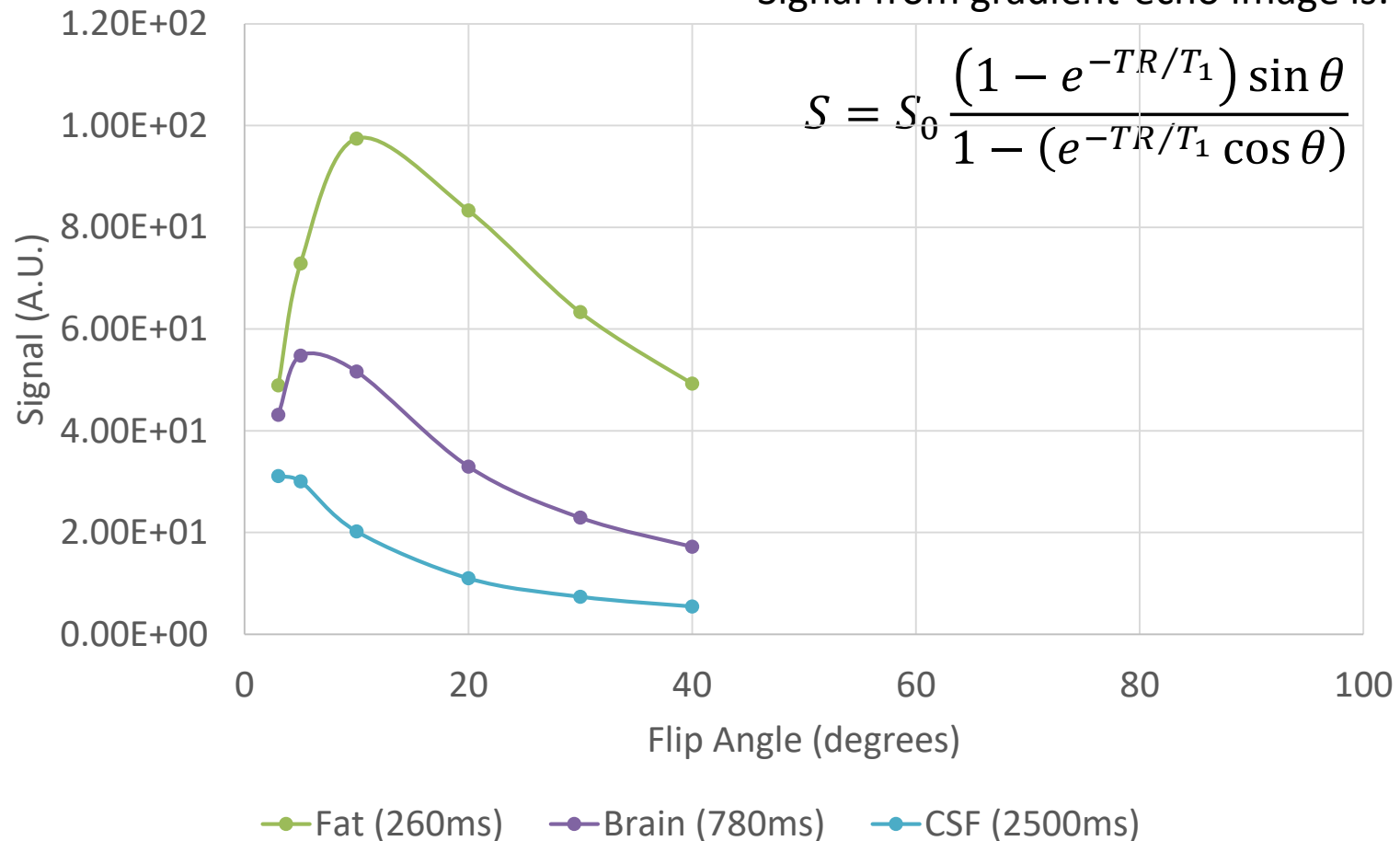
Signal from gradient-echo image is:

$$S = S_0 \frac{(1 - e^{-TR/T_1}) \sin \theta}{1 - (e^{-TR/T_1} \cos \theta)}$$

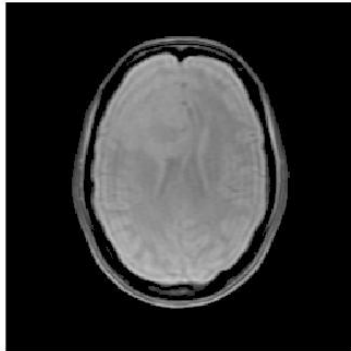


Signal from gradient-echo image is:

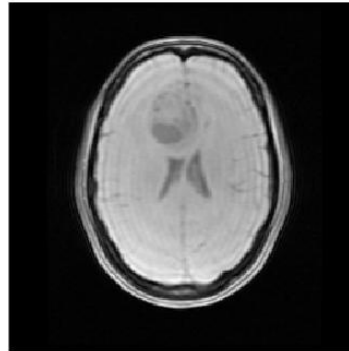
$$S = S_0 \frac{(1 - e^{-TR/T_1}) \sin \theta}{1 - (e^{-TR/T_1} \cos \theta)}$$



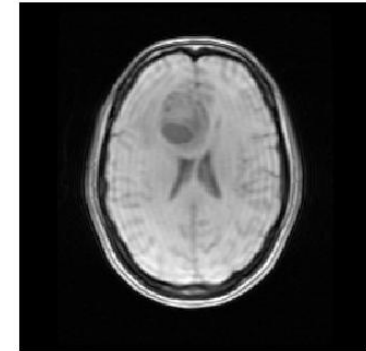
Variable Flip Angle T_1 Mapping



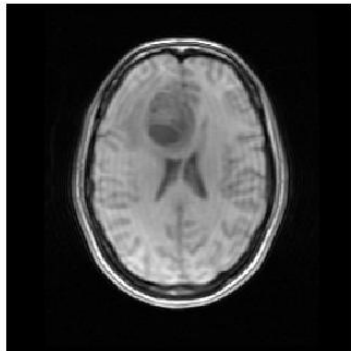
FA=3°



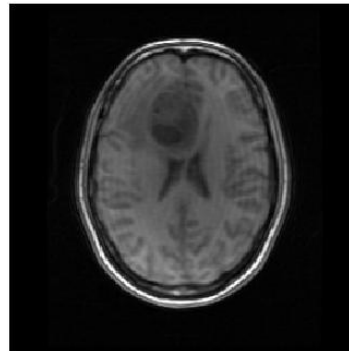
FA=5°



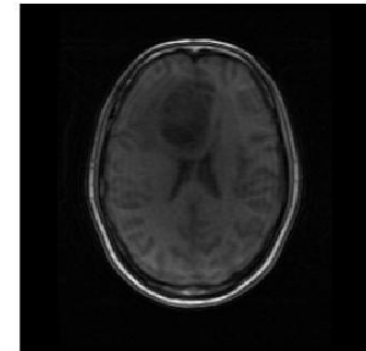
FA=7°



FA=10°

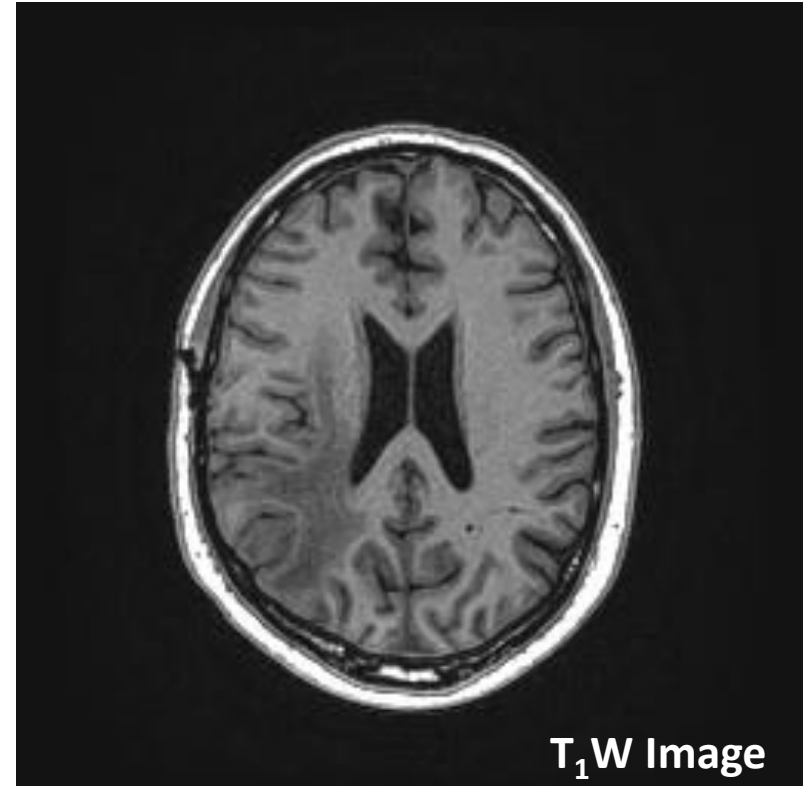
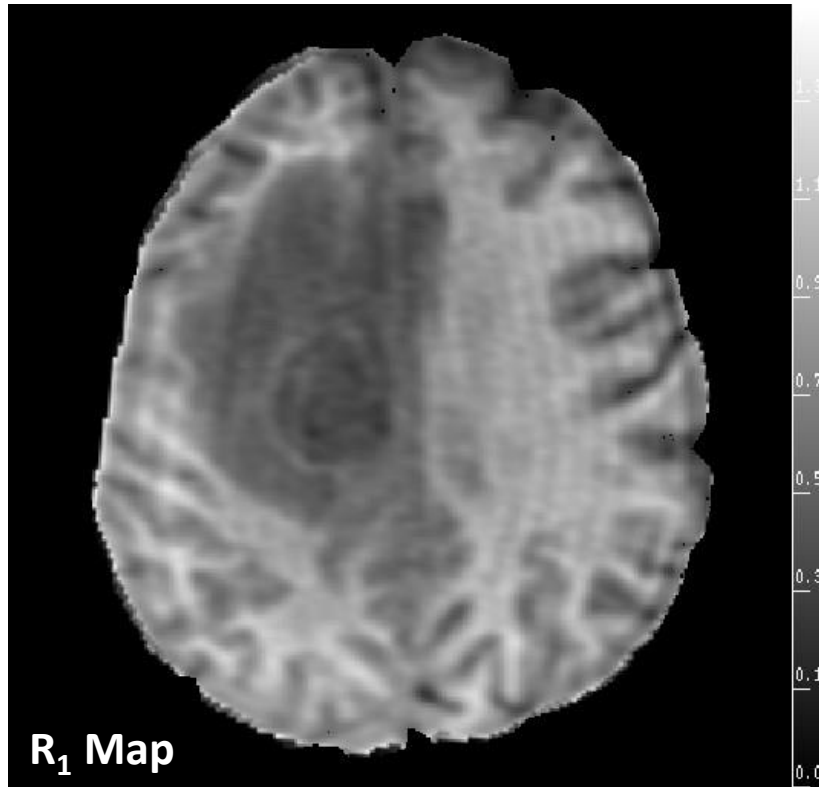


FA=20°



FA=30°

Variable Flip Angle T_1 Mapping

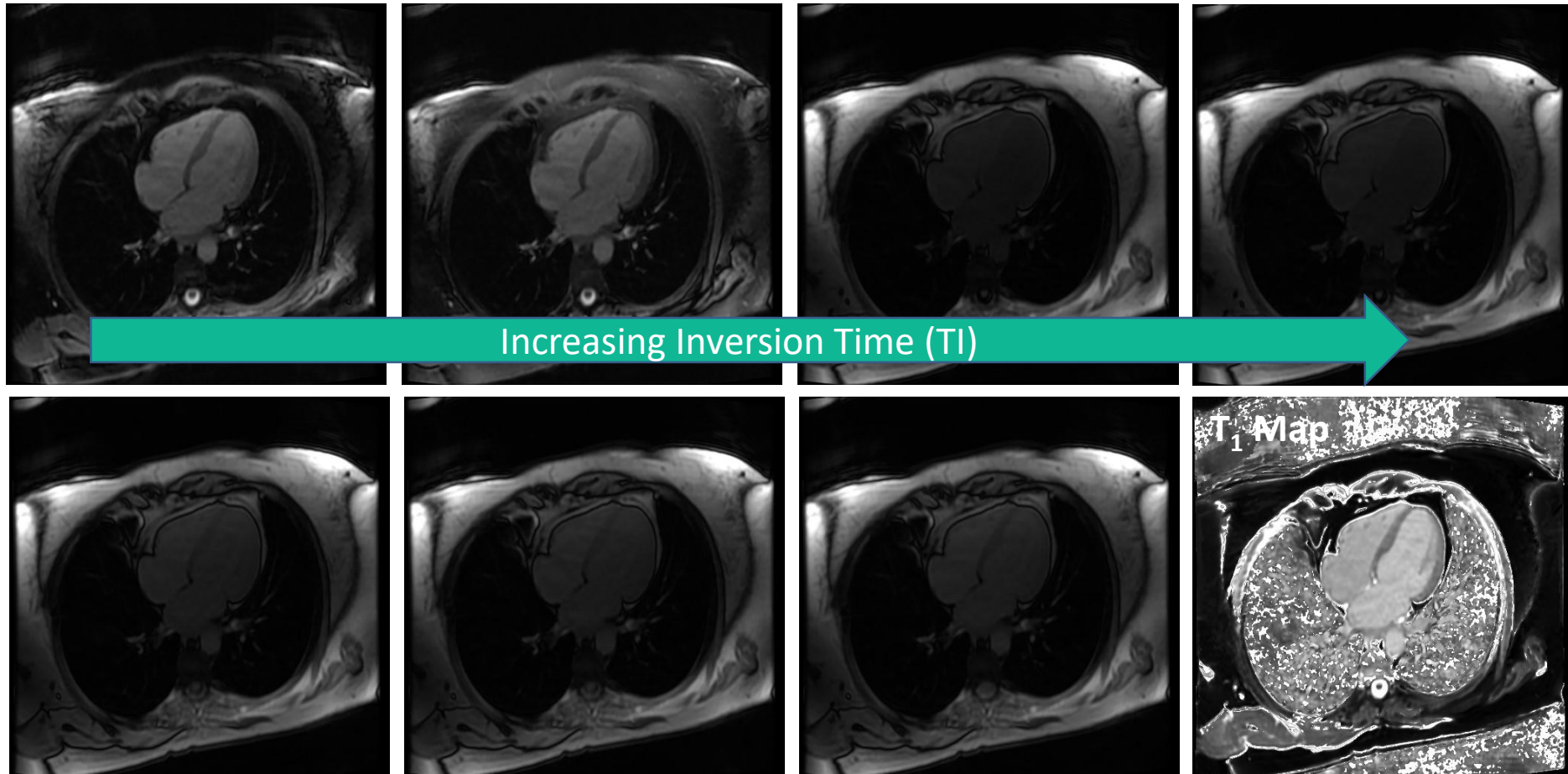


$$R_1 = 1/T_1 \text{ and } R_2 = 1/T_2$$

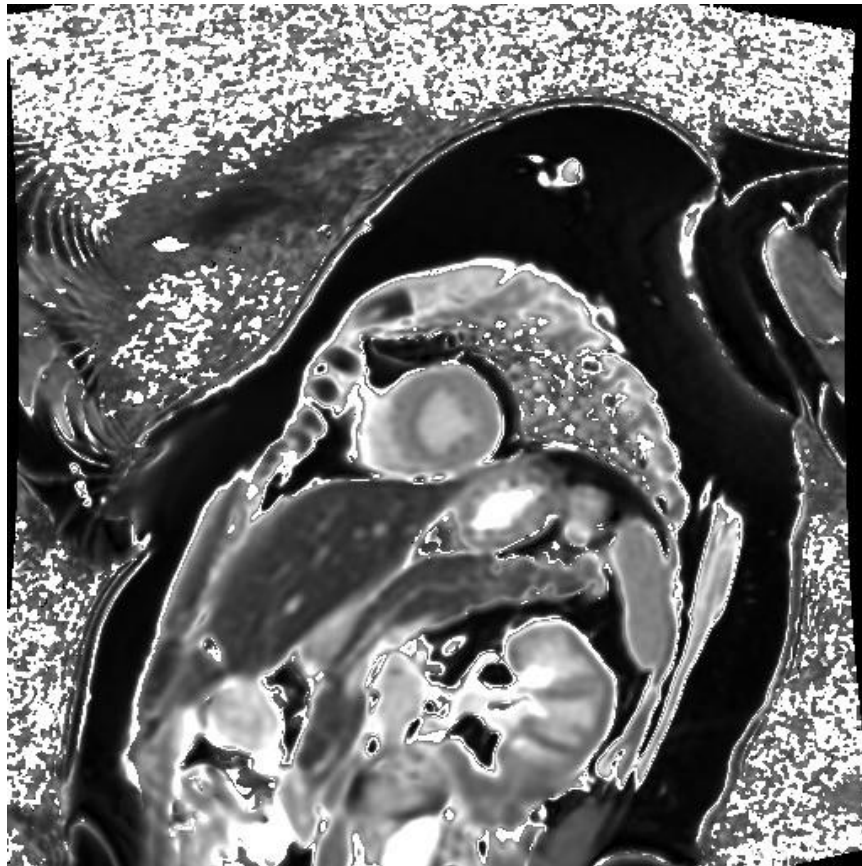
Variable Flip Angle
(VFA) mapping is ~1-2
minutes per sample

Difference between a contrast-weighted MR image and a quantitative image (map)

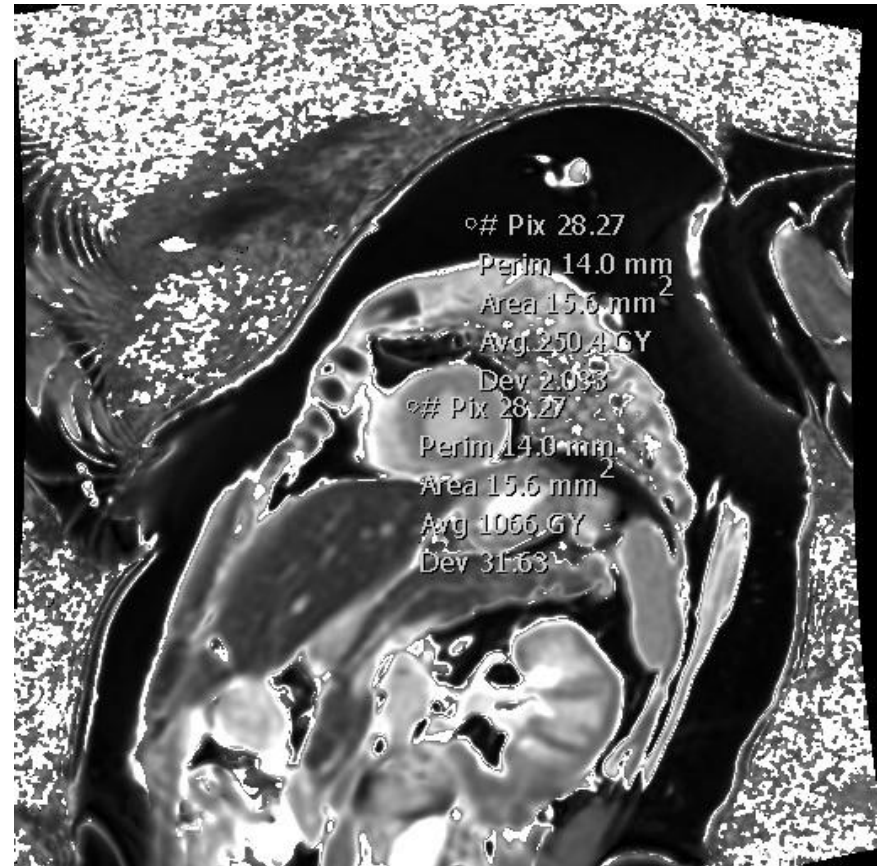
Look-Locker / modified Look-Locker (MOLLI)



Difference between a contrast-weighted MR image and a quantitative image (map)



T₁ Map



T₁ Map

Look-Locker / modified Look-Locker (MOLLI) mapping is ~1-2 breath holds per sample

Difference between a contrast-weighted MR image and a quantitative image (map)

Look-Locker / modified Look-Locker (MOLLI)

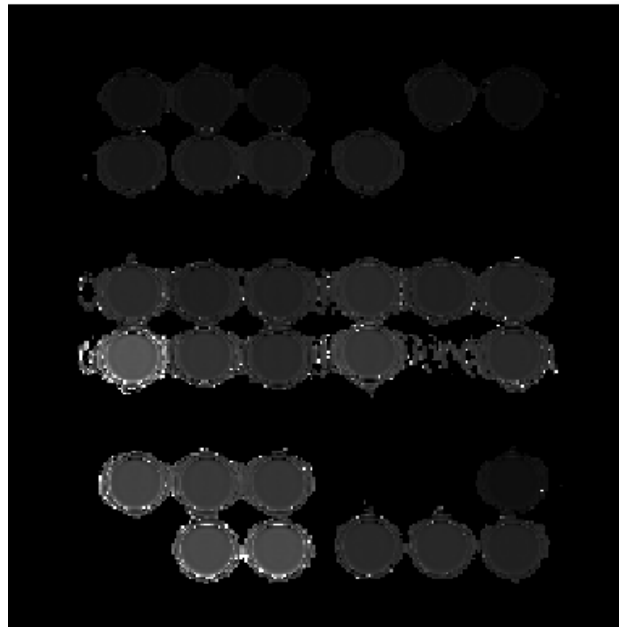


T₁ Map Post-Contrast

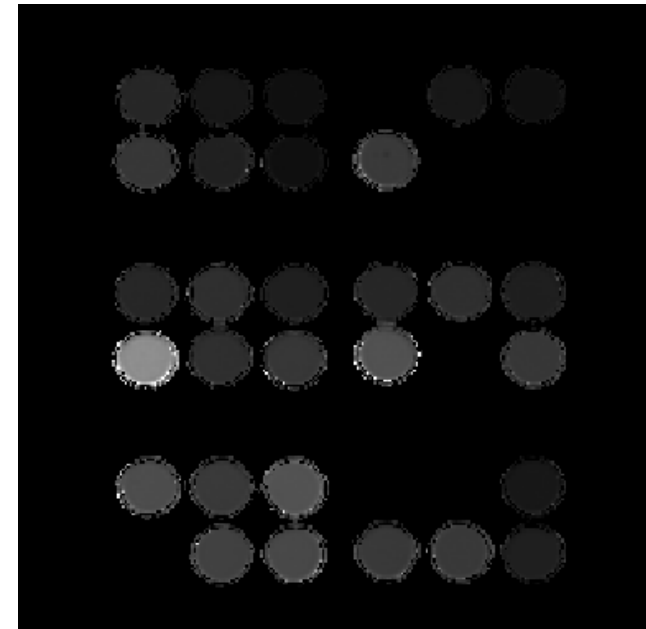


T₁ Map Post-Contrast

Difference between a contrast-weighted MR image and a quantitative image (map)



T_1 Map



T_2 Map

Expected Parameters

B value should be 0.

Repetition time should be 4500.

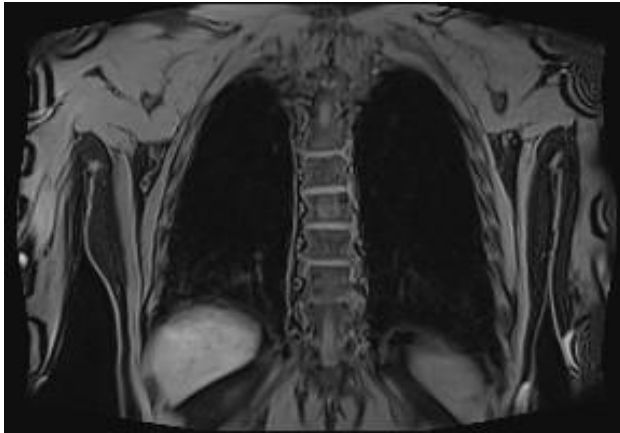
Echo time should be at most 7.6.

Slice thickness should be 6.

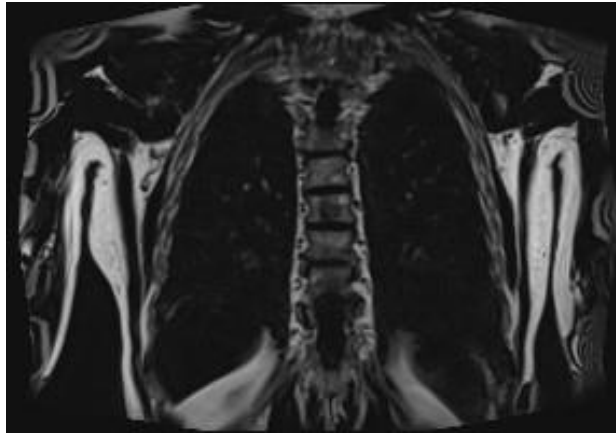
Inversion times should be 35 (or 50 on a GE scanner), 75, 100, 125, 150, 250, 1000, 1500, 2000, 3000.

“Gold standard” T_1 variable inversion time (TI) mapping is ~1 hour per sample

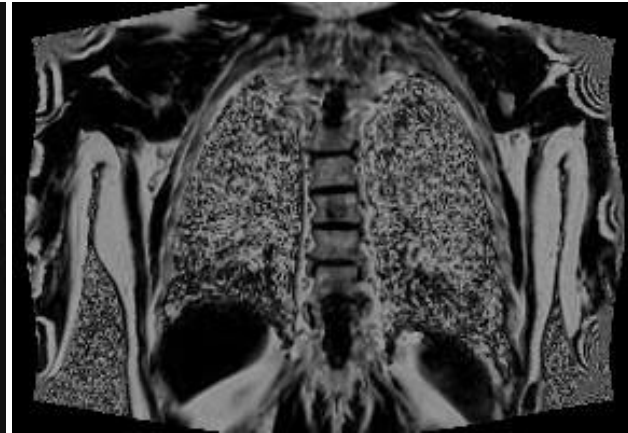
Fat fraction



Water only image



Fat only image



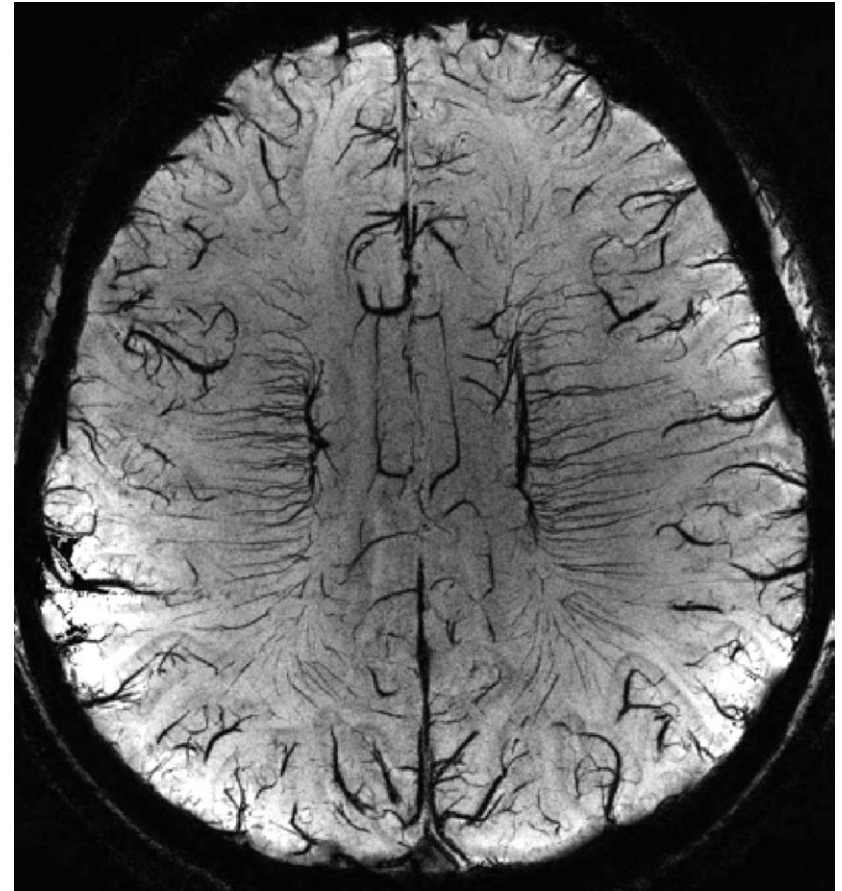
PDFF, proton density fat fraction

$$\text{PDFF} = F / (F+W)$$

PDFF mapping is ~1-2 breath holds per sample

Extension of T_2^* -weighted MRI to susceptibility-weighted imaging (SWI)

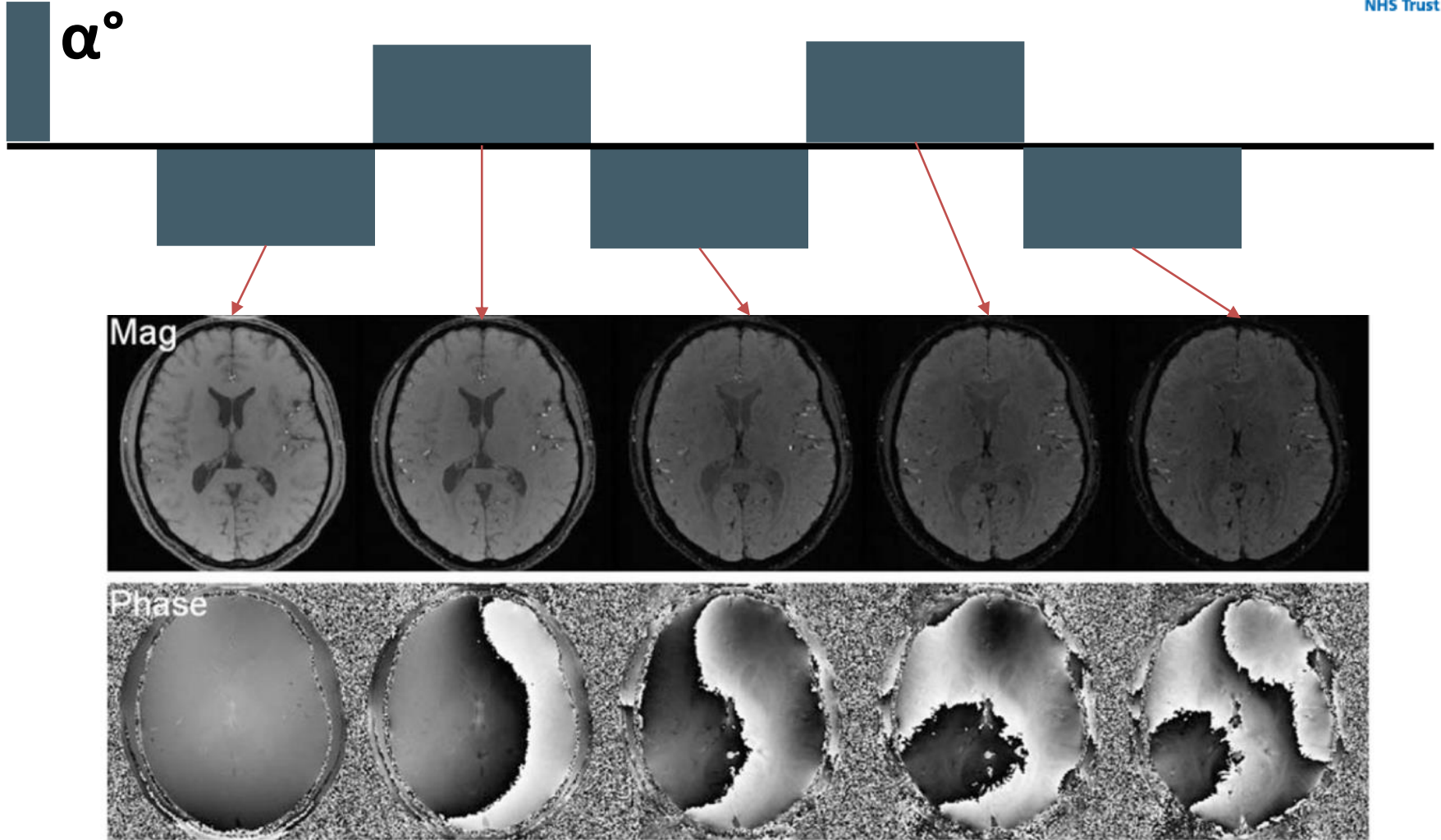
- Susceptibility-weighted imaging (SWI) was initially developed to provide an improved method for cerebral magnetic resonance (MR) venography
- Imaging of venous blood with SWI is a blood-oxygen-level dependent (BOLD) technique (BOLD venography)
- Deoxyhaemoglobin is paramagnetic causing a gradient which attenuates the signal (shortens T_2^*)
- fully velocity-compensated (with gradient moment nulling in all three orthogonal directions), three-dimensional, gradient-echo sequence



- Conventional diagnostic MR imaging relies only on magnitude information:
magnitude = $\sqrt{(\text{Real}^2 + \text{Imaginary}^2)}$
- Phase information is ignored and usually discarded during image reconstruction: phase = $\tan^{-1}(\text{Imaginary}/\text{Real})$
- Phase images contain information about local susceptibility changes between tissues
- Useful for measuring iron content and other substances that alter the local magnetic field
- Combining phase and magnitude information generates a new type of image called the susceptibility-weighted magnitude image (SWI)

- SWI combines a T_2^* -weighted magnitude image with a filtered phase image acquired using a gradient echo sequence in a multiplicative relationship
- While T_2^* -weighted imaging provides some susceptibility contrast, SWI further enhances the contrast between tissues of differing susceptibility
- Phase images can differentiate calcification from haemorrhage because calcification is diamagnetic, whereas haemorrhage is paramagnetic, resulting in opposite signal intensities on SWI filtered phase images
- The appearance of phase images will depend on whether your scanner!
- LHS: Siemens & Canon => calcification is dark
- RHS: GE & Philips => calcification is bright

Extension of T_2^* -weighted MRI to susceptibility-weighted imaging (SWI)

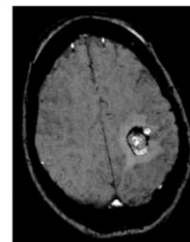
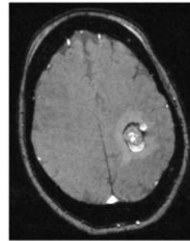


Extension of T_2^* -weighted MRI to susceptibility-weighted imaging (SWI)

Post-Processing

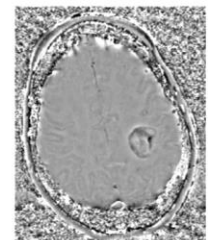
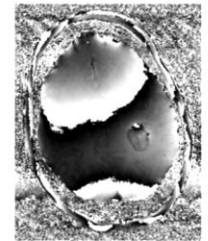
- Start with a magnitude image and a phase image
- The phase image is filtered and a mask is created from this filtered image using a high-pass Hamming window filter (typically 64x64 to reduce aliasing artefacts). Phase images constrained from $-\pi$ to π
- the phase mask is multiplied with the magnitude data to enhance the visualization of vessels or microbleeds

Magnitude
Image

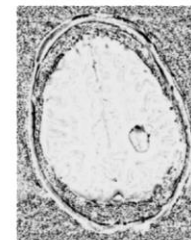


SWI

Phase Image



Filtered Phase
Image



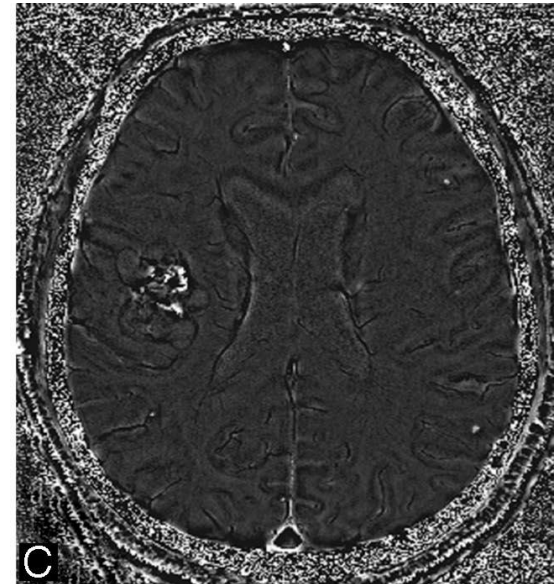
Phase mask
Image



$\times 4$

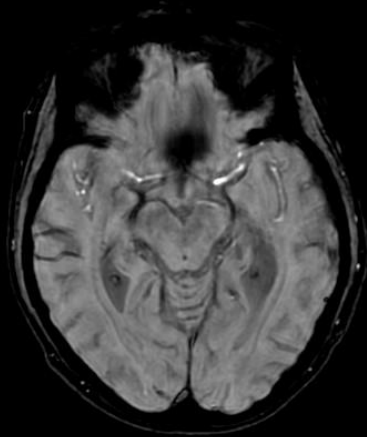
Intratumoral Calcifications

- Calcification cannot be definitively identified by GRE imaging since haemorrhage also cause local magnetic field changes and appears as hypointensities
- Phase images can differentiate calcification from haemorrhage because calcification is diamagnetic, whereas haemorrhage is paramagnetic, resulting in opposite signal intensities on SWI phase images

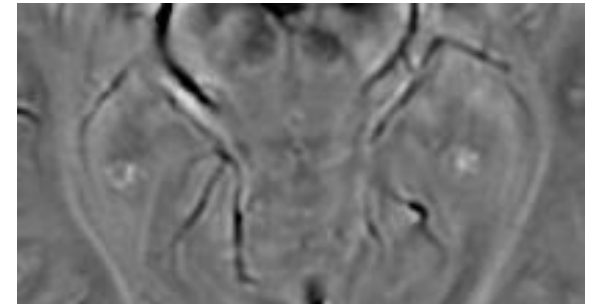
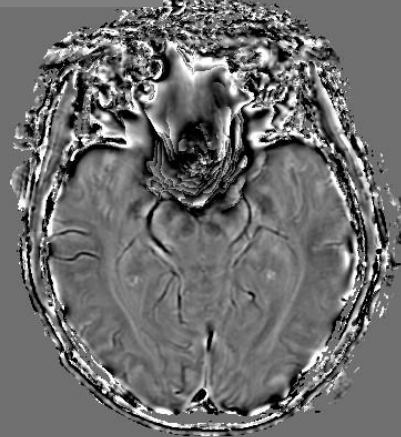


Extension of T_2^* -weighted MRI to susceptibility-weighted imaging (SWI)

SWI RHS - GE

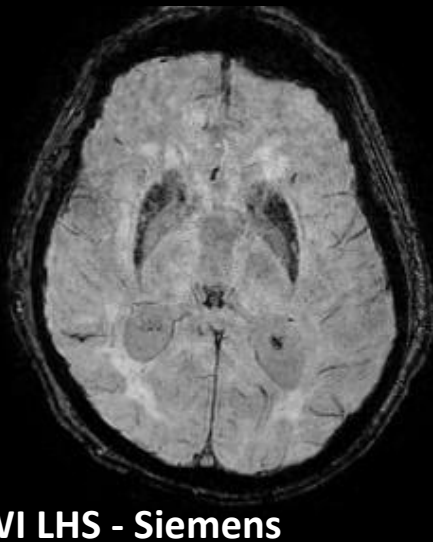


Phase RHS

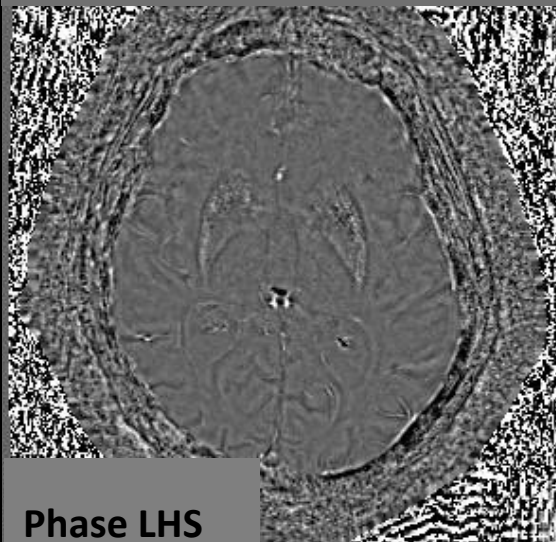


- RHS: GE & Philips calcification is bright

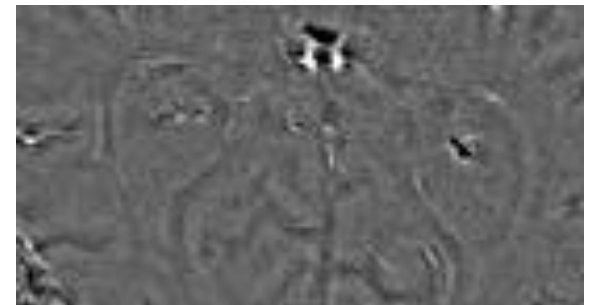
SWI LHS - Siemens



Phase LHS

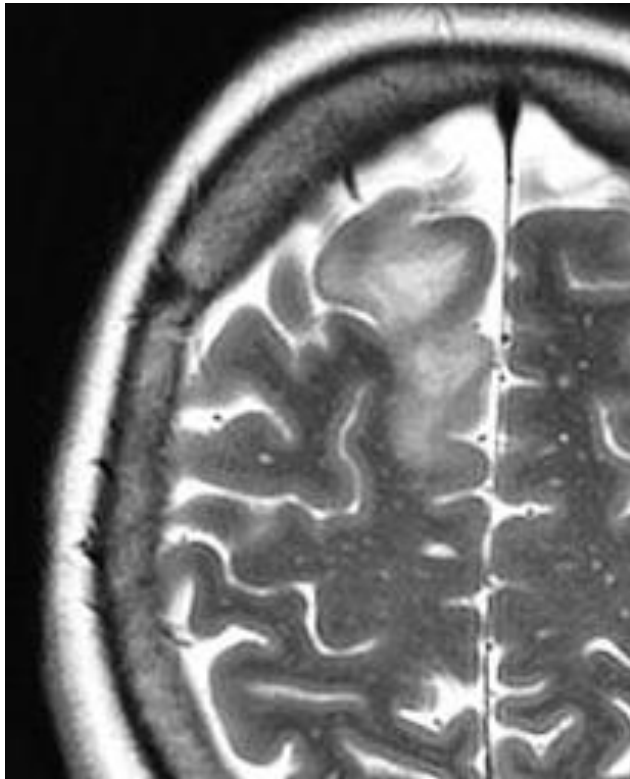


- LHS: Siemens & Canon calcification is dark

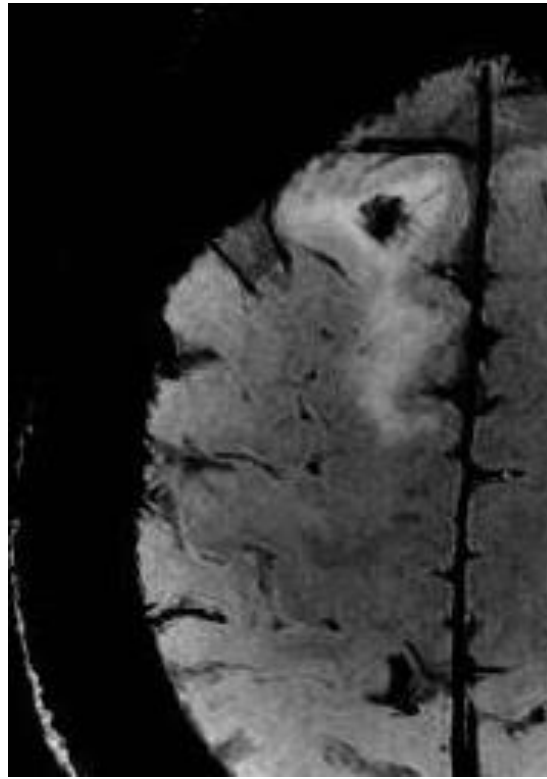


choroid plexus SWI

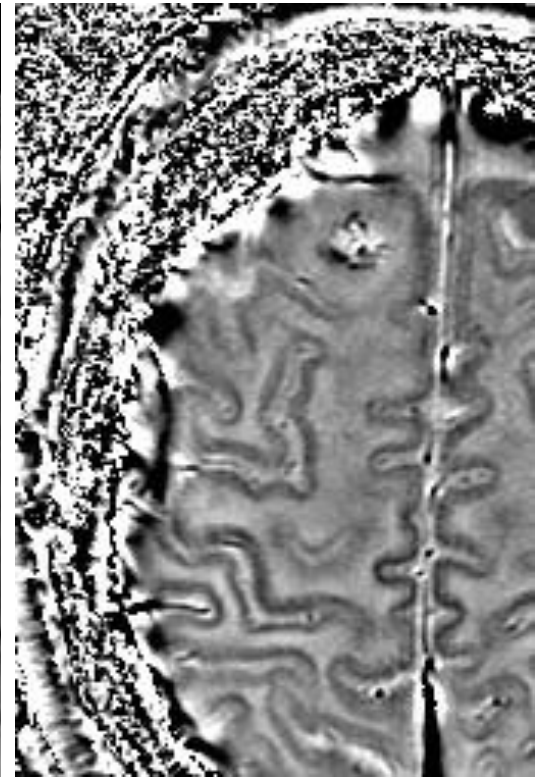
Calcification – Low Grade Glioma



T2 FSE



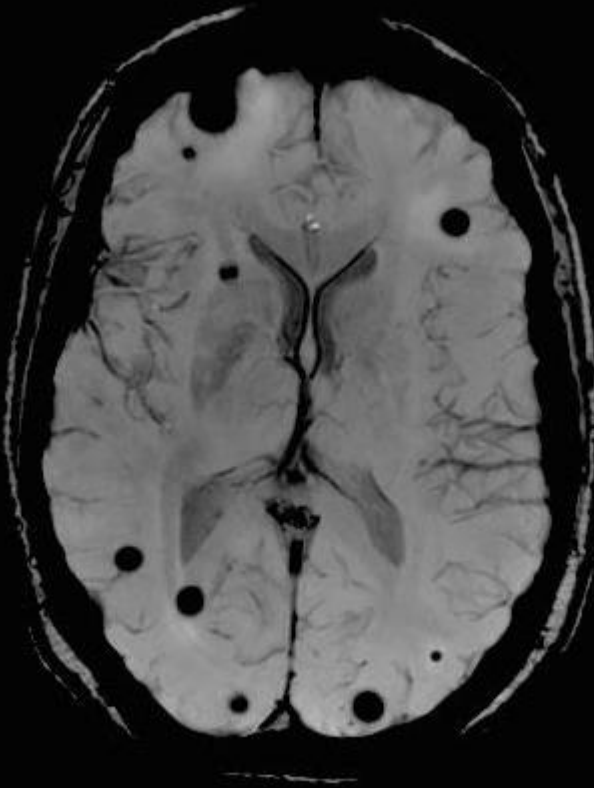
3D SWI minIP



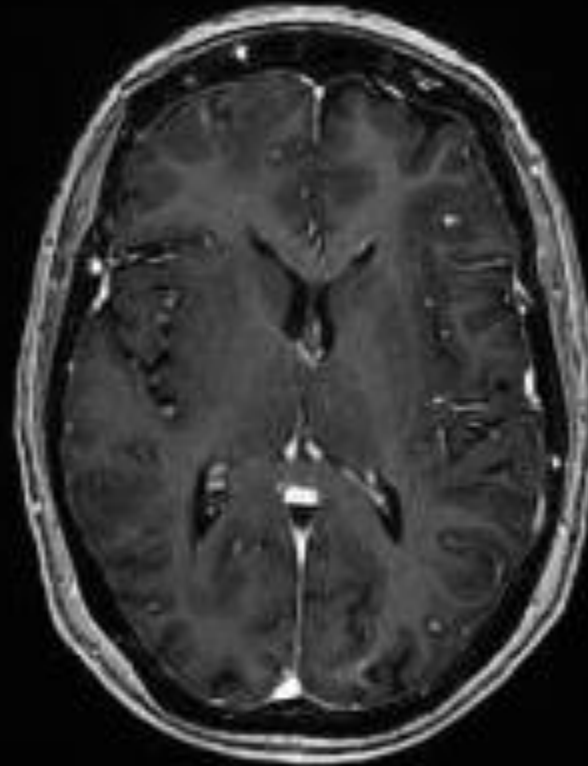
Filtered Phase Map (r.h.s)

Haemorrhagic Metastatic Lesions

Renal Cell Carcinoma



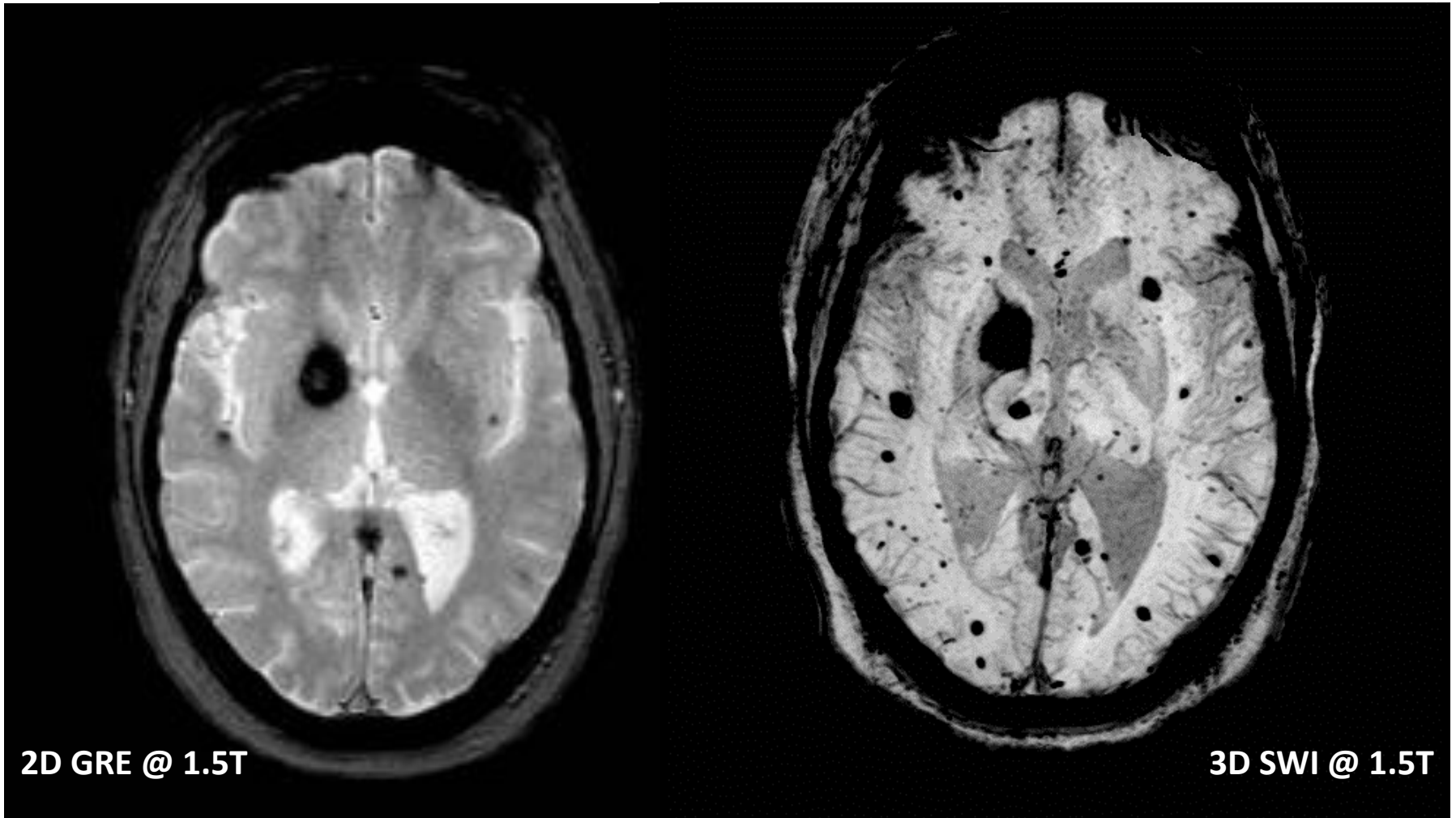
SWI minIP



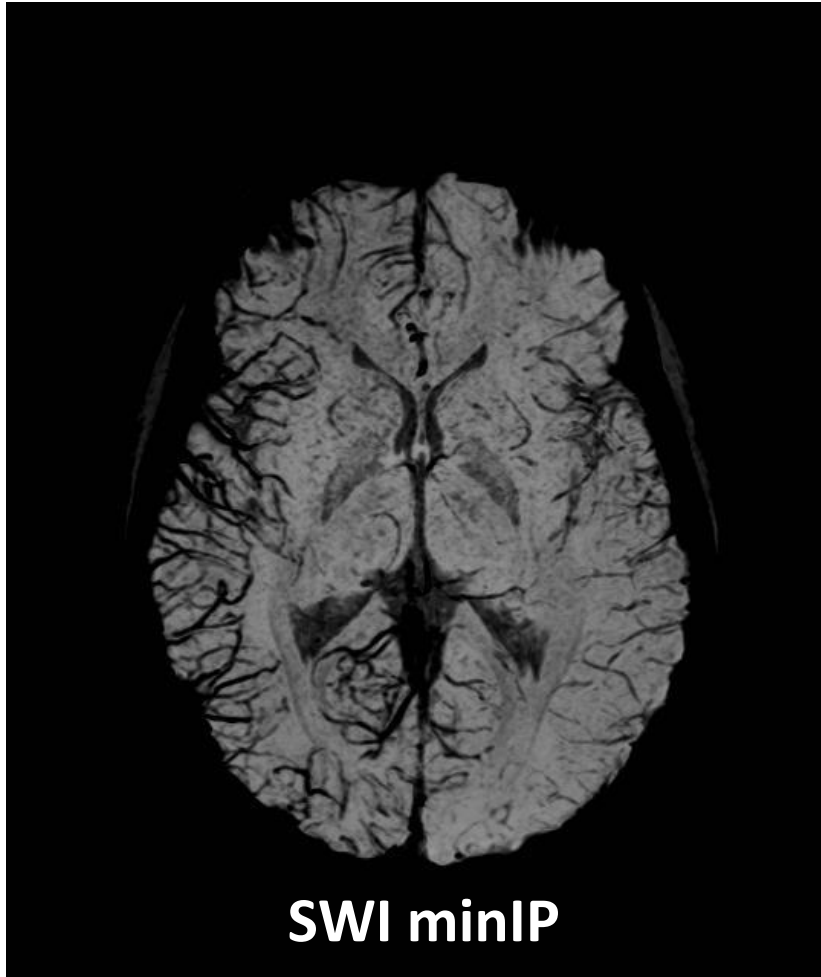
BRAVO +C

Many cerebral parenchymal metastatic lesions, including those from renal cell carcinoma, melanoma, and bronchogenic carcinoma, frequently show intratumoural haemorrhage

Cavernous haemangioma (Cavernoma)



Transient Changes



Migraine

Blood Oxygen Level Dependent (BOLD)
Contrast

Deoxyhaemoglobin is paramagnetic:
causes a gradient which attenuates signal
(shortens T_2^*)

7.2 Basic Contrast Mechanisms

- *Magnetic Materials*
 - *calcification is diamagnetic, haemorrhage is paramagnetic and gadolinium based contrast agents are paramagnetic*
- *Spin Echo*
 - *Simple $90^\circ - 180^\circ$ pulse sequence. TR/TE manipulated to produce T_1W , T_2W and P.D. weighted imaging*
- T_1 . Understand concept of MR signal saturation
 - *Spin-lattice relaxation. Time for 63% signal to recover. MR signal will saturate if TR is too short. Controlled with TR.*
- T_2 and T_2^*
 - *Spin-spin relaxation. T_2 is time to M_{xy} to decay to 37% signal. T_2 observed using spin echo. T_2^* observed using gradient echo. Controlled with TE.*

7.2 Basic Contrast Mechanisms

- Impact of relaxivity of gadolinium-based contrast agents on T_1 -weighted and T_2^* weighted images
 - *T_1 shortening effect leads to an increase in signal on a T_1 weighted imaging “enhancement”. T_2 shortening effect can also be observed on T_2 / T_2^* weighted images but with reduced effect*
- Difference between a contrast-weighted MR image and a quantitative image (map)
 - *Most MR images are “weighted” with arbitrary signal. Quantitative imaging (T_1 , T_2 etc.) are becoming more common but require specialist sequences. Should be more repeatable.*
- Extension of T_2^* -weighted MRI to susceptibility-weighted imaging (SWI)
 - *More sensitive than conventional T_2^* weighted imaging. Differentiate calcification and haemorrhage using phase maps.*

Questions

- What weighting would a SE sequence with a long TR (3000ms) and a long TE (100ms) have?

- A) T_1
- B) T_2
- C) P.D.

- Which combination of parameters is required to produce a SE image with proton density weighting?

- A) long TR and long TE
- B) short TR and short TE
- C) long TR and short TE

- On a T_2 weighted image, what signal intensity would free fluid produce?
 - A) Bright
 - B) Intermediate
 - C) Dark

Questions

In magnetic resonance imaging the following are true:

- A. A spin echo sequence with a short repetition time TR and a short echo time TE is T_1 weighted.
- B. A spin echo sequence with a long repetition TR and a long echo time TE is proton density weighted.
- C. A spin echo sequence with a long repetition TR and a short echo time TE is T_2 weighted.

Questions

In magnetic resonance imaging the following are true:

- A. Signal strength depends only on the proton density of the material.
- B. A short TE and a long TR will give a T_1 -weighted image.
- C. A T_1 -weighted image will show water as high signal.
- D. Most soft tissues show as high signal on proton density (PD) weighted images.
- E. If TE is longer than TR, the image is weighted towards PD.

Questions

Concerning T_1 , which of the following are true:

- A. It is the time taken for transverse recovery to reach 37% of the maximum value.
- B. T_1 is increased with greater field strength.
- C. Fat and melanin both produce a high signal on a T_1 -weighted image.
- D. A short time to echo (TE) and short time to repeat (TR) will give a T_1 -weighted image.
- E. T_1 is always longer than T_2 .

Questions

Concerning T_2 , which of the following are true:

- A. Occurs due to spin-lattice relaxation.
- B. T_2 relaxation time increases with an increase in magnet field strength.
- C. Is affected by magnetic field inhomogeneities.
- D. When 63% of the transverse signal is lost, this is referred to as time T_2

Questions

In magnetic resonance imaging the following are true:

- A. FID is a commonly used basic sequence
- B. A spin-echo sequence removes the dephasing effect of field inhomogeneities with a second 90° pulse
- C. The longer the TE, the smaller the subsequent signal

Questions

In magnetic resonance imaging the following are true:

- A. The SE sequence allows the T_2 effect of a specific tissue to be measured
- B. Immediately following a single 90° pulse, all the dipoles are in phase
- C. The 180° rephasing pulse is applied at $TE/2$ after the initial RF excitation