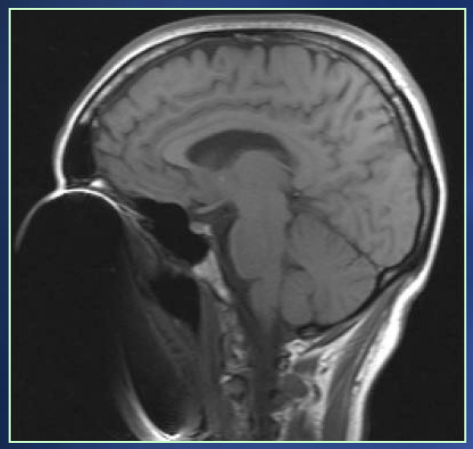
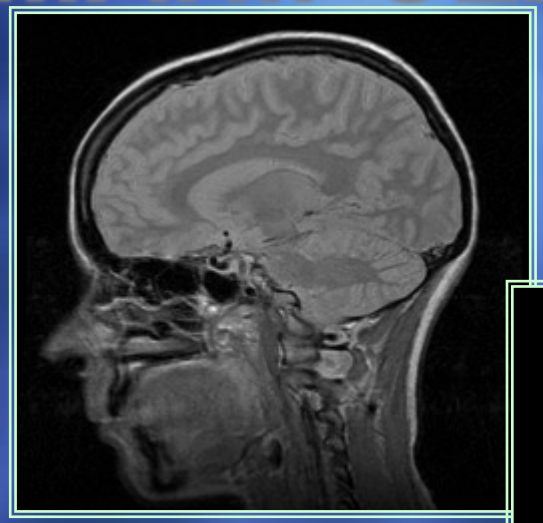
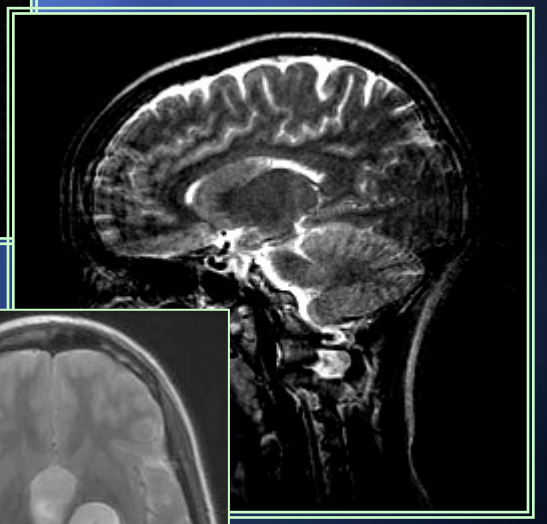
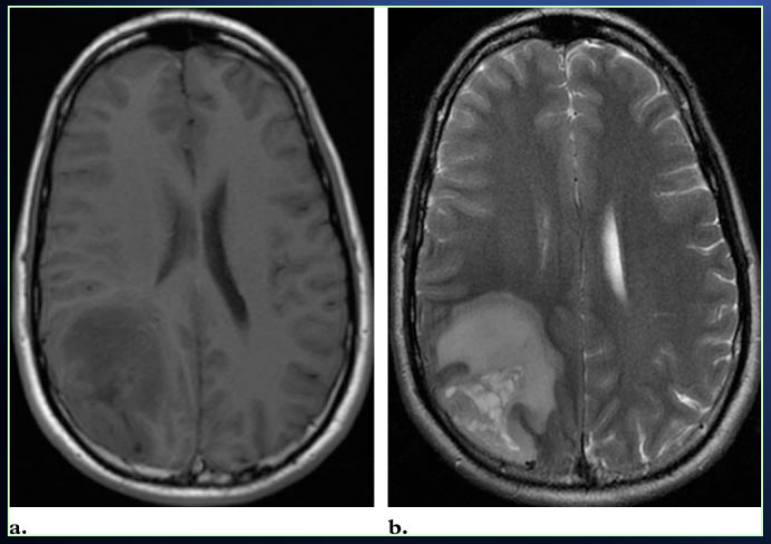
PULSE SEQUENCES AND CONTRAST MANIPULATION









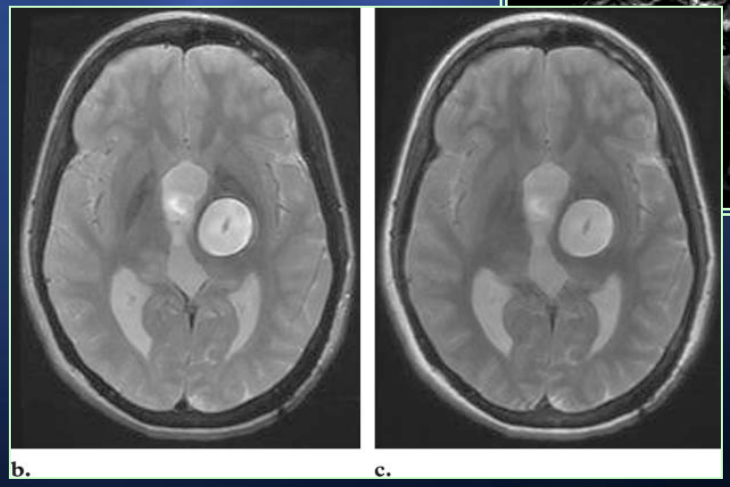
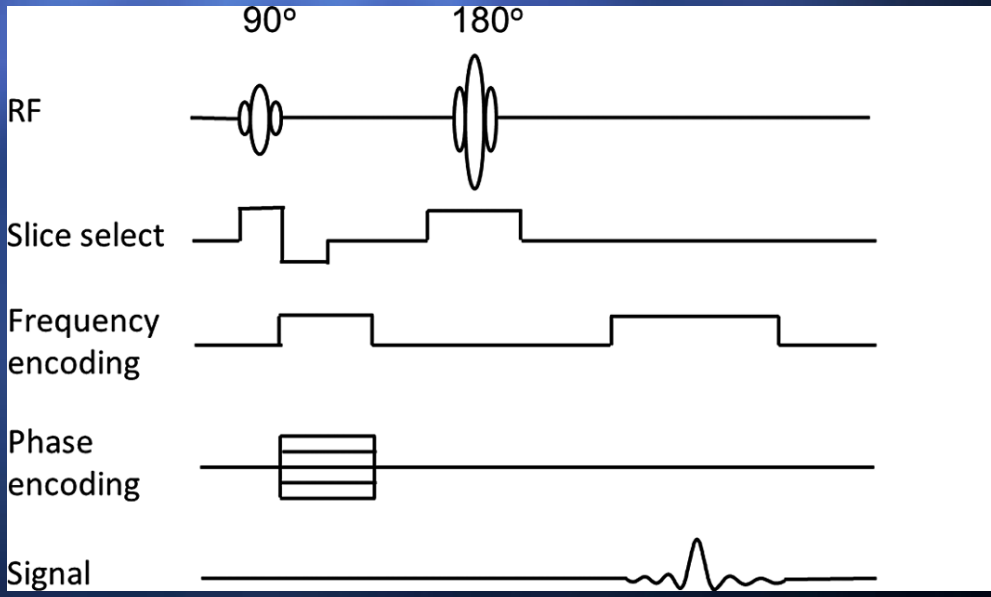


Image contrast in MRI

- ✓ Parameters of the image sequence that affect image contrast and SNR
  - Echo time
    - ❖ TE
  - Repetition time
    - ❖ TR
  - Voxel dimensions
    - ❖ FOV
    - ❖ Nx & Ny
    - ❖ Slice thickness

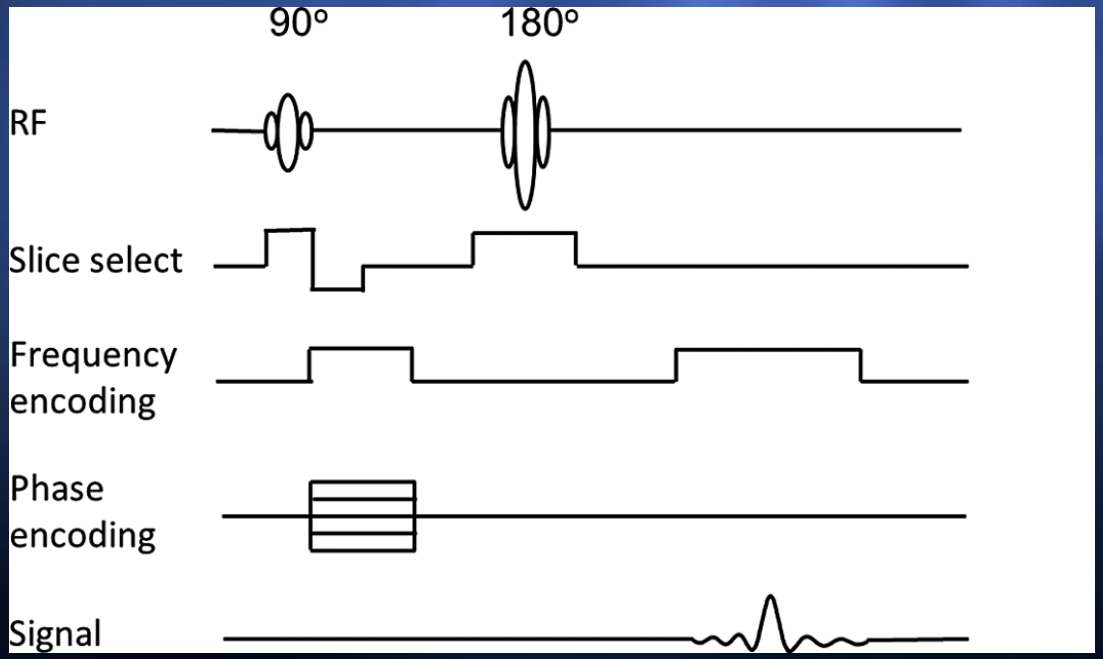
Pulse Sequence

- ✓ **The properties of the RF pulses and gradients determine the geometrical properties of image**
  - **the slice thickness**
  - **field of view**
  - **spatial resolution**



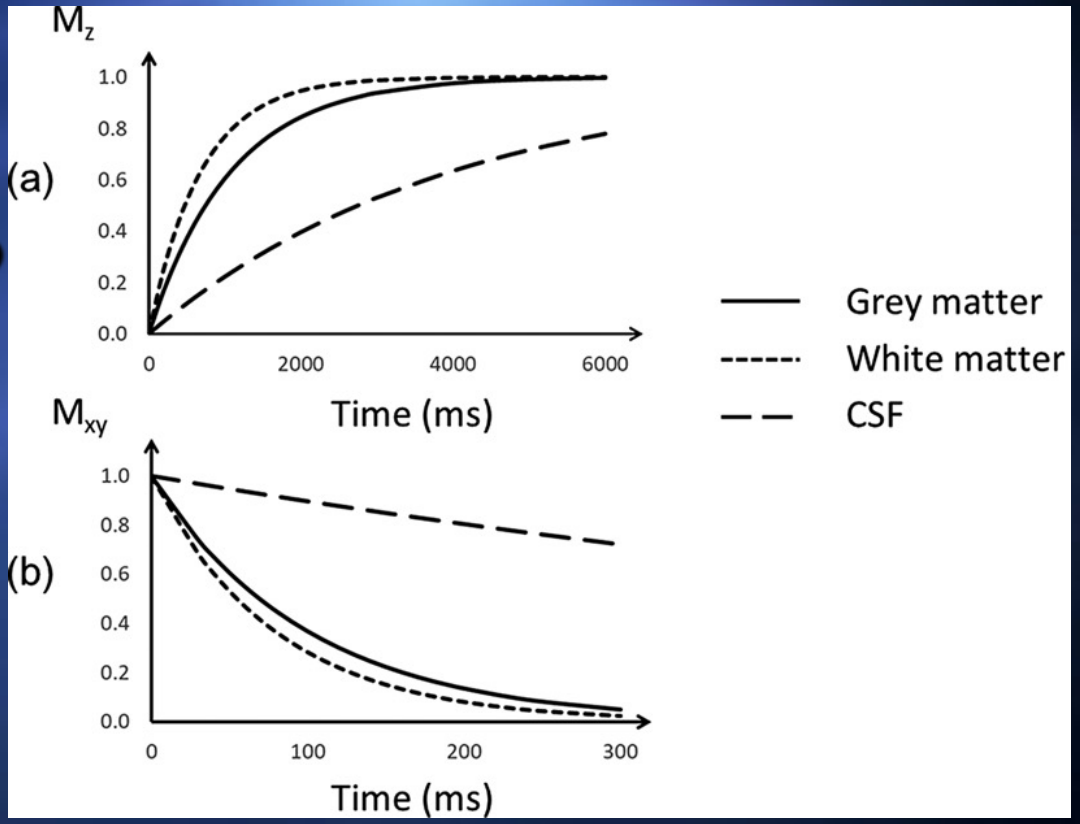
PULSE SEQUENCES AND CONTRAST MANIPULATION

the contrast between different structures is manipulated by modifying the pattern and timing of RF and gradient pulses



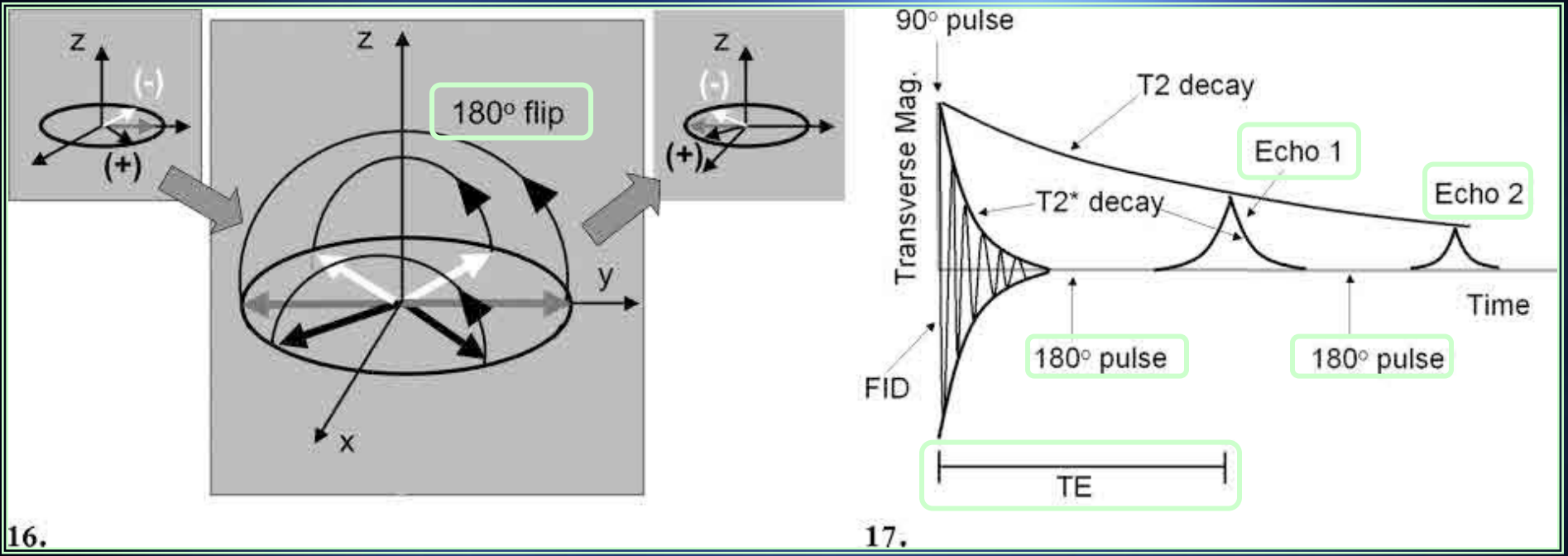
Tissue characterizations

- ✓Tissues are different in T_1 T_2 and protons density ρ
- ✓A set of images recording T_1, T_2 and ρ weighted images allows tissues recognition
- ✓The contrast is a function of a lot of parameters
  - with different weights



https://www.imaios.com/en/e-Courses/e-MRI/MRI-signal-contrast/Spin-echo-TR-TE

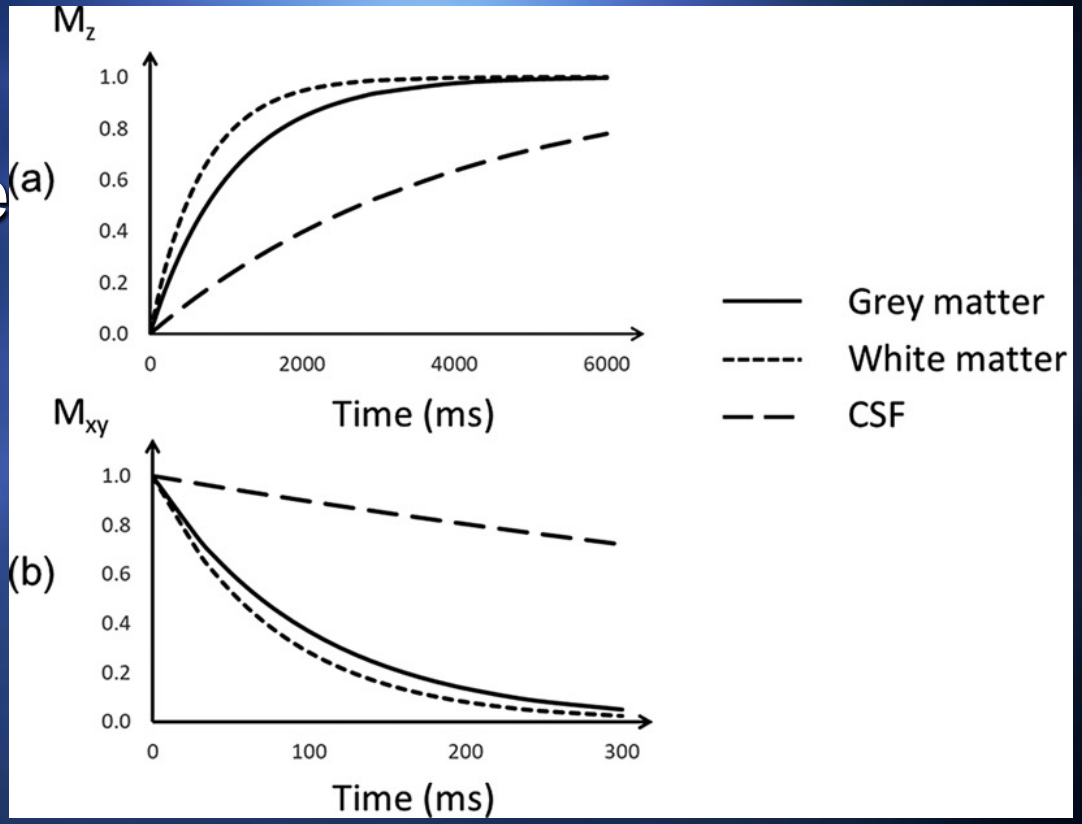
Contrast Manipulation in the Spin-Echo Pulse Sequence



$$S(TE)=M_{z0}e^{-TE/T_2}$$

Contrast Manipulation in the Spin-Echo Pulse Sequence

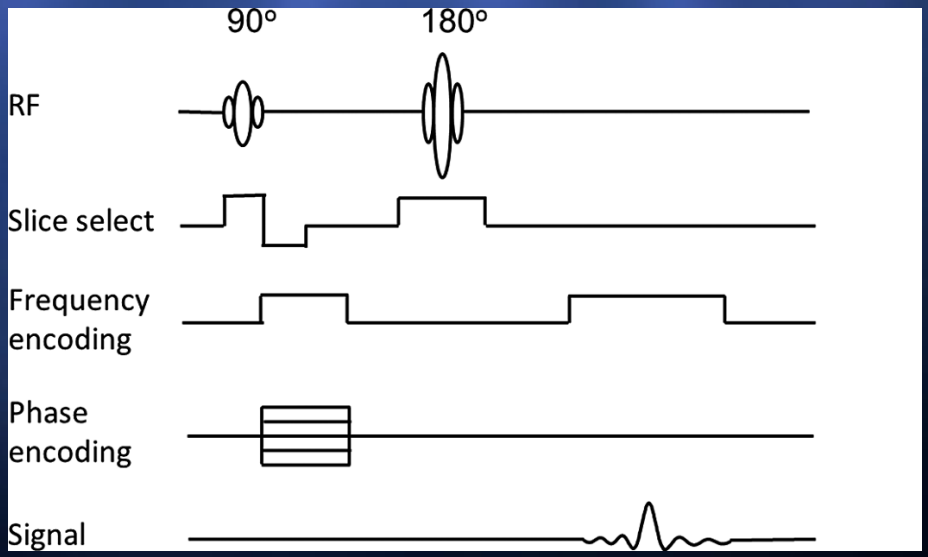
- ✓To maximise the contrast between grey matter and white matter a T_E of around 90 ms is a good choice
- ✓At very long T_E values there is very little signal from grey or white matter, and the image is dominated by CSF



As a general rule, optimal T_2 contrast occurs if the T_E is set equal to the mean of the T_2 values of the tissues of interest

Contrast Manipulation in the Spin-Echo Pulse Sequence

- ✓ Repetition time T_R: The interval between successive 90° pulses during the series
- ✓ During T_R longitudinal magnetisation M_z undergoes T_1-recovery
- ✓ Recovery is essentially complete at $T_R = 5T_1$
  - $M_z = 0.993|M|$

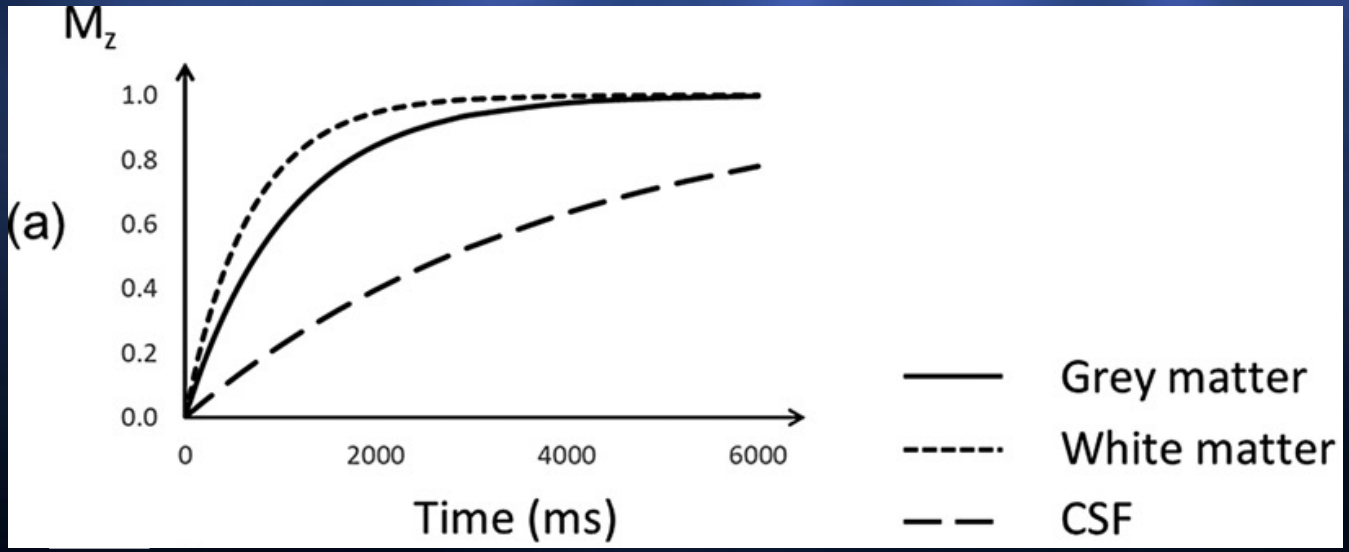


Contrast Manipulation in the Spin-Echo Pulse Sequence

- If $T_R < 5T_1$, then the amount of M_z recovered for a specific tissue will be

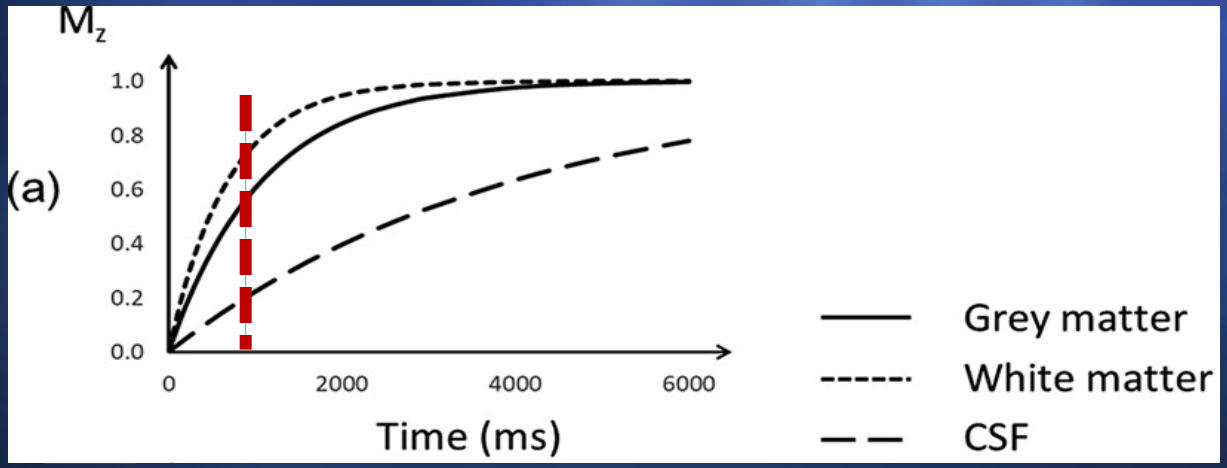
$$M_z = |\mathbf{M}|\left(1 - e^{-\frac{t}{T_1}}\right)$$

- resulting in recovery of different amount of M_z in different tissues



Contrast Manipulation in the Spin-Echo Pulse Sequence

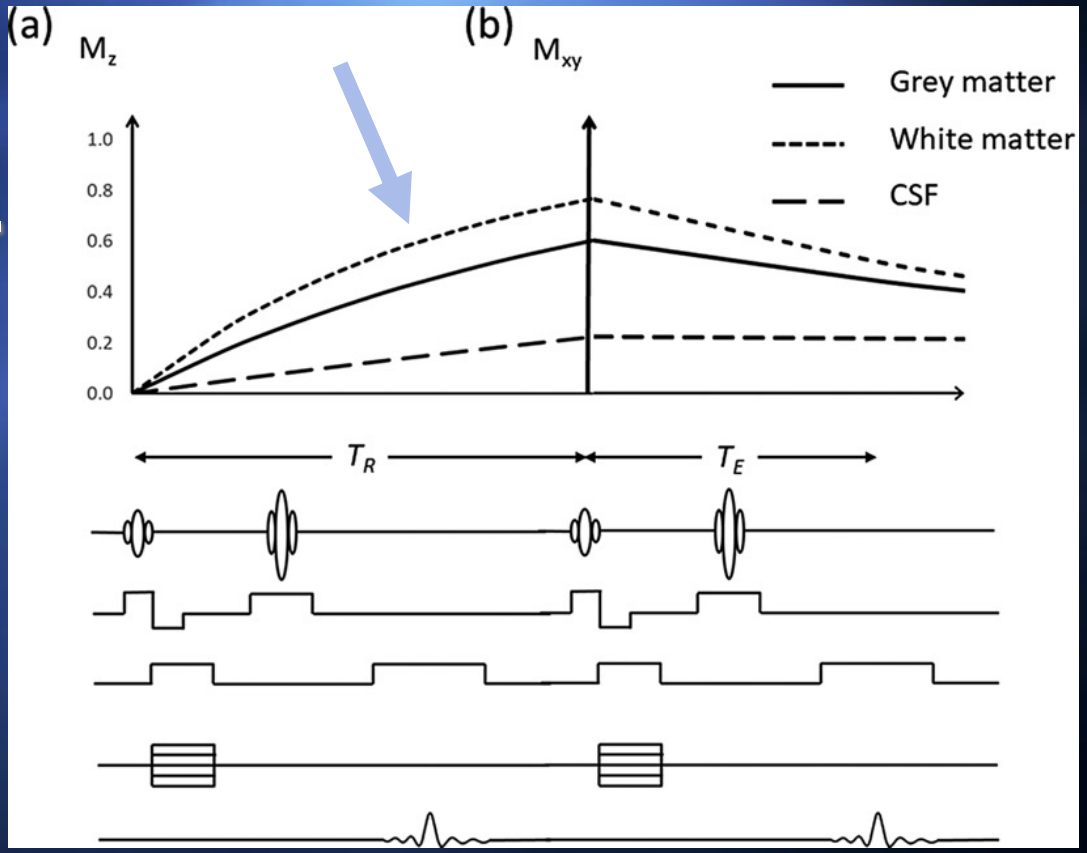
- ✓ **The maximum difference in recovery between grey matter and white matter in the figure occurs at a T_R value of about 850 ms**
  - **the mean of the T1 values of the two tissues**



the amount of M_Z that has recovered in a specific tissue at T_R determines the amount of M_{xy} that will be generated by the 90° pulse

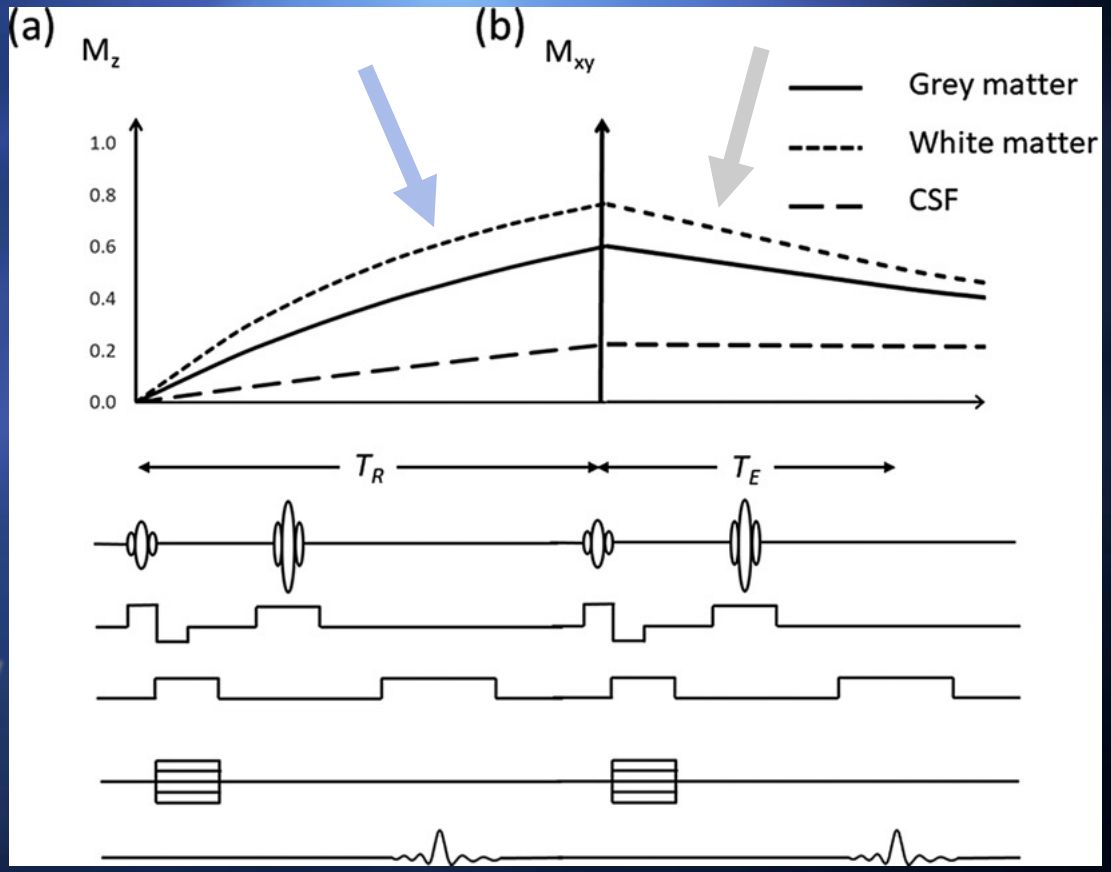
Contrast Manipulation in the Spin-Echo Pulse Sequence

- development of T_1- and T_2- weighting over 2 consecutive repetitions of a spin-echo pulse sequence
- During the first repetition M_z is reduced to 0 by the initial 90° pulse and then recovering through T_1 relaxation



Contrast Manipulation in the Spin-Echo Pulse Sequence

- During the second repetition the 90° pulse in this repetition of the sequence converts the M_z that was present at TR into M_{xy}, which undergoes T_2 decay
- An echo signal is collected at T_E

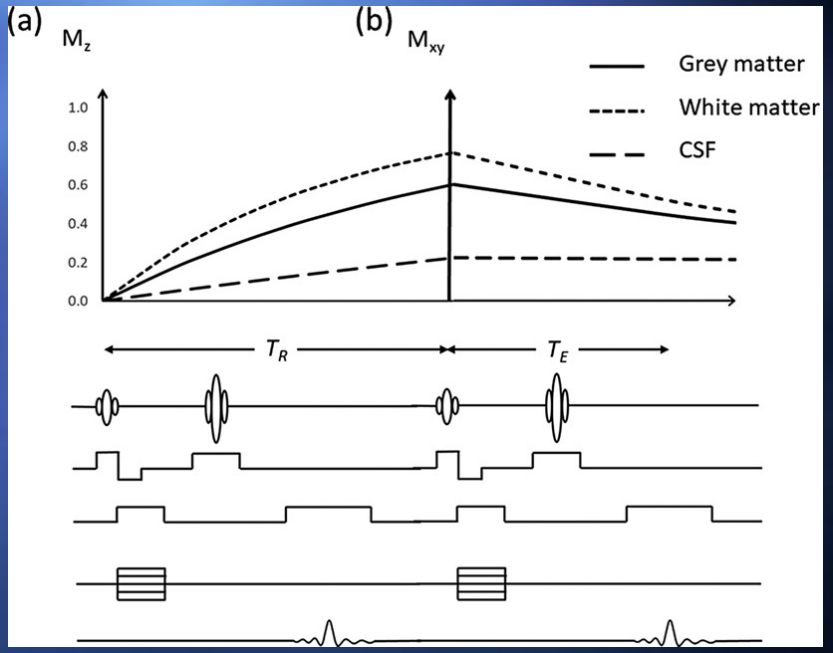


https://www.imaios.com/en/e-mri/nmr-signal-and-mri-contrast/tr-and-t-weighting

Contrast Manipulation in the Spin-Echo Pulse Sequence

- ✓ the signal intensity from each tissue type will depend on both T_1 and T_2

$$I \propto \rho(x,y)\left(1 - e^{-\frac{T_R}{T_1}}\right)e^{-\frac{T_E}{T_2}}$$



- $\rho(x,y)$ proton density as a function of position within the slice

Contrast in spin-echo images

Timing Parameters Required for Different Spin-Echo Image Weighting

Weighting	T_R	T_E
Proton density	Long	Short
T_1	Short (≈ mean of tissue T_1 values)	Short
T_2	Long	Long (≈ mean of tissue T_2 values)

- ✓ to increase T1-weighting short TR
- ✓ to increase T2-weighing long TE

- ❖ longitudinal relaxation is a recovery process
- ❖ transverse relaxation is a decay process

- https://www.imaios.com/en/e-Courses/e-MRI/MRI-signal-contrast/TR-and-T1-weighting
- https://www.imaios.com/en/e-Courses/e-MRI/MRI-signal-contrast/Signal-weighting

Contrast in spin-echo images

Timing Parameters Required for Different Spin-Echo Image Weighting

Weighting	T_R	T_E
Proton density	Long	Short
T_1	Short (≈ mean of tissue T_1 values)	Short
T_2	Long	Long (≈ mean of tissue T_2 values)

Optimization

- ✓ T_R influences the time taken to acquire the MR image
- ✓ There is a strong incentive to minimise T_R from the perspectives of patient experience and throughput
  - degree of T_1-weighting is tolerated in a nominally T_2-weighted image

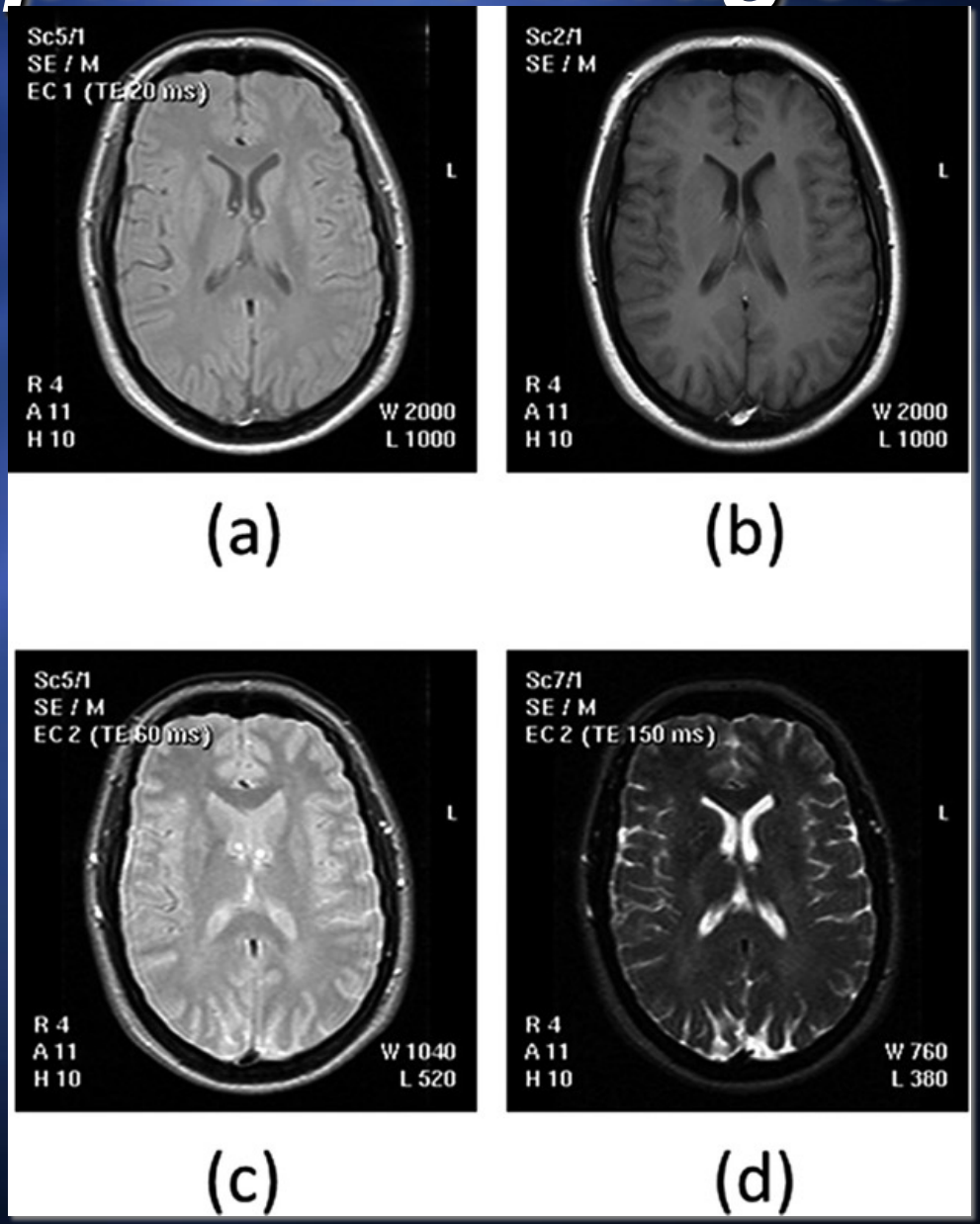
Contrast in spin-echo images

a) Proton density weighting:
TR = 2000 ms
TE = 20 ms

b) T1-weighting
TR = 500 ms
TE = 30 ms

c) T2-weighting
TR = 2000 ms
TE = 60 ms

d) Heavy T2-weighting
TR = 2000 ms
TE = 150 ms



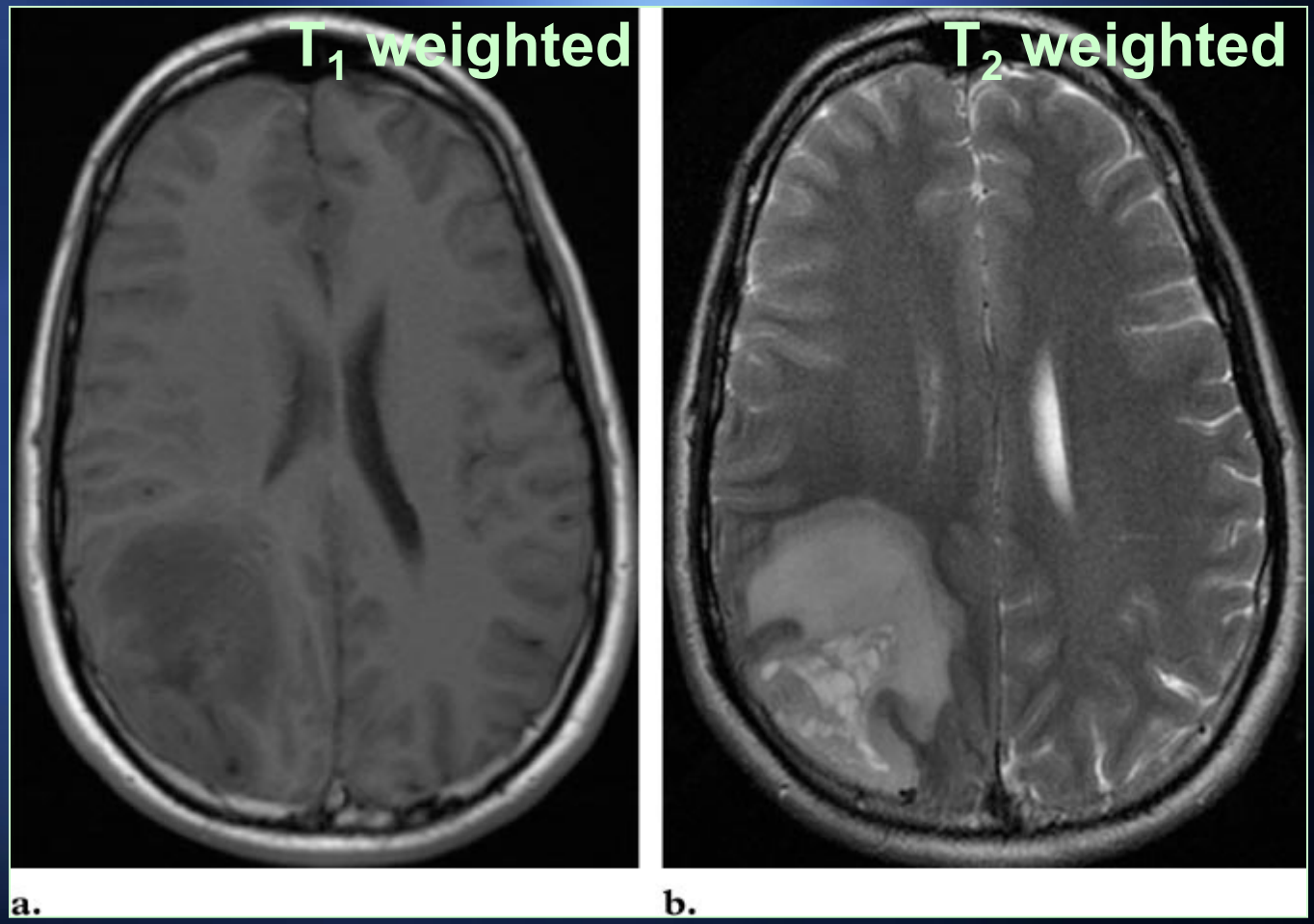
Contrast in spin-echo images

- ✓ CSF appears dark in the T1-weighted image and increasingly bright as T2-weighting is increased
- ✓ Fat around the scalp is the brightest tissue in the T1-weighted image
  - reflecting the short T1 of fat (≈ 250 ms at 1.5 T)
- ✓ The bone of the skull is not seen at all
  - solid materials have such short T2 values that they cannot be seen

https://www.imaios.com/en/e-Courses/e-MRI/MRI-Sequences/Spin-echo

T_1 e T_2 weighted images

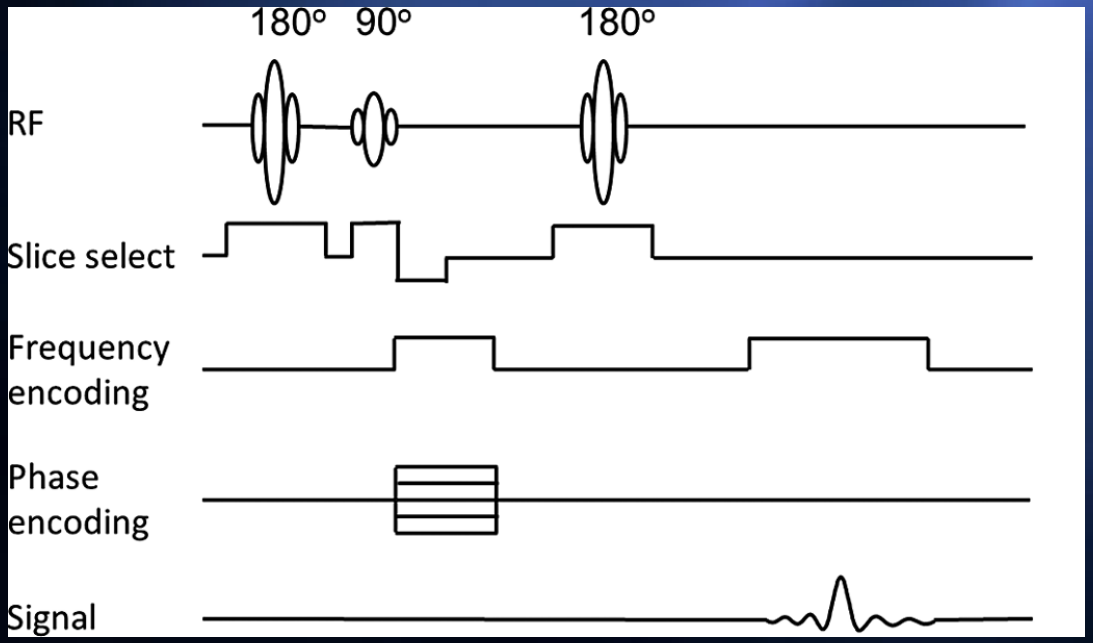
- Axial T1-weighted (a) and T2-weighted (b) fast SE images show a low-grade glioma.
- Because of hypercellularity, the tumor appears with hypointense signal in (a) and hyperintense signal in (b)
- The cystic components and edema are better depicted in (b) than in (a)

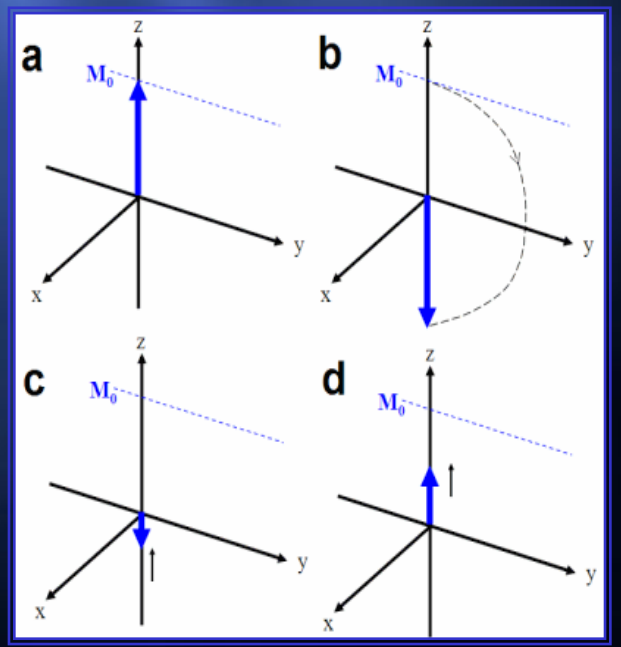


R. Bitar et al. RadioGraphics 2006; 26:513–537

Enhancing T_1 Contrast: The Inversion Recovery Sequence

- ✓ a spin-echo sequence with an additional slice selective 180° pulse before the 90° excitation pulse
- ✓ The purpose is to nutate M_Z into the –z-direction
  - it is also known as an 'inversion pulse'

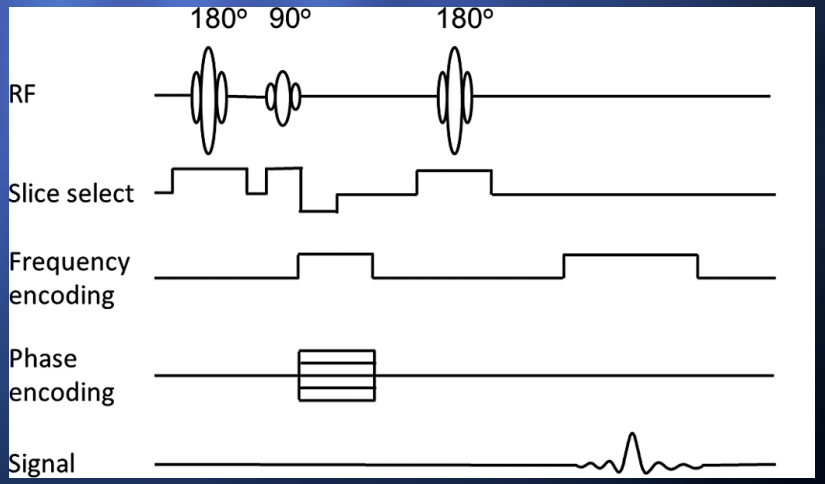




Enhancing T_1 Contrast: The Inversion Recovery Sequence

- ✓ The inverted M_z undergoes T_1 recovery
- ✓ The negative M_z vector gets shorter over time, passes through 0 and then grows along the positive z-axis
  - until it has fully recovered

$$M_z = |\mathbf{M}|\left(1 - 2e^{-\frac{t}{T_1}}\right)$$



- ✓ No transverse magnetisation is generated during this process

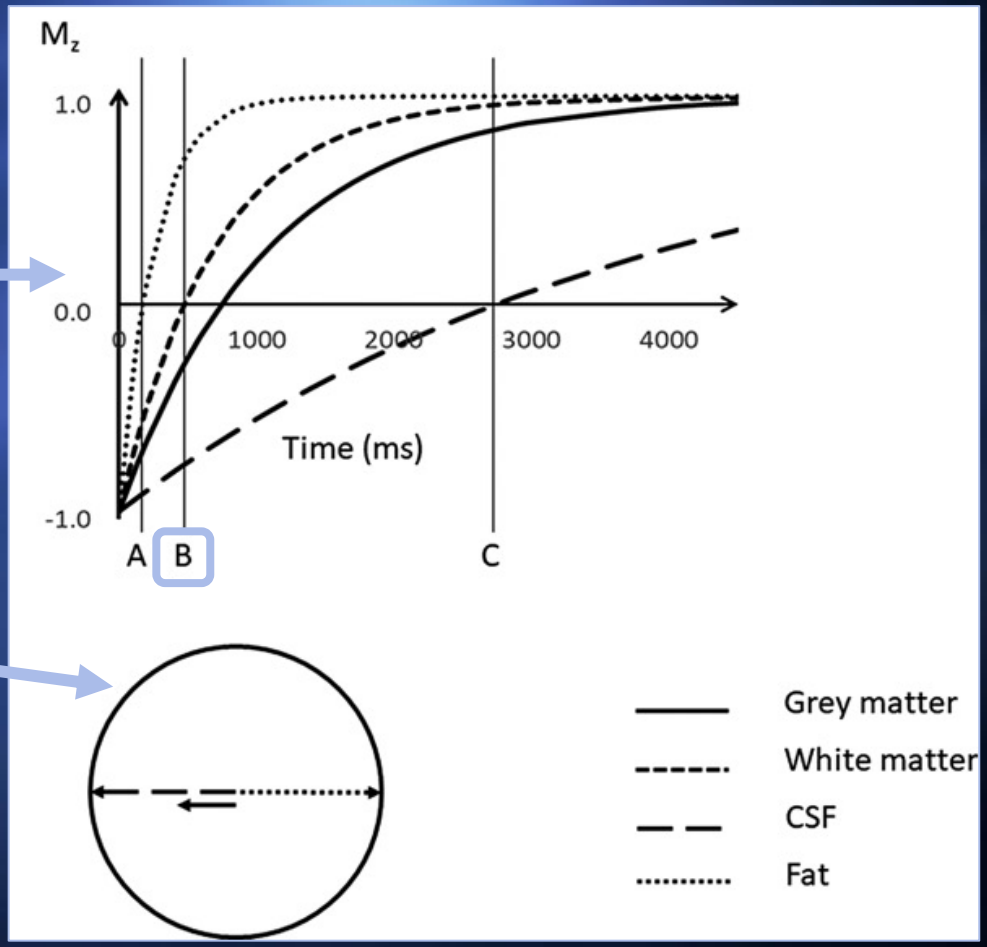
Enhancing T_1 Contrast: The Inversion Recovery Sequence

- ✓ At T_I a 90° pulse is applied, tipping M_Z into the transverse plane
  - inversion time T_I
- ✓ Differences in T_1 between tissues are reflected in different degrees of recovery at T_I and in different amounts of M_{XY} following the 90° pulse
- ✓ M_z can take both positive and negative values
  - there is potential for much greater T_1 contrast than in a conventional spin-echo sequence
    - ❖ where only the positive z-axis is used

$$M_z = |\mathbf{M}|\left(1 - 2e^{-\frac{t}{T_1}}\right)$$

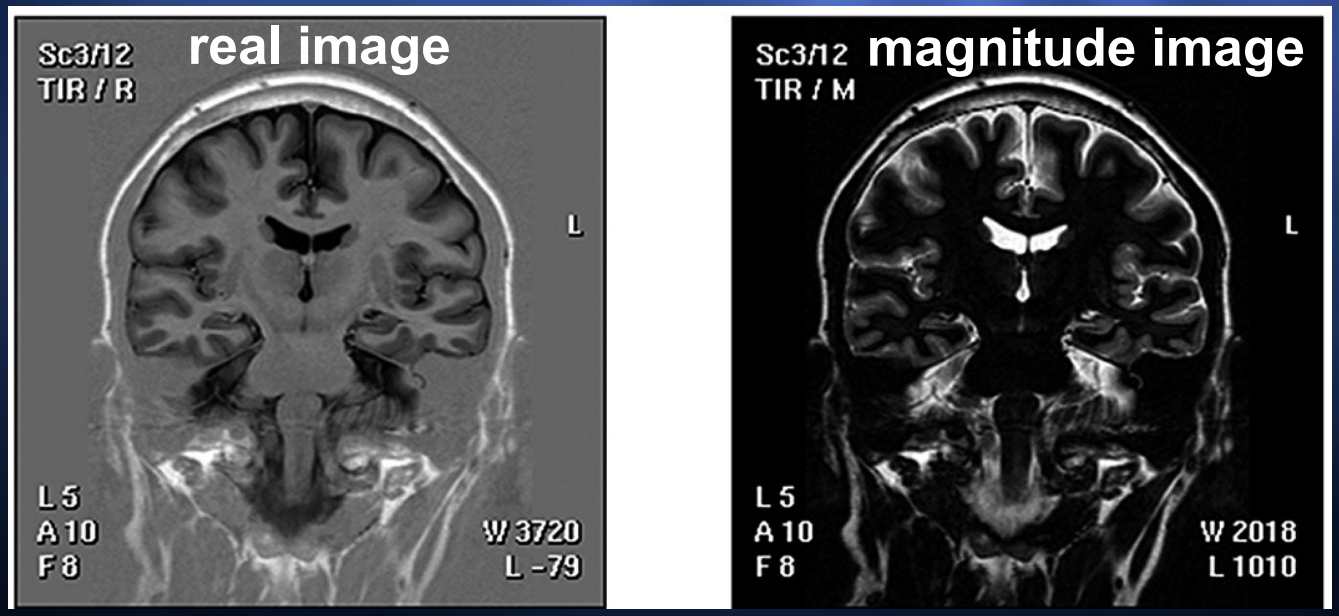
Enhancing T_1 Contrast: The Inversion Recovery Sequence

- ✓ Recovery of M_Z in grey matter, white matter, CSF and fat following an inversion pulse
- ✓ distribution of magnetisation in the transverse plane following a 90° pulse applied at time point B



The Inversion Recovery Sequence

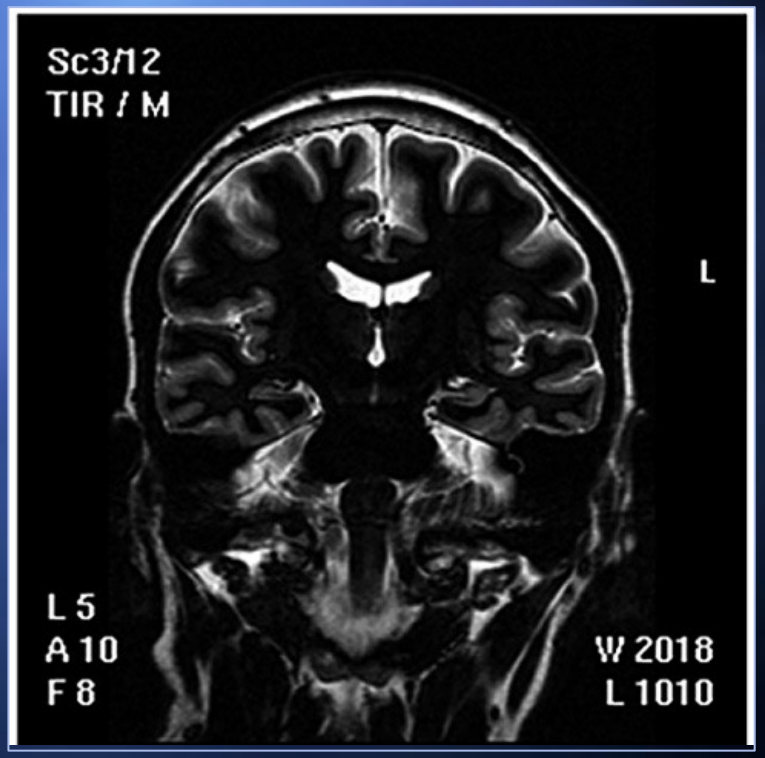
- Inversion recovery images can be presented as real image or magnitude image
  - depending on whether or not we pay attention to the 180° phase difference between magnetisation



The Inversion Recovery Sequence

Magnitude Inversion Recovery Image

- ✓ areas outside of the head appear black as does white matter
  - M_z in white matter is passing through the 0 point when the 90° pulse is applied
- ✓ signal intensity in CSF and in fat are the same
  - despite their very different T_1 values

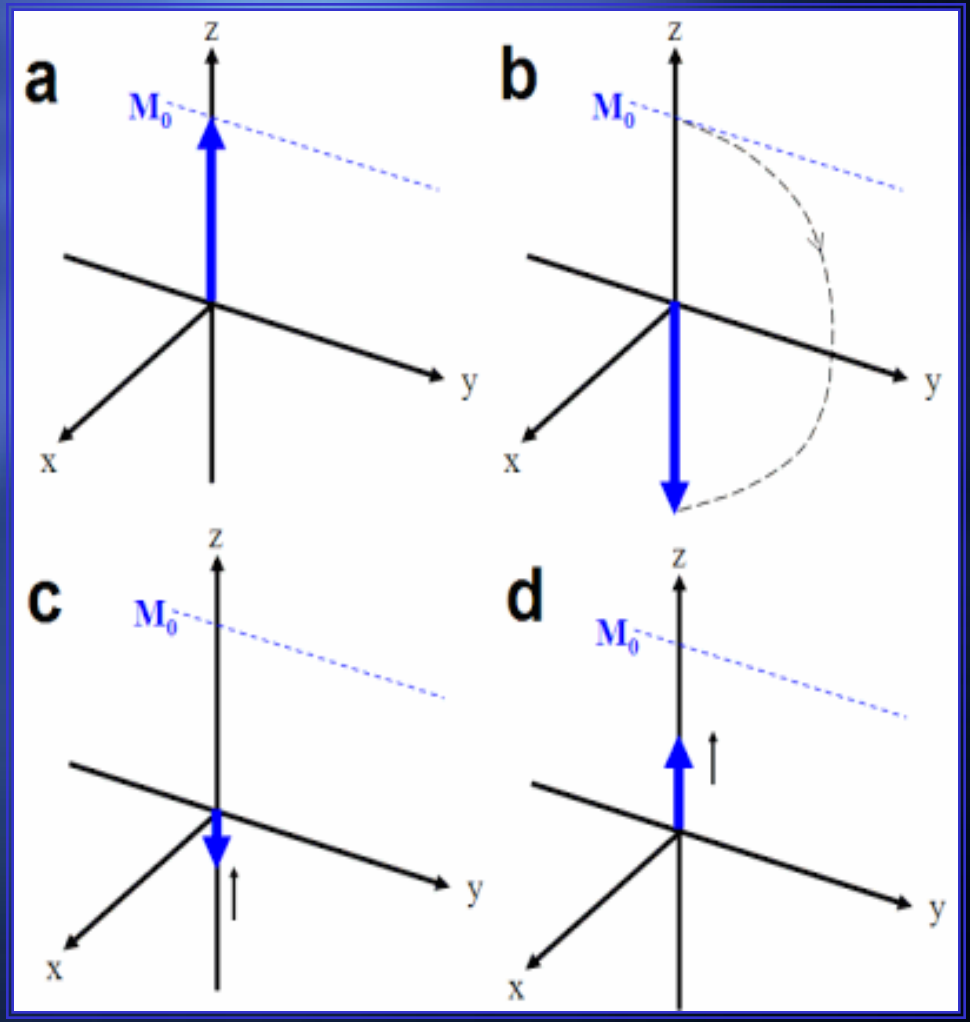


The inversion pulse

- RF $\gamma H_1 \Delta t = \pi$
- $M_z(0) = -M_z^\circ$
- $M_z(t) = M_z^\circ[1-2\, e^{-t/T1}]$
- $M_{xy}(t) = 0$

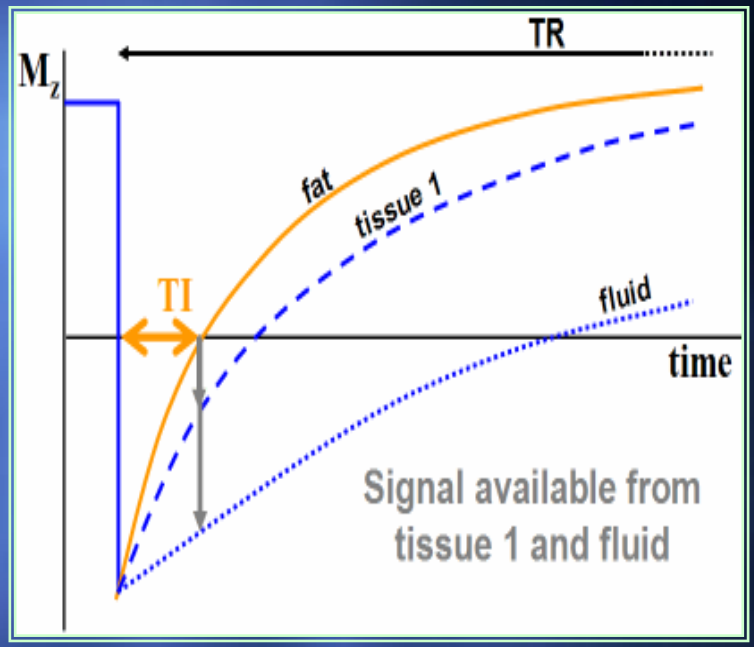
- What happen if the 90° pulse is applied close to the M_z=0 of one tissue

$$T_I = \ln 2 T_1 \approx 0.693 T_1$$

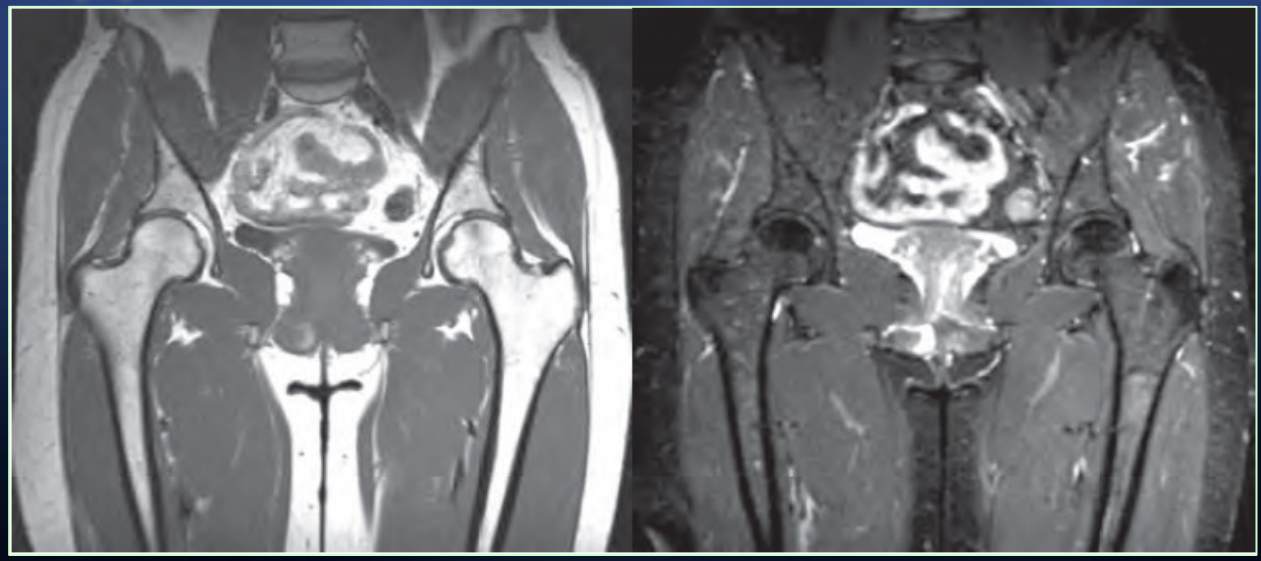


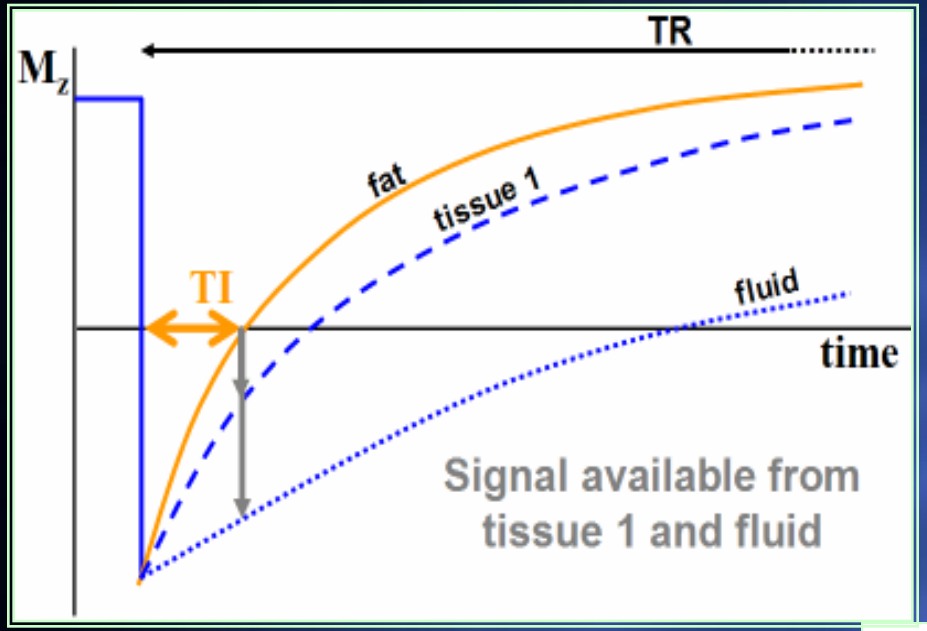
STIR sequence

What happen if the 90° pulse is applied close to the M_z=0 of one tissue ?



- ✓ **STIR: Short Tau IR**
  - **Fat suppression**





IR and fat suppression

STIR
Short T_1 Inversion Recovery

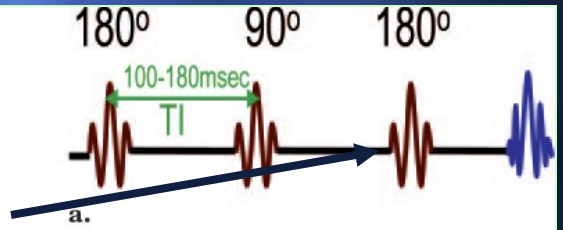
SE and STIR sequences for depiction of bone marrow edema

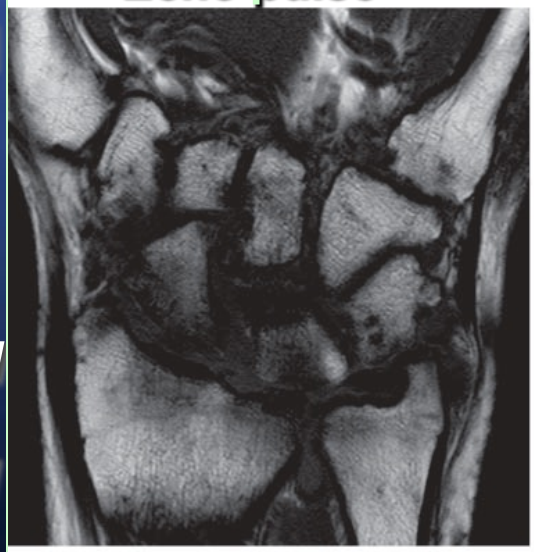
a) Diagram of the STIR seq
   - TI 100–180 ms for fat

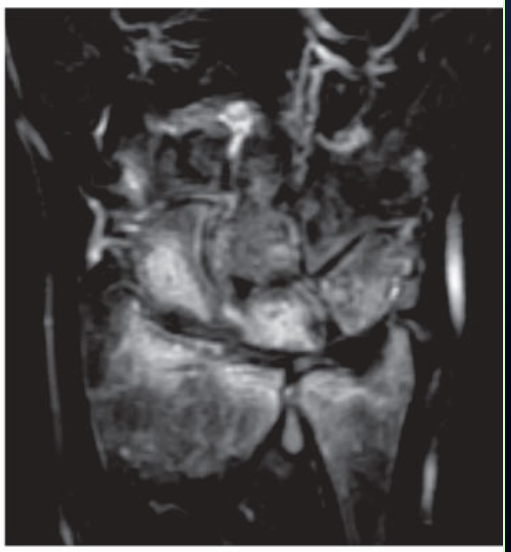
b) Coronal T1-w fast SE image

c) coronal STIR image

both show pancarpal rheumatoid arthritisthe extent of bone marrow edema is better depicted in c than in b



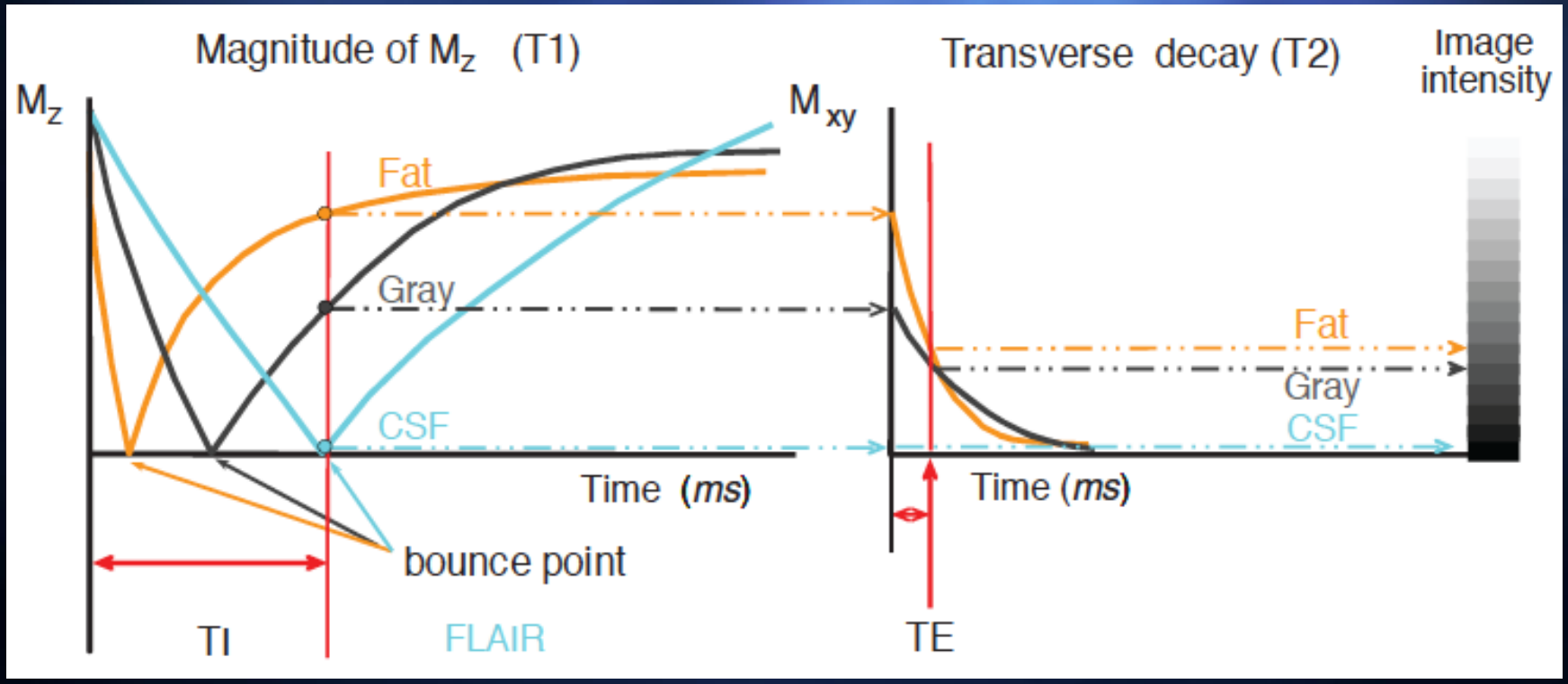




FLAIR sequence

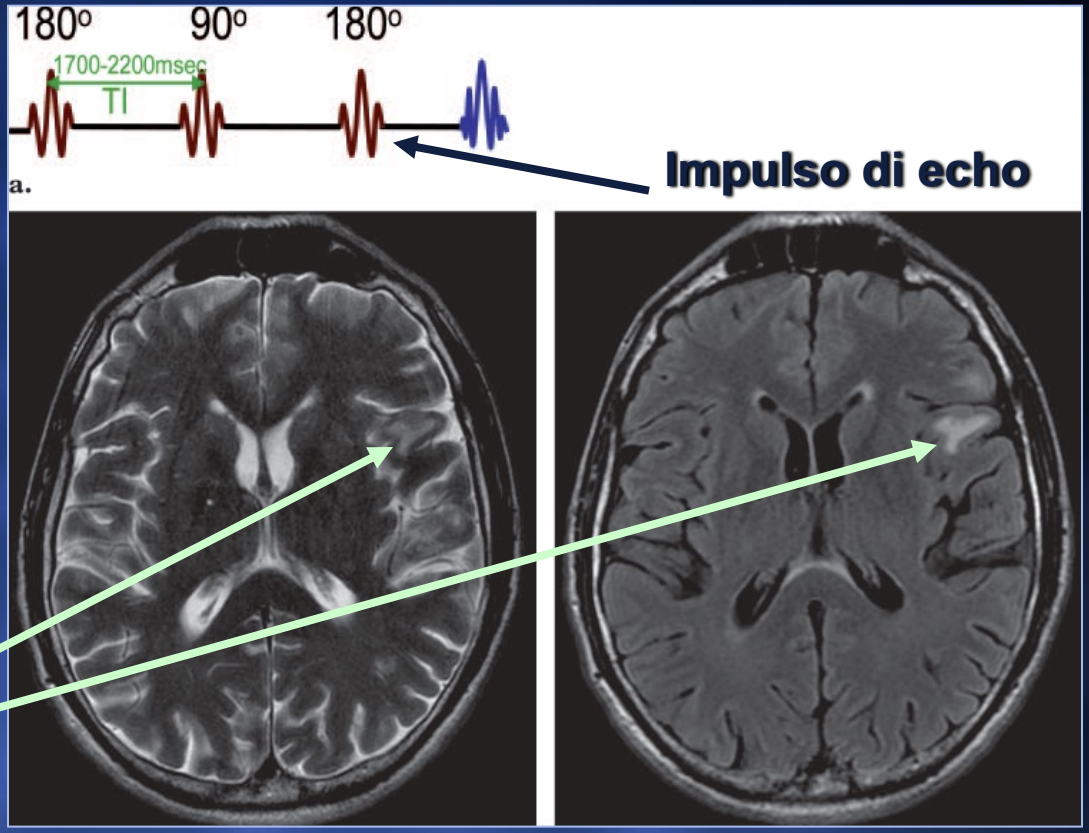
FLAIR: Fluid Attenuated IR

- sequence shows a TI of 1700–2200 ms for CSF suppression



IR and CSF signal suppression

Comparison of fast SE and FLAIR sequences for depiction of lung cancer metastases to brain



a) Diagram of the FLAIR sequence shows a T_I of 1700–2200ms for cerebrospinal fluid

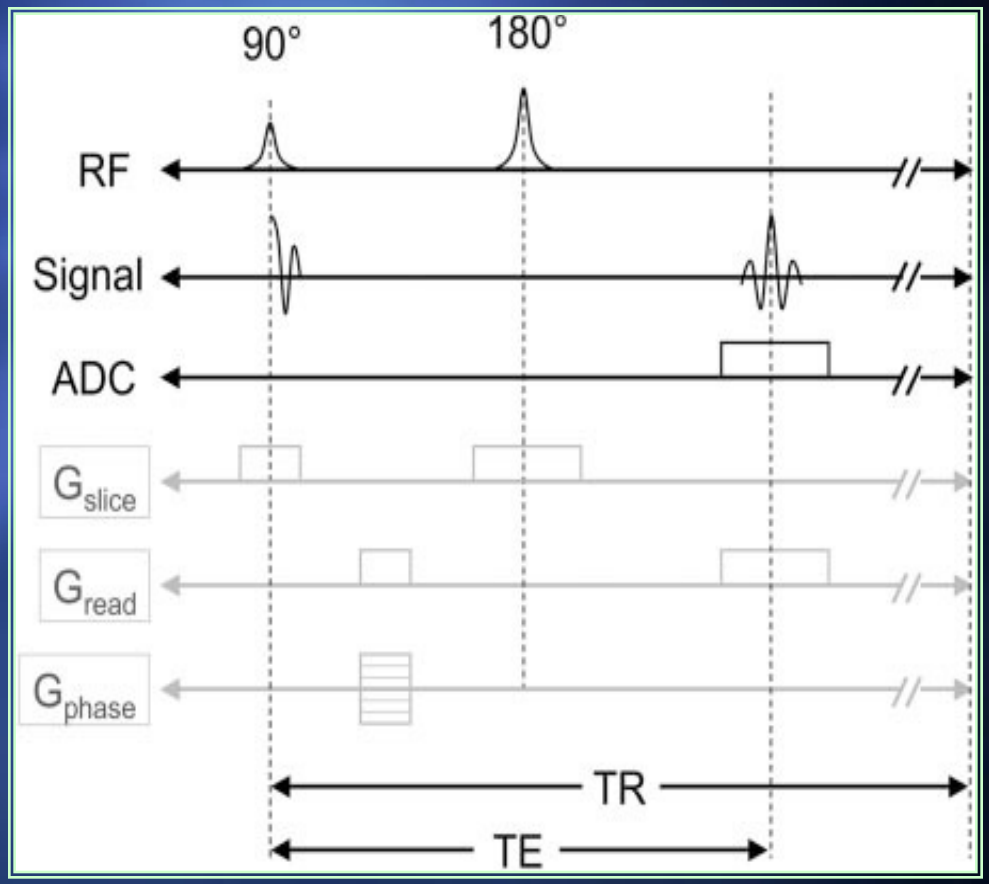
b) Axial T2 weighted fast SE image shows white matter abnormalities in the left temporal lobe

c) Axial T2 weighted FLAIR image obtained with nulling of the signal from cerebrospinal fluid shows the metastatic lesions more clearly

www.imaios.com/en/e-Courses/e-MRI/MRI-Sequences/inversion-recovery-stir-flair

The acquisition time

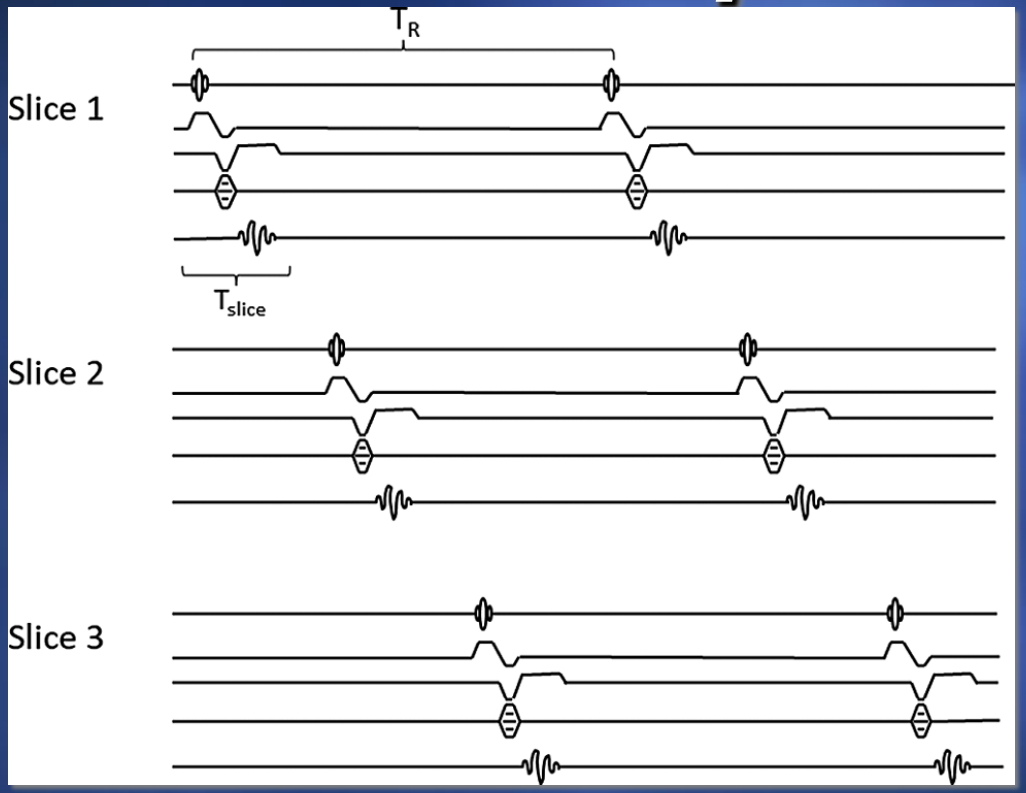
- ✓ In the SE sequence is necessary to acquire echo signals how many rows of k space
  - Ny
- ✓ The repetition time TR is comparable with the T_1
- ✓ Since the NMR signal is low it may be necessary to repeat identical acquisitions to improve the SNR
  - Nrep



Acquisition time

$$T_{acq}=T_R\ N_y\ N_{rep}$$

Multi-slice sequence



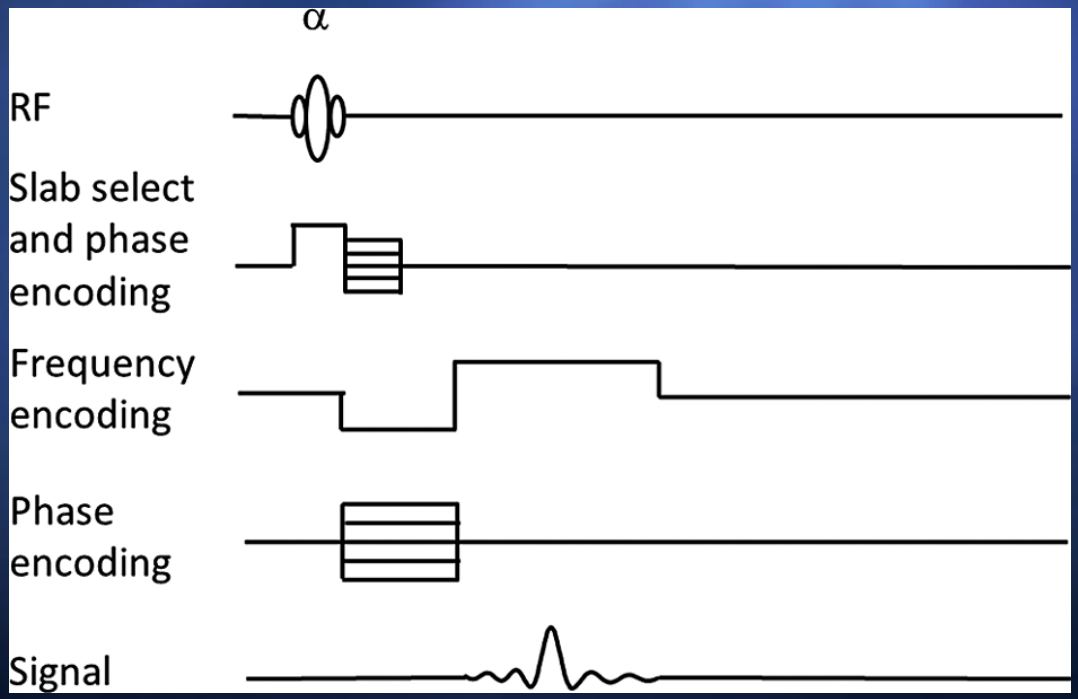
- ✓ the number of slices is T_R / T_{slice}
- ✓ T_{slice} the time to acquire one line of data
  - slightly longer than TE as it includes the whole of the echo acquisition time
    - ❖ whereas TE is measured to the centre of the echo

3D spatial encoding

- ✓ rather than perform 2D tomographic imaging it is possible to collect image data from an entire volume simultaneously and encode it in 3D
- ✓ the slice select axis has become 'slab select'
  - with a gradient and selective excitation pulse used to generate transverse magnetisation within a thick slab of the patient's body
- ✓ Signal from this slab is spatially encoded using frequency encoding on one axis and phase encoding on the other two

3D spatial encoding

diagram shows the phase encoding gradient ‘ladder’ on the slab select axis as well as the usual phase encoding axis

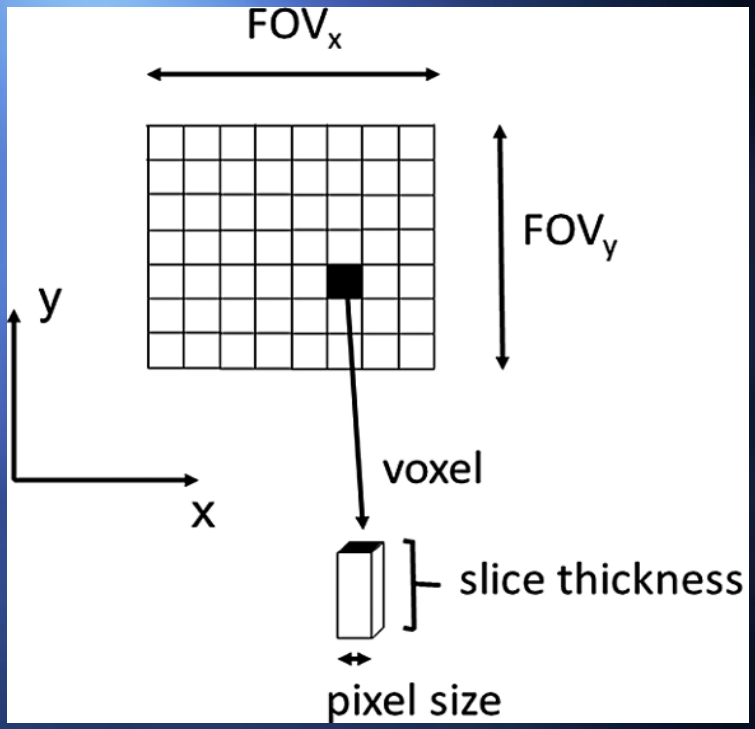


http://www.imaios.com/en/e-Courses/e-MRI/Signal-spatial-encoding/3D-spatial-encoding

3D spatial encoding

3D imaging allows to overcome a drawback of multislice imaging

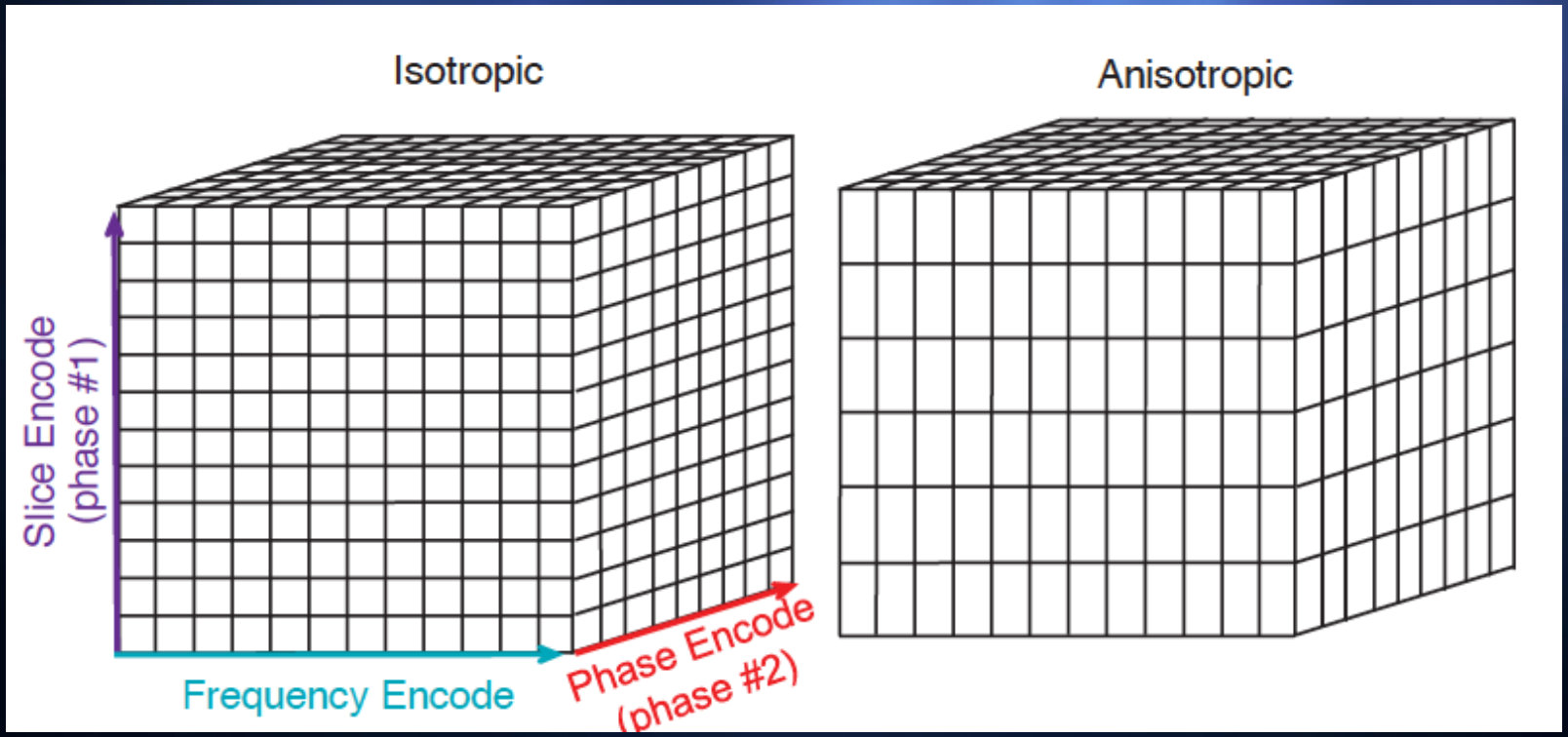
- ✓ the slice thickness is frequently greater than the spatial resolution within the slice
- ✓ 'Isotropic' imaging: equal spatial resolution in all 3 dimensions
  - is an advantage in many clinical applications that require imaging of small and complex anatomical structures



3D spatial encoding

- ✓ spatial encoding in 3D by adding phase encoding in the 3rd dimension
- ✓ Acquisition time: TR x Ny x Nz

Long acquisition time !



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