ARTEFACTS: PROBLEMS, SOLUTIONS AND NEW IDEAS

Artefacts are features appearing in an image that are not present in the investigated object

- ✓ **In MRI, artefacts test our understanding of the underpinning physics**
  - **if this is understood the artefacts can be avoided, reduced or compensated for**

Moreover

- ✓ **a number of artefacts, or the solutions developed to minimise them, provided the seeds of advanced MRI techniques**

Motion Artefacts in MRI

- ✓ Each data point in the k space contains information from the entire selected slice
  - or selected volume in 3D imaging
- ✓ Interleaved multislice imaging is used to cover the whole of an organ or body area of interest
- ✓ Movement during acquisition affects all the slices in the investigated volume
  - not a limited number of them
  - The acquisition time of an MRI dataset is typically a few minutes

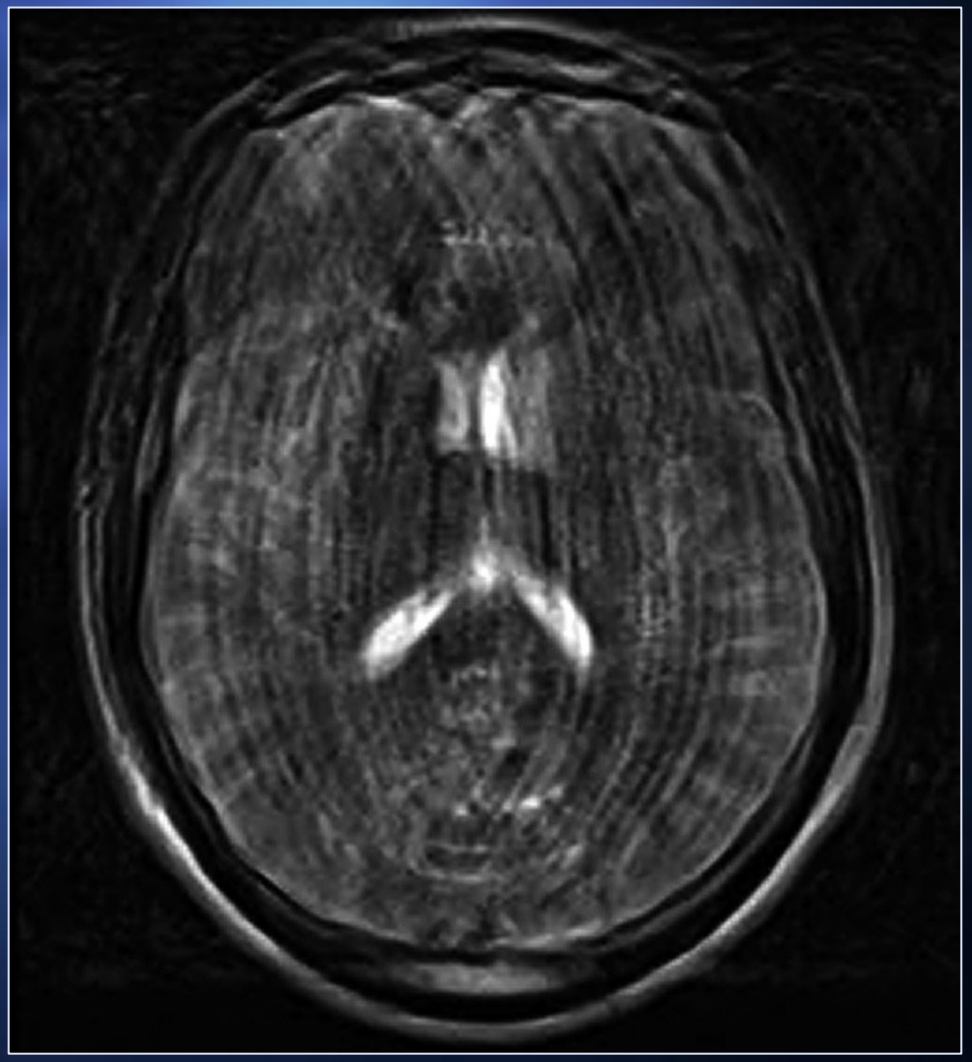
Motion Artefacts in MRI

- ✓ **Movement during acquisition affects all the slices in the investigated volume**
  - **not a limited number of them**
  - **The acquisition time of an MRI dataset is typically a few minutes**

- ✓ **it is of utmost importance to optimise patient positioning**
- ✓ **an uncomfortable position increases the probability of movement during the exam**

Motion Artefacts in MRI

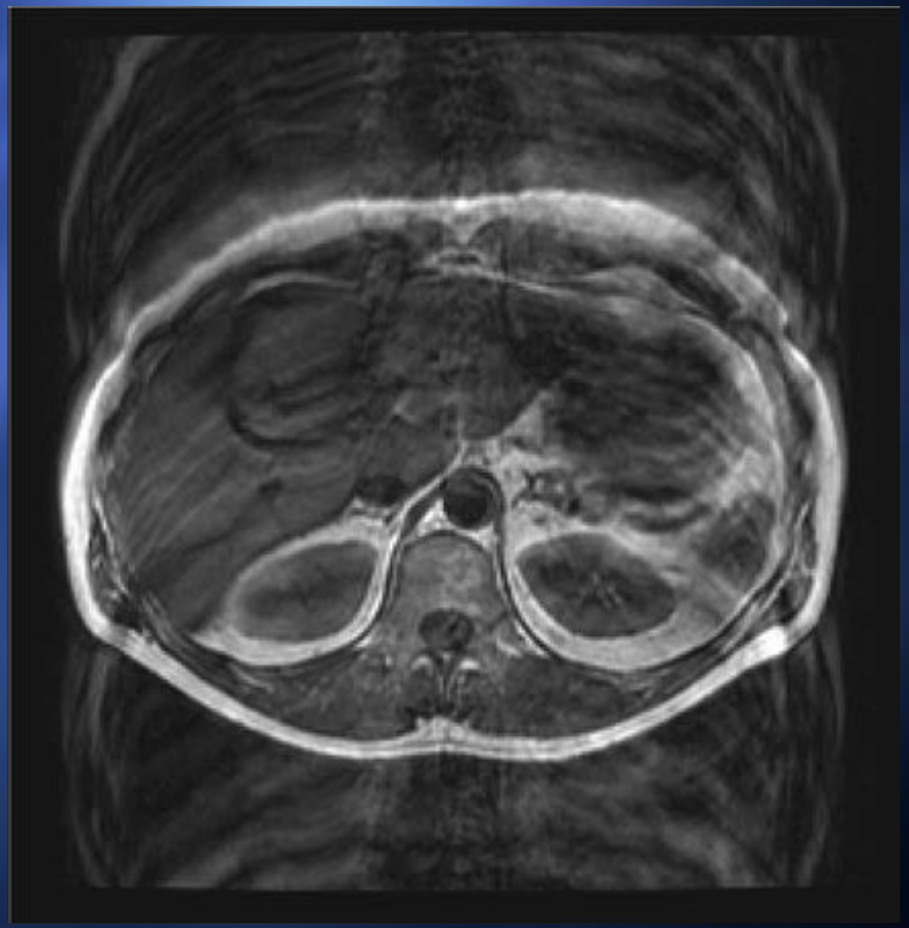
- ✓ Patient movement disrupts the relationship between phase and position
- ✓ This can result in faint displaced images
  - known as ghosts



phase encoding gradient
in the left–right direction

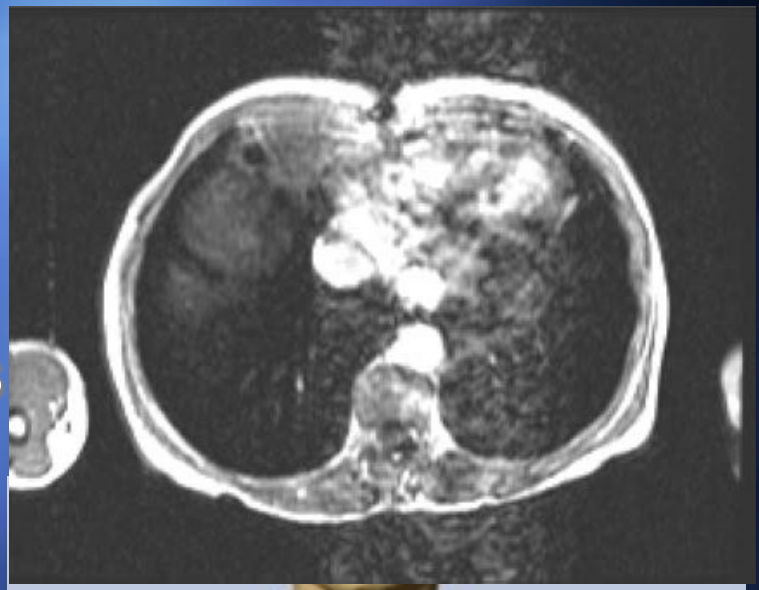
Motion Artefacts in MRI

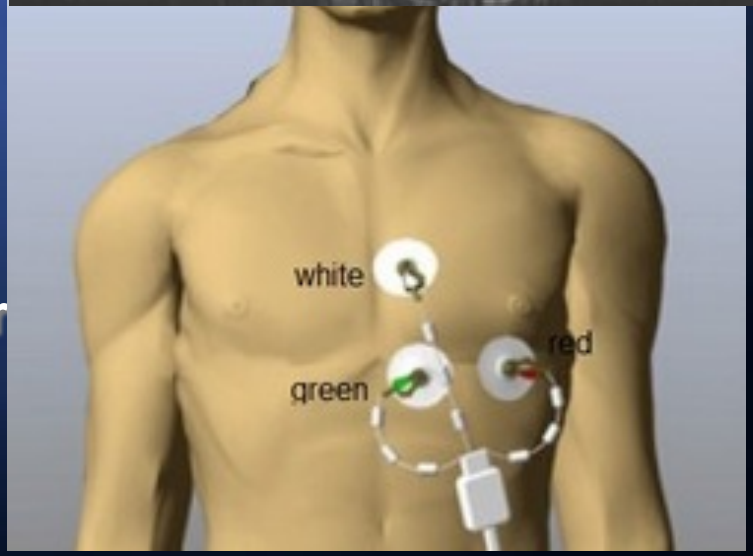
- ✓ In medical imaging, some types of motion cannot be avoided
  - breathing, the cardiac cycle, and blood flow
- ✓ there are some techniques to minimise the resulting artefacts



Cardiac Motion

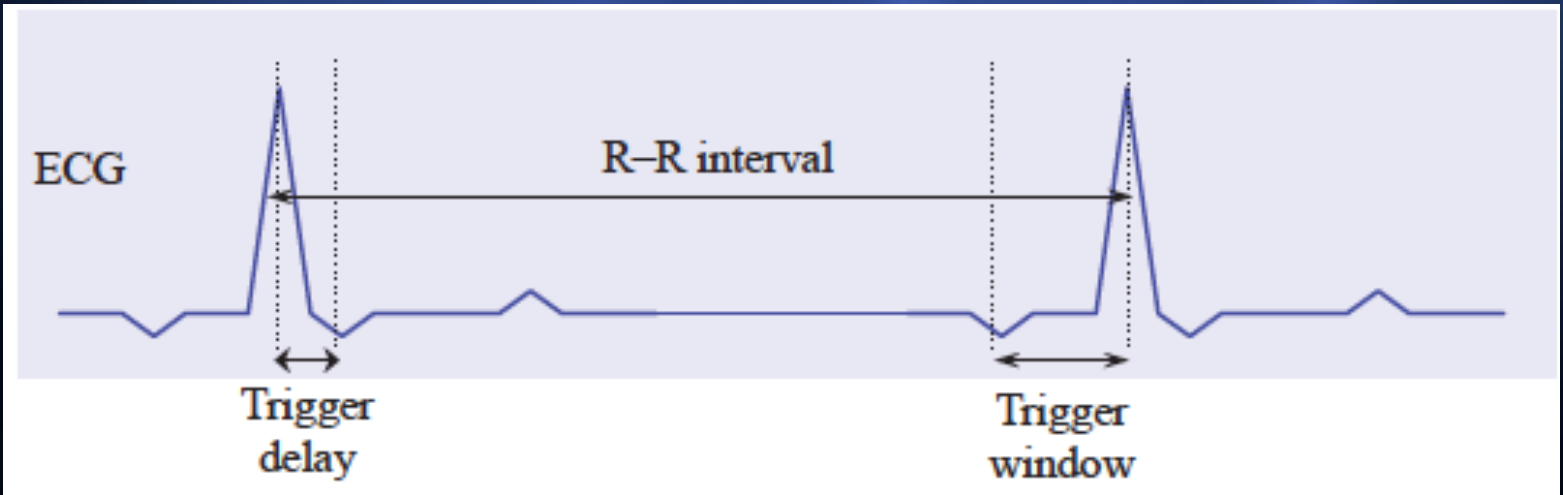
- ✓ **Synchronizing the sequence to the cardiac cycle**
  - known as ‘gating’
- ✓ **Special electrocardiogram (ECG) non-metallic electrodes**
  - to reduce artefacts on the images
  - to avoid local skin heating
  - The ECG wires typically have high impedance
    - ❖ reducing the chance of RF burns for the patient





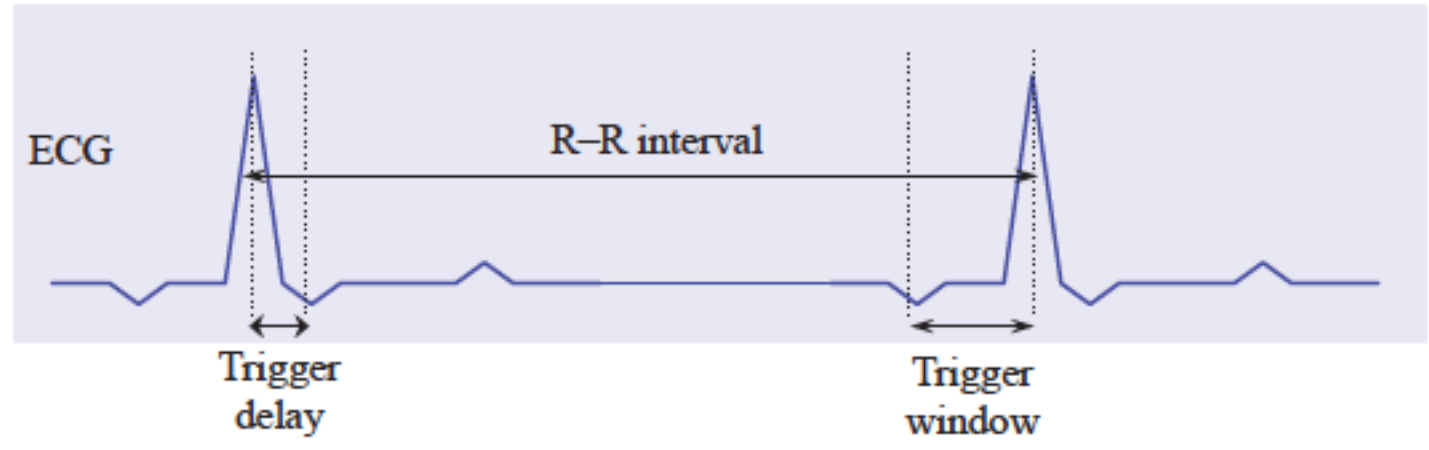
Cardiac Motion

- ✓The peak of the R wave is used to trigger the next acquisition
- ✓Each line of K space is acquired at the same point in the cardiac cycle
- ✓The T_R is determined by the heart rate (HR)
  - typical HR of 75 beats per minute (bpm)
  - TR ~ 800 ms or multiple of the cardiac cycle



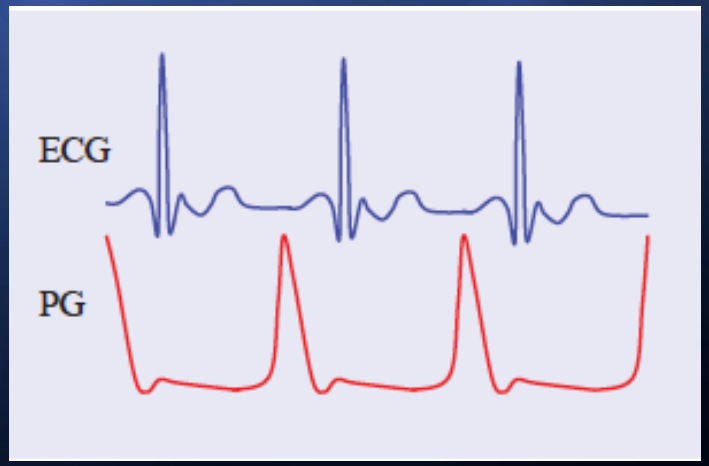
Cardiac Motion

- ✓Each line of k space is acquired at the same point in the cardiac cycle
  - Ghosting is removed
  - Cine imaging of the cardiac movement
    - ❖https://www.imaios.com/en/e-Courses/e-MRI/Image-quality-and-artifacts/motion-artifact-remedies



Peripheral Gating

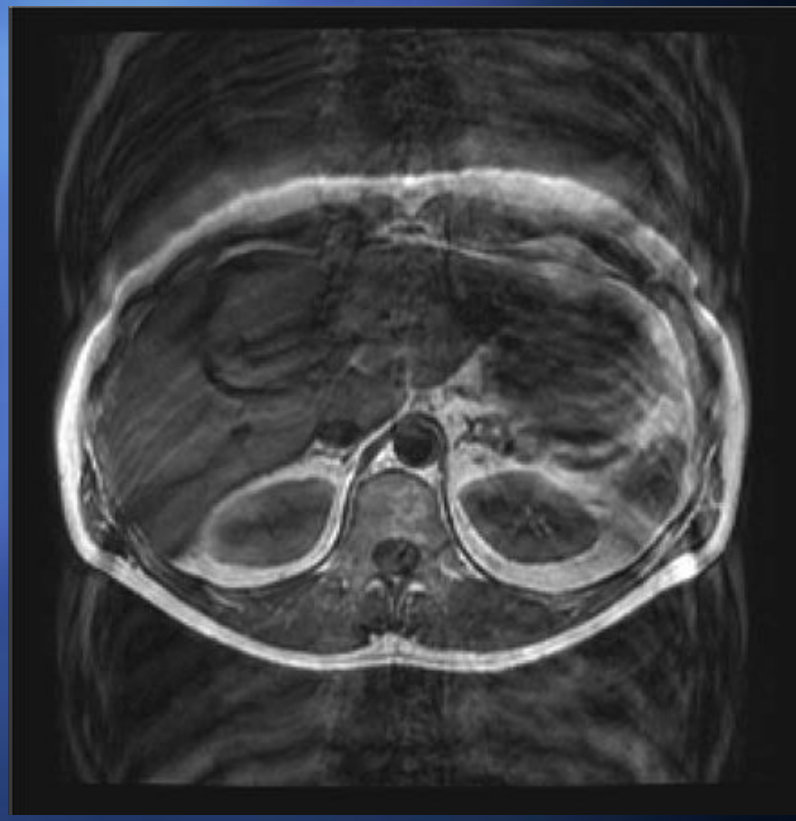
- ✓ **Cardiac gating by detecting the arterial pulse of blood in the patient's finger**
  - **the blood vessels are very close to the skin**
  - **an infrared light detector pick up the increased volume of blood as the arterial pulse reaches the extremity**
    - ❖ **sufficient to provide a trigger for the MR sequence**
- ✓ **Peripheral gating is useful for removing pulsatility artefacts in the brain and spine**



Respiratory Motion

Breathing motion causes ghosting thoracic and abdominal imaging

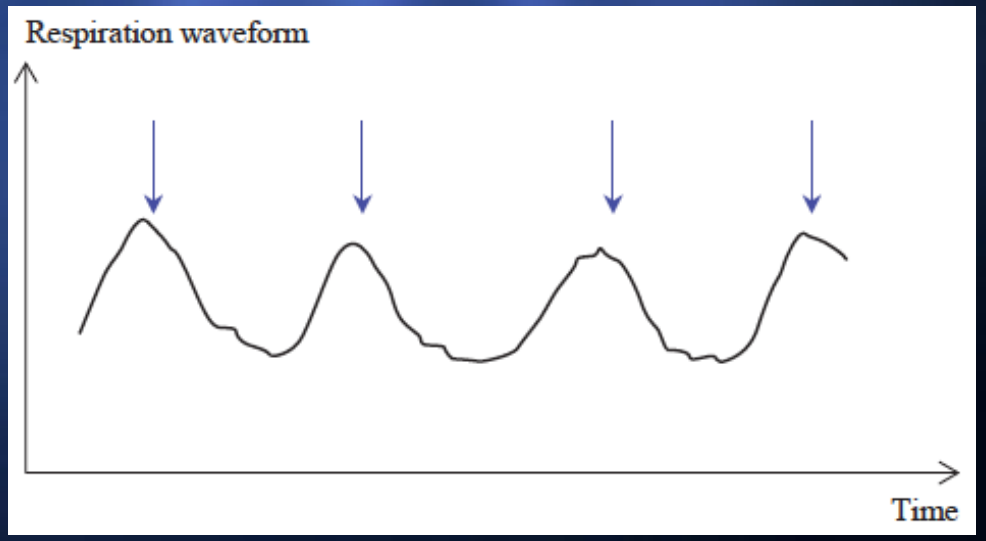
- ✓**15 s scan time or less than can be acquired during a single breath-hold**
  - **The acquisition can be split up so that packages of slices are acquired in separate breath-holds**
    - ❖**The position of the liver and kidneys is more reproducible if the breath is held in expiration**



Careful coaching with the patient is needed before the examination

Respiratory gating

- ✓ The respiratory cycle can be monitored using a ‘breathing belt’ strapped around the thorax
- ✓ this generates an electric signal dependent on the pressure of the thorax on the belt
  - allowing breathing to be monitored



https://www.imaios.com/en/e-Courses/e-MRI/Image-quality-and-artifacts/motion-artifact-remedies

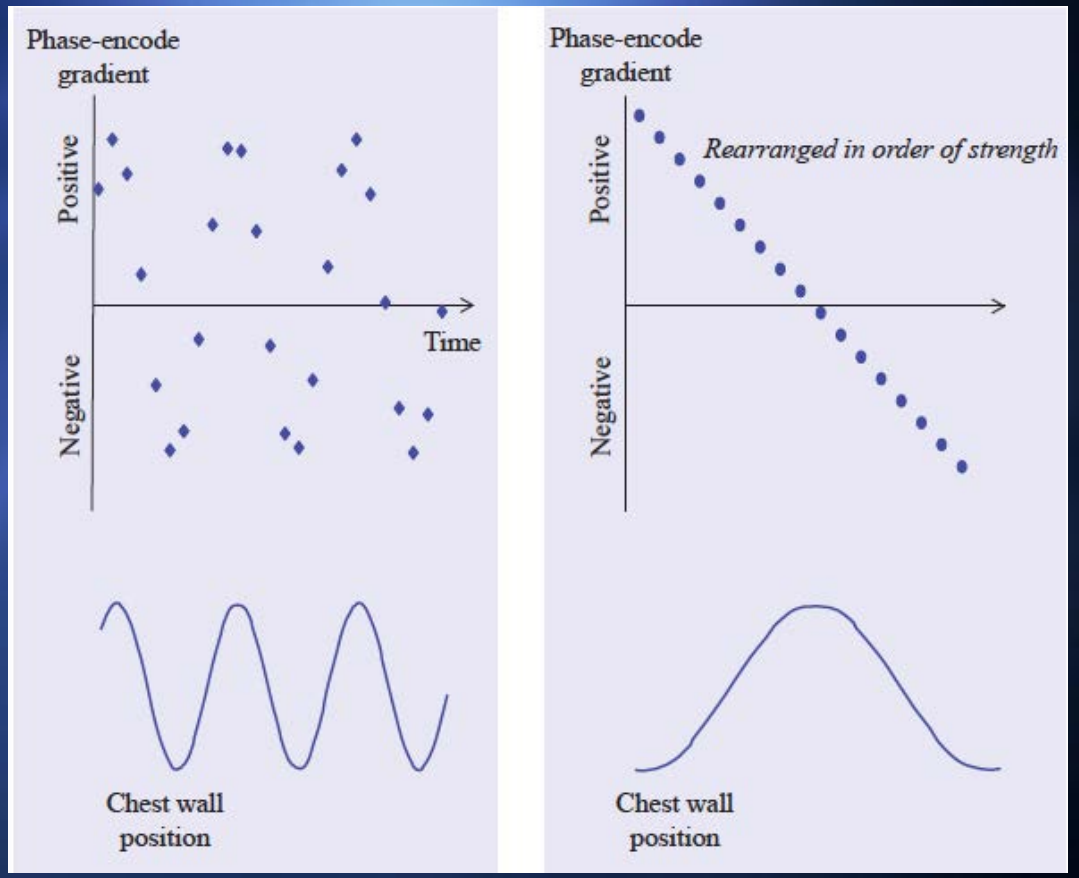
Respiratory gating

- Respiratory gating can then be applied in order to perform acquisition of k-space lines during the end-expiration phase
  - when chest motion is minimal
- T_R is defined by the breathing cycle
  - the interval between 2 consecutive triggers
  - a normal breathing rate of about 10–15 breaths per minute gives an effective TR of at least 4000 ms
    - respiratory gating useful for PD or T2-weighted imaging

Respiratory compensation

Respiratory- Ordered Phase Encoding (ROPE)

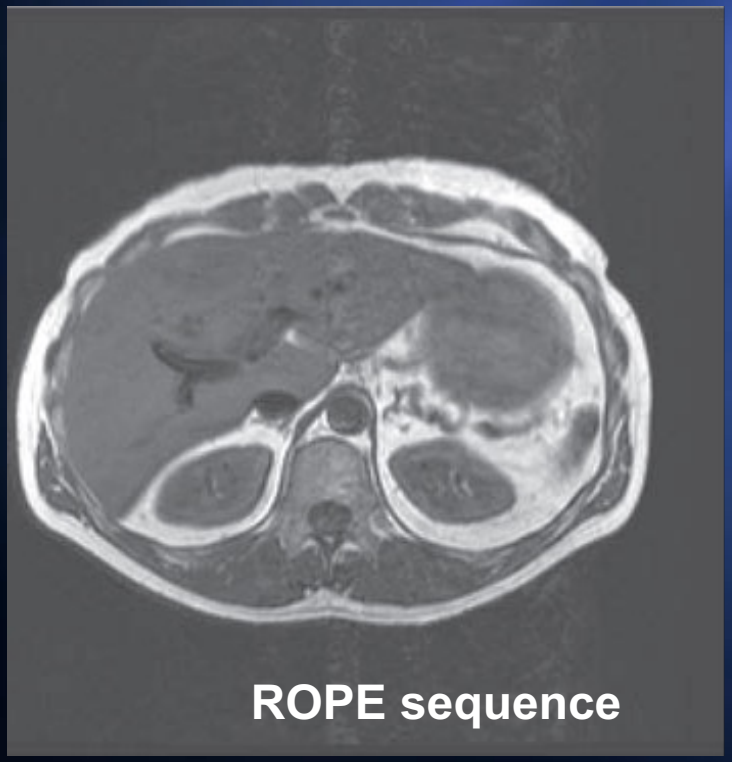
- ✓ **k-space lines are acquired during the whole respiratory cycle**
- ✓ **similar phase encoding gradient amplitudes are used with the thorax at similar positions**
- ✓ **This avoids abrupt variation in the position of chest structures between closely-spaced k-space lines**
  - **minimising artefacts**

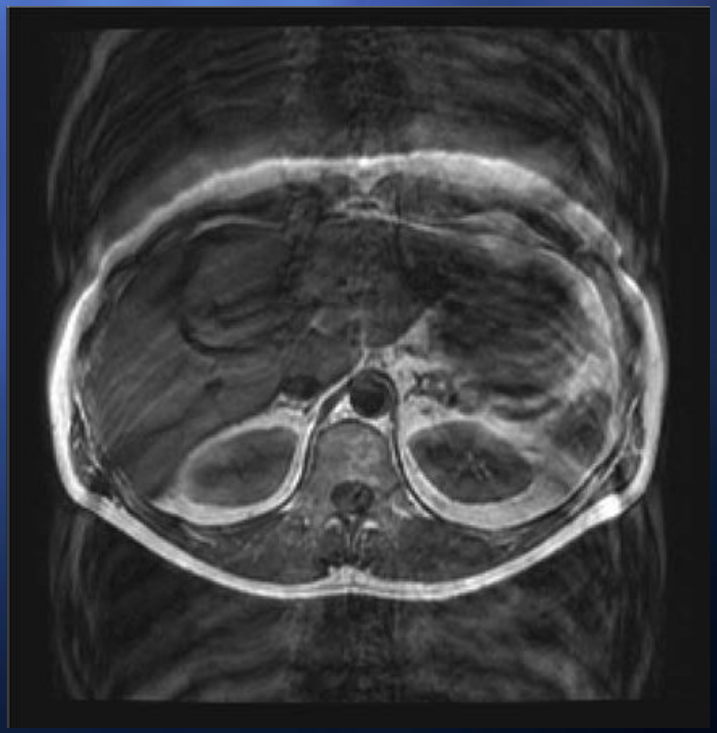


https://www.imaios.com/en/e-Courses/e-MRI/Image-quality-and-artifacts/motion-artifact-remedies

Respiratory compensation

- ✓in respiratory gating only the quasi-stationary phase of the cycle is used for acquisition
- ✓ROPE is more effective because data are acquired throughout the respiratory cycle

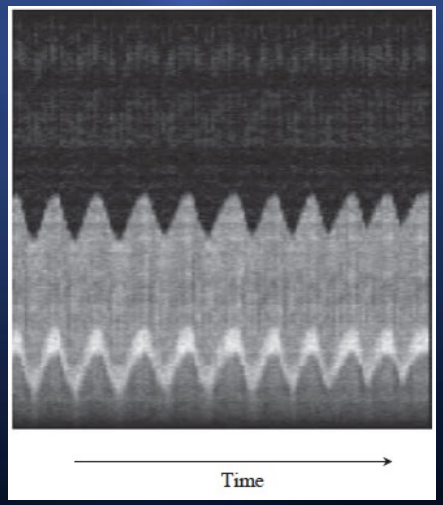


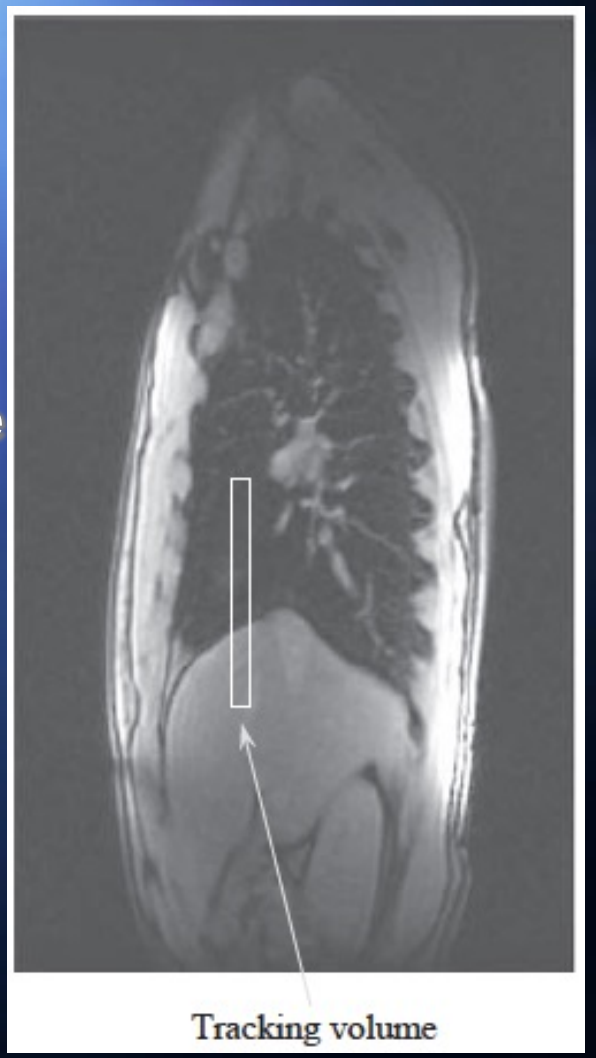


Navigator echoes

- ✓ The navigator 'signal' is from a single column of voxels used to monitor the position of the diaphragm
  - 1D signal acquired from 1 echo
  - Strong contrast between the lung and the liver shows up clearly
  - The boundary automatically detected and controls the acquisition: the image data are acquired when the diaphragm is within certain spatial limits
    - ❖ typically 2–4 mm
  - ROPE acquisition <u>without respiratory belt</u>

The navigator signal is spatially encoded in one direction: the other direction is time





What is the best ?

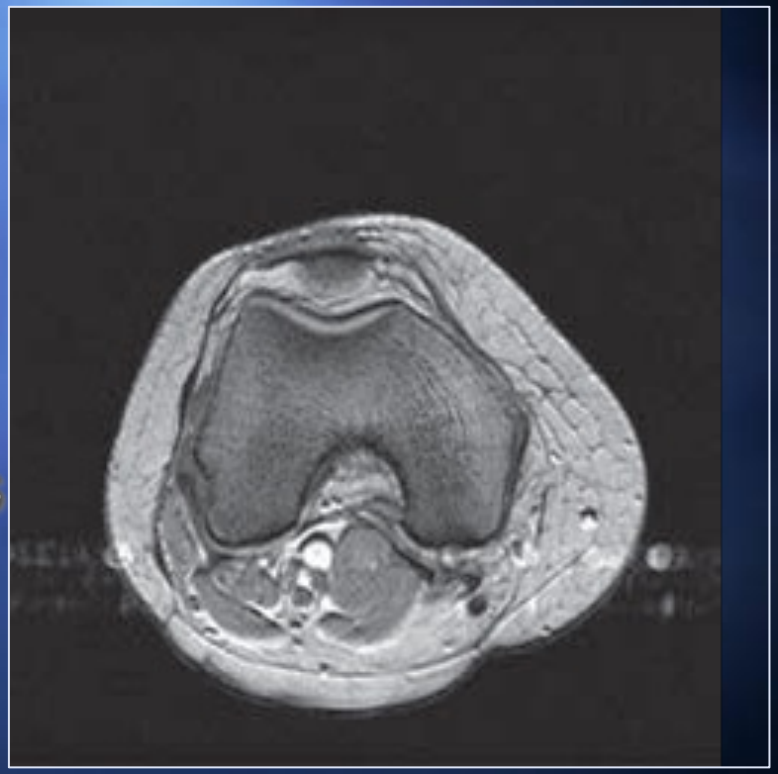
- ✓ a breath-hold is usually the best choice
- ✓ breath-hold for morphology and perfusion scans
- ✓ navigators for coronary arteries and high-resolution viability
- ✓ ROPE can also be used with classic SE or GE sequences in abdomen imaging
- ✓ respiratory gating
  - Too long T_R

Flowing blood and cerebrospinal fluid

- ✓ flowing blood and CSF represent large numbers of moving spins
- ✓ sometimes they undergo pulsatile flow
  - more complex than flow at a constant velocity
- ✓ when spins are moving in the time interval between the RF excitation pulse and echo acquisition, they accumulate a phase shift different from the phase expected for a stationary spin

Flowing blood and cerebrospinal fluid

- when spins are moving they accumulate a phase shift different from the phase expected for a stationary spin
- in the phase encoding direction we observe ghosts of the vessel
- if the motion is pulsatile the intensities of the ghosts have a periodic modulation



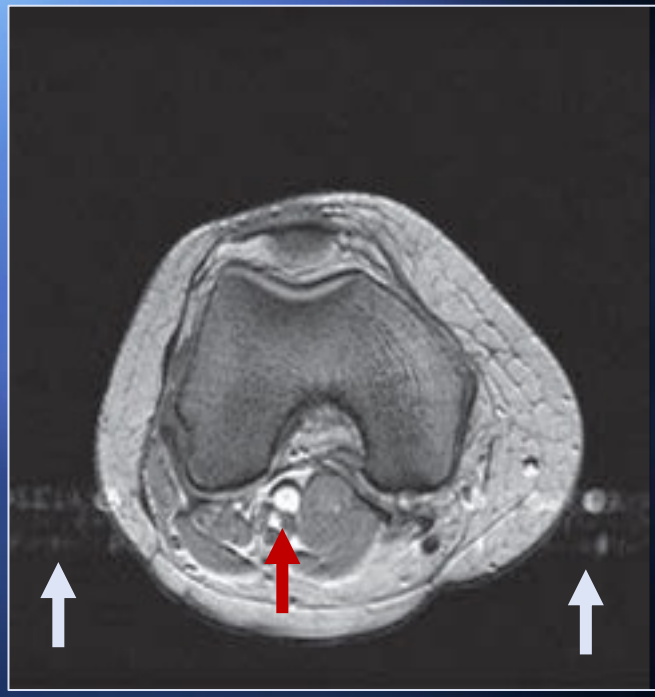
Flow compensation gradient

- ✓ **The phase-encoding gradient waveform can be modified to cancel the additional phase shift associated with flow**
  - **The drawback is that the duration of a flow-compensated phase-encoding gradient is longer limiting the minimum echo time**
    - https://www.imaios.com/en/e-Courses/e-MRI/MR-Angiography-Flow-imaging/flow-compensation
- ✓ **Sometimes the flow artefacts overlie the region of clinical interest : the simplest solution is to swap frequency and phase encoding directions and repeat the acquisition**
  - **artefacts are still present but the direction will be rotated by 90°**
    - https://www.imaios.com/en/e-mri/image-quality-and-artifacts/motion-and-ghosting-artifacts-remedies

Motion Artefacts from Flowing Blood

Two effects

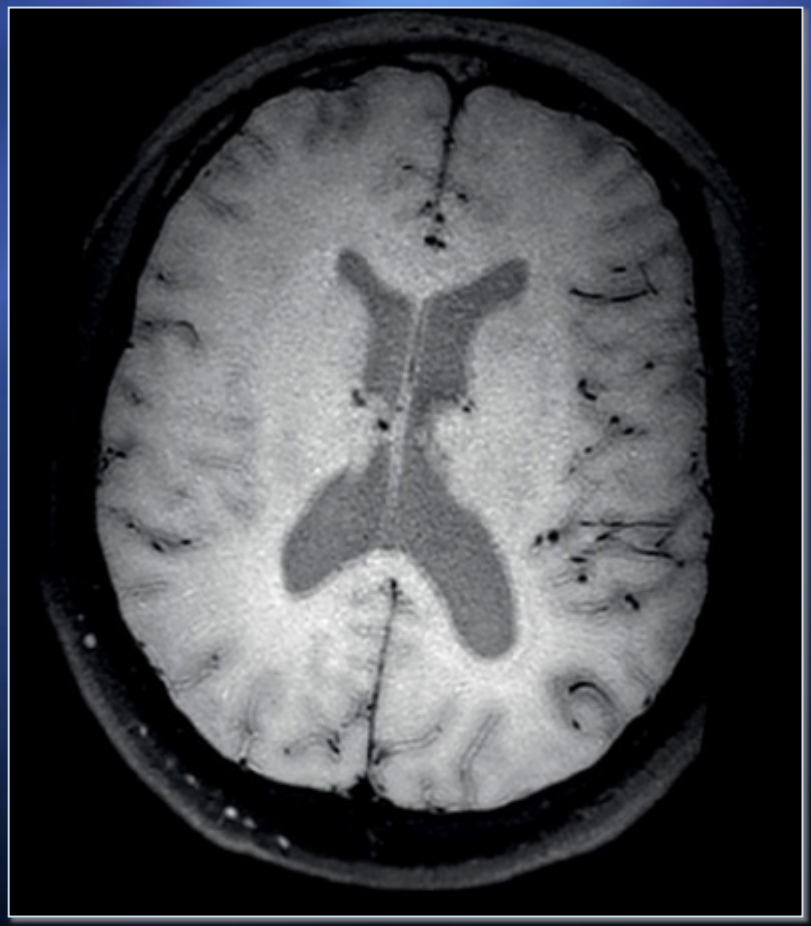
- ✓ an in-flow effect which produces high signal within blood vessels on GE images
  - new protons flow into the imaging slice during the T_R
- ✓ velocity-induced phase effects
  - reduce the blood signals
  - create ghost images of vessels in the phase encode direction



Motion Artefacts from Flowing Blood

SE sequence

- ✓ Signal loss within the blood vessel
- ✓ Characteristic dark-blood appearance of spin-echo images

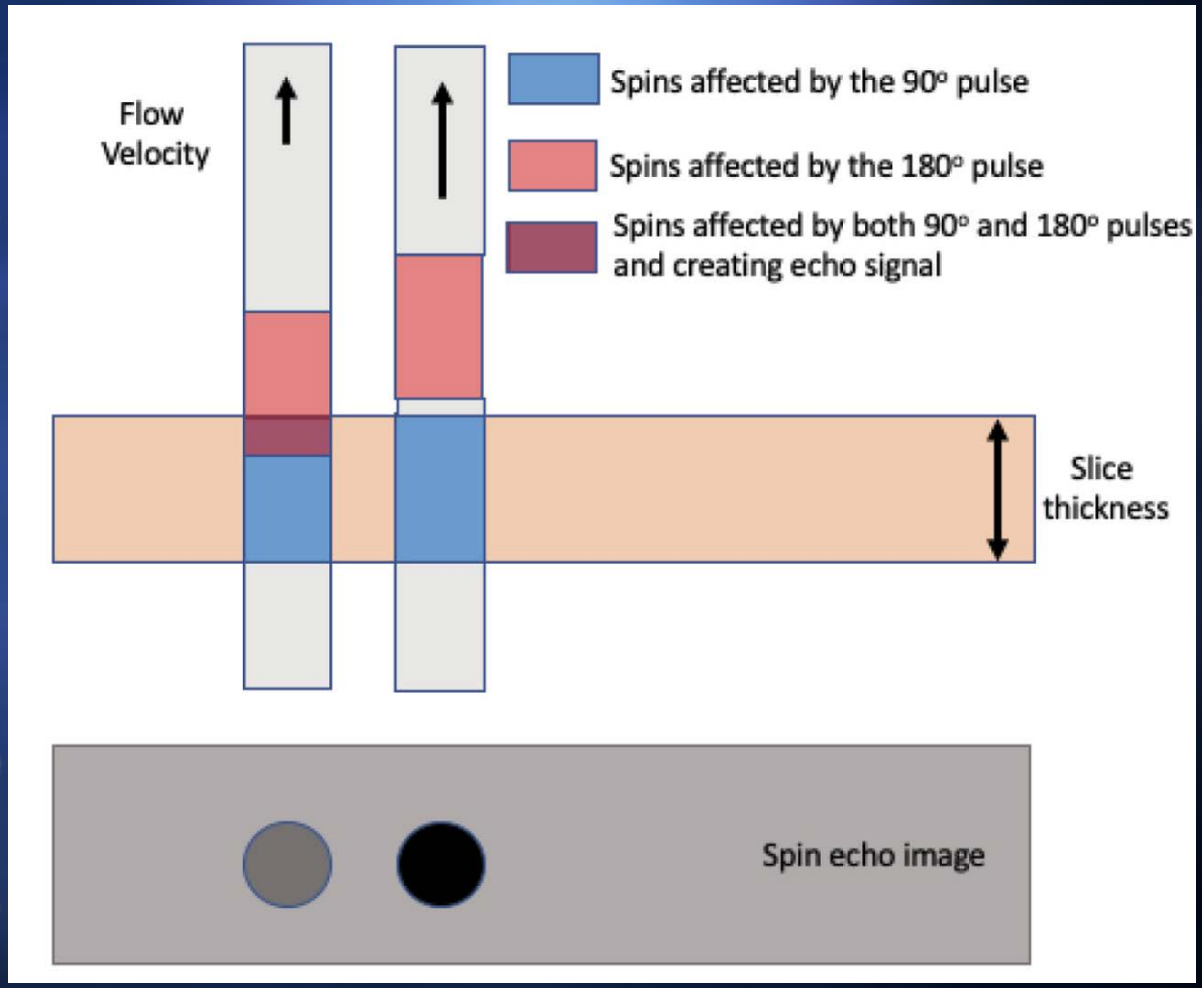


https://www.imaios.com/en/e-Courses/e-MRI/MR-Angiography-Flow-imaging/flow-phenomena-mri

Motion Artefacts from Flowing Blood

SE sequence

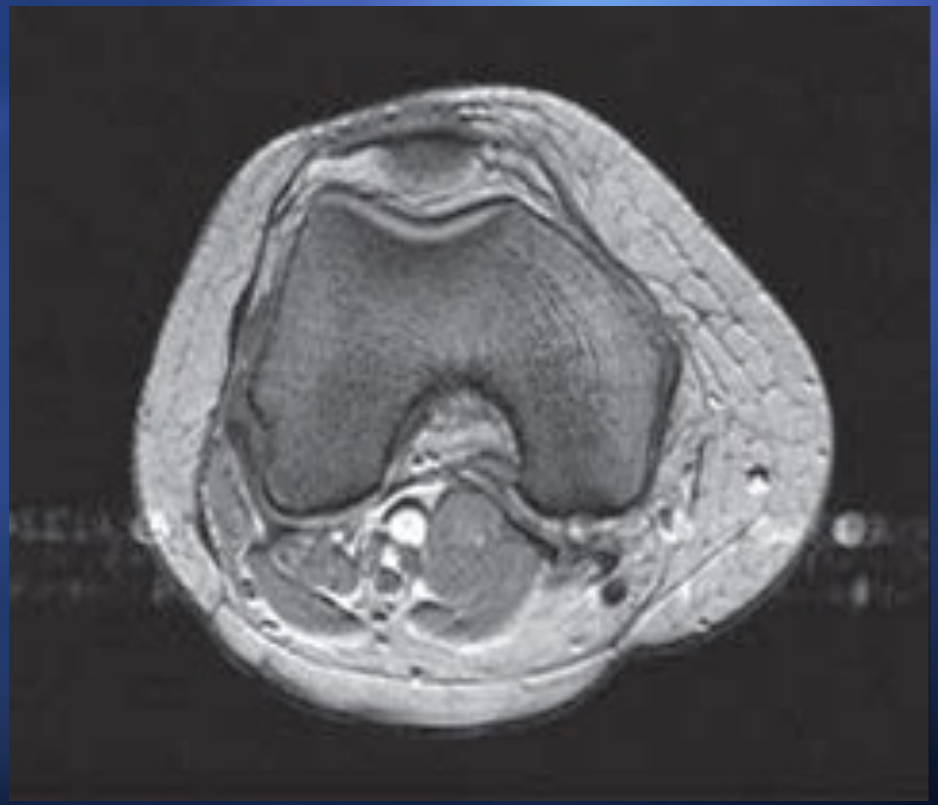
- ✓ The bolus of blood within the imaging slice is replaced by a second bolus of fresh unsaturated blood during the gap between the 2 pulses
  - The first bolus receives a 90° pulse but not the 180°
  - The second receives only the 180° pulse
  - No bolus produces an echo



Motion Artefacts from Flowing Blood

GE sequence

- ✓ on GE images blood vessels have high intensity
- ✓ easily produce ghost images in the phase encode (PE) direction

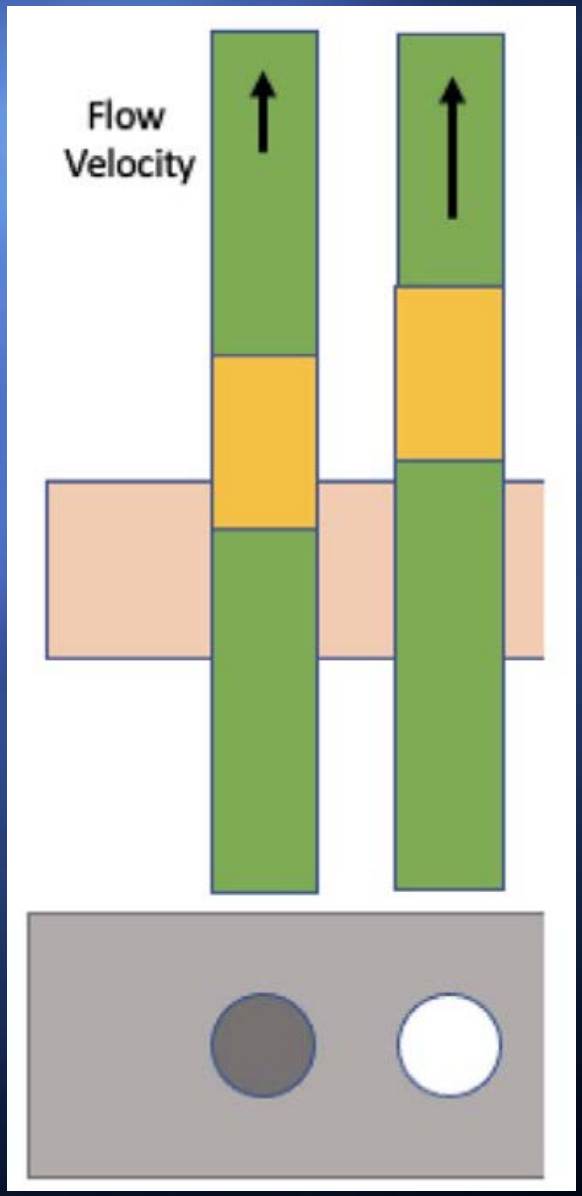


https://www.imaios.com/en/e-Courses/e-MRI/MR-Angiography-Flow-imaging/time-of-flight-mra

Motion Artefacts from Flowing Blood

GE sequence

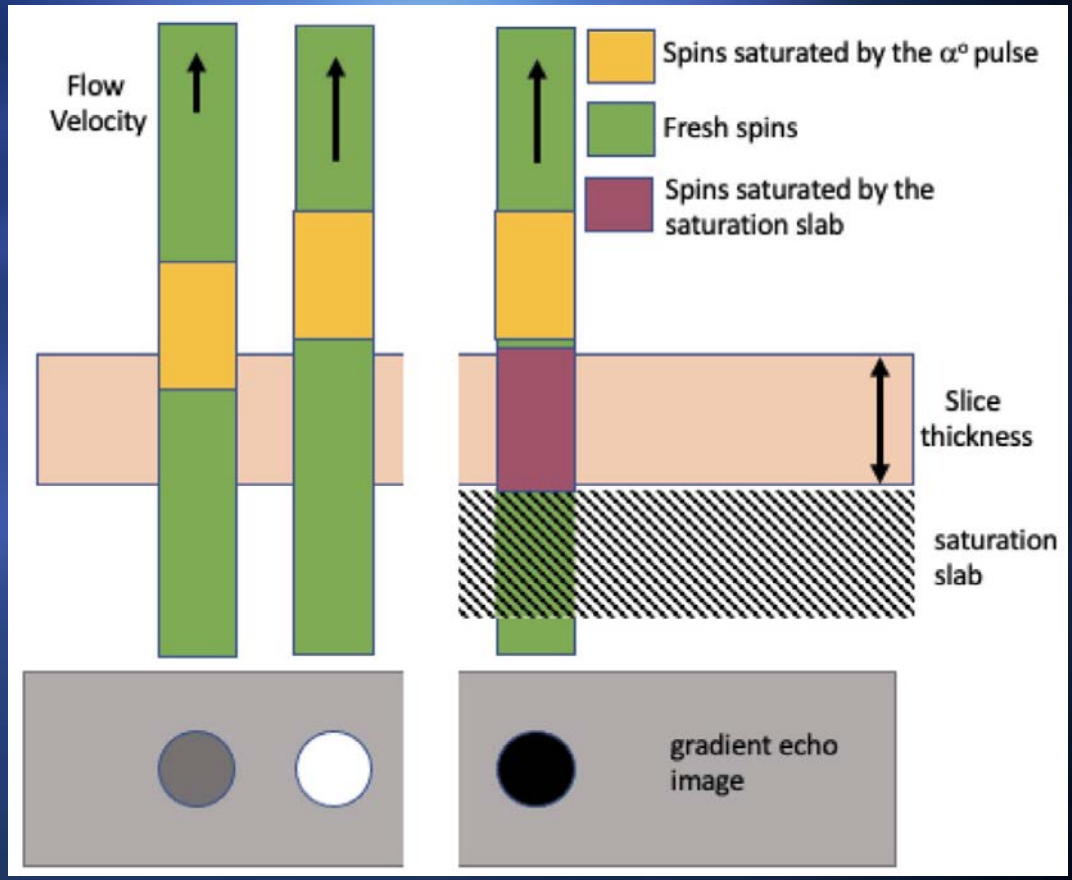
- ✓ an excitation pulse and the echo is formed using the gradients
- ✓ Excited bolus of blood always contributes a signal, provided it is still within the gradient volume
- ✓ For every subsequent slice there is a fresh bolus of blood within the slice
  - fully relaxed magnetization



REgional Saturation Technique REST

To avoid flow or movement artefacts

- ✓ spatial saturation slabs just outside the field of view or in the slice direction



REgional Saturation Technique REST

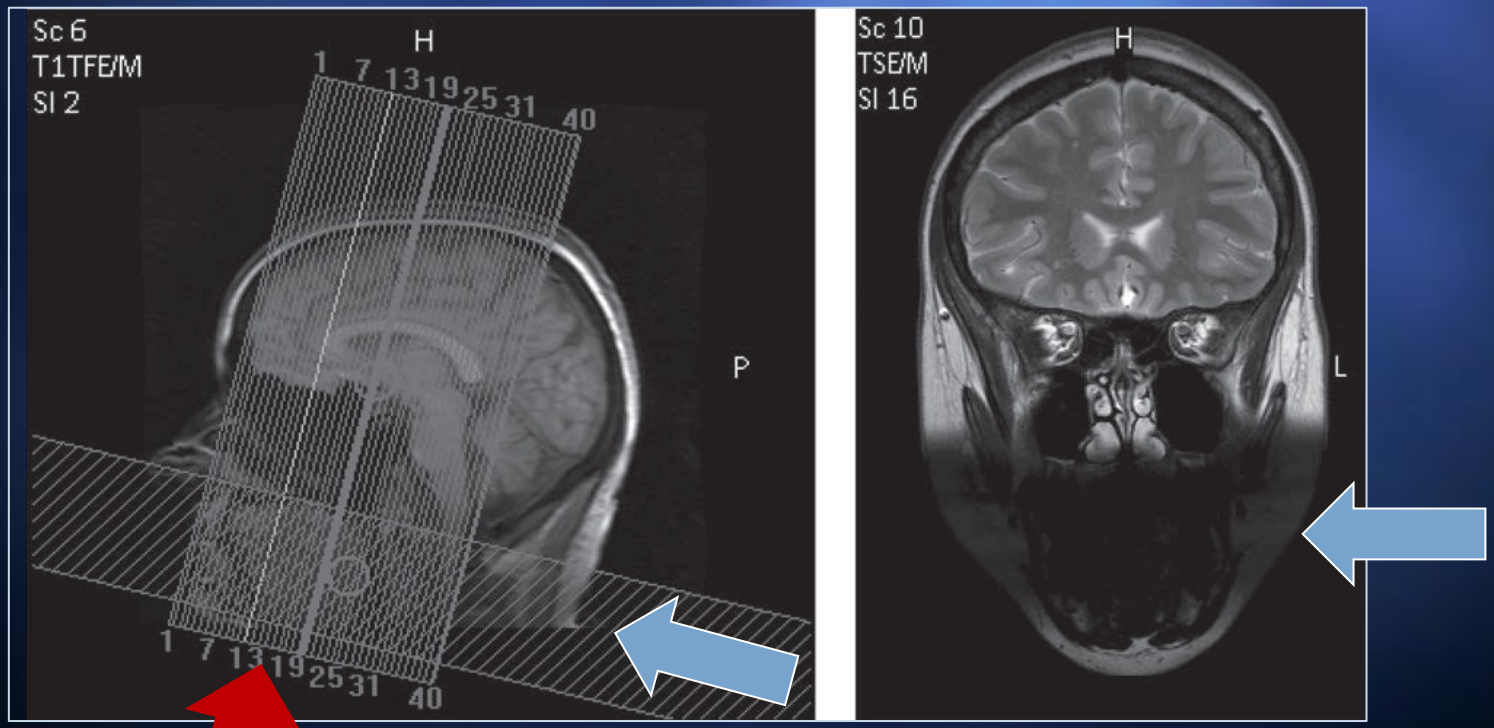
To avoid flow or movement artefacts

- ✓ **spatial saturation slabs just outside the field of view or in the slice direction**
  - **A 90° pulse to all the tissues within the slab immediately before the RF excitation pulse for the imaging sequence**
  - **After the saturation pulse a large gradient pulse is applied to diphase the protons**
    - ❖ **leaving no signals from the tissues in the sat band**
  - **https://www.imaios.com/en/e-Courses/e-MRI/Image-quality-and-artifacts/motion-artifact-remedies**

REgional Saturation Technique REST

To avoid flow or movement artefacts

- ✓ **spatial saturation slabs just outside the field of view or in the slice direction**



REgional Saturation Technique REST

To avoid flow artifacts

- ✓spatial saturation slabs in the slice direction
  - Placed above and/or below the image FOV
- ✓sat bands remove arterial and/or venous blood flow

Pay attention to the flow direction to make sure you put the sat band in the right place!

- ✓REST is used if a moving organ in the FOV prevents correct visualisation of the region of diagnostic interest

Water and Fat Frequency Shift

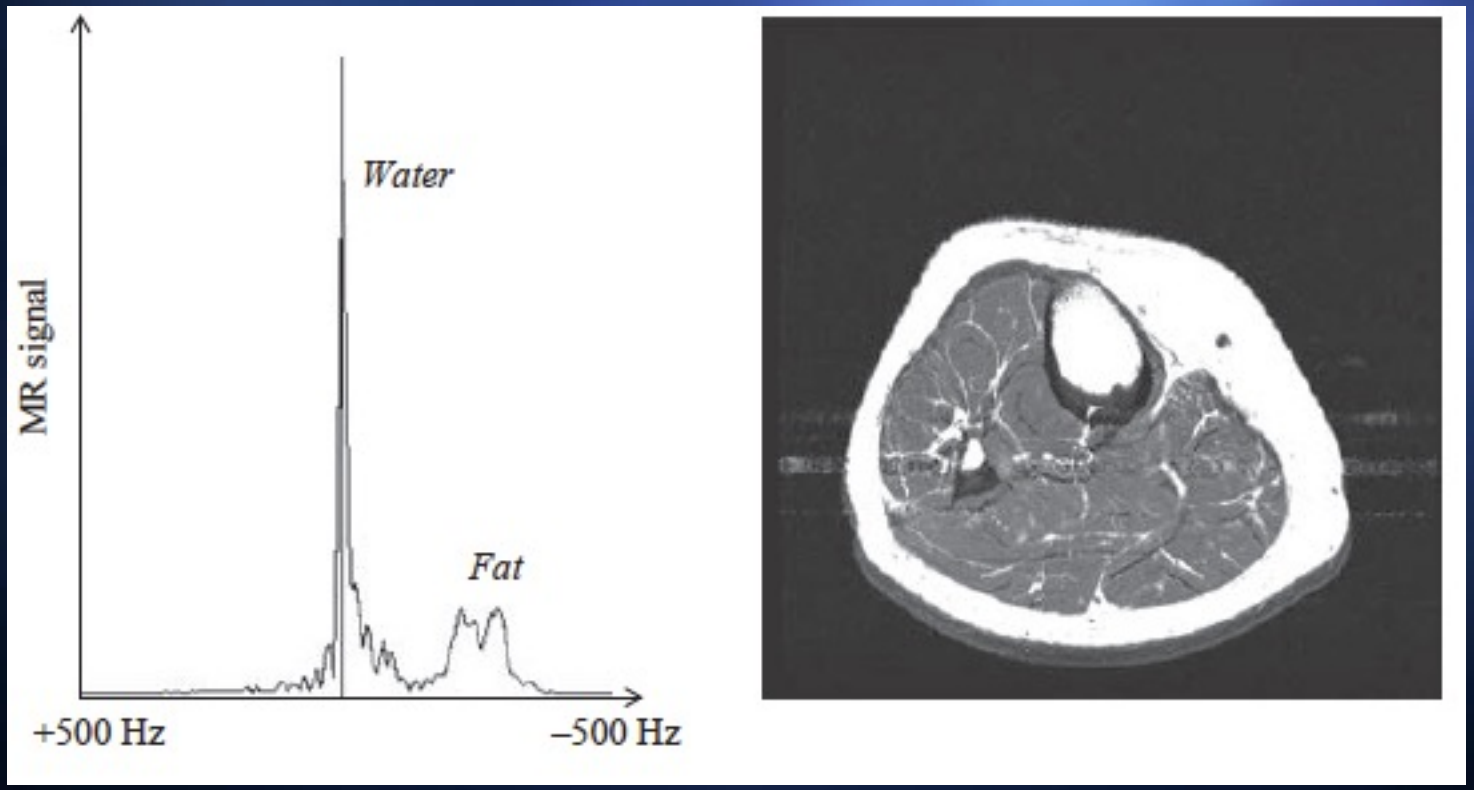
- ✓The resonance frequencies of water and fat protons are slightly different
  - chemical shift

$$\omega_0 = \gamma B_0$$

- ✓The cloud of moving electrons surrounding each molecule creates a magnetic field of its own
  - Depending on the structure of the molecule
- ✓as a result the local magnetic field experienced by the H nucleus differs from B_0
- ✓The frequency shift between different molecules is proportional to magnetic field strength
  - at 1.5 T the water–fat shift is about 220 Hz

Water and Fat Frequency Shift

- https://www.imaios.com/en/e-Courses/e-MRI/Image-quality-and-artifacts/chemical-shift



water–fat shift and fat suppression

Chemical Shift Selective Saturation (CHESS)

- an alternative to STIR for fat suppression

✓ immediately before the imaging pulse sequence a selective 90° pulse is applied at the fat proton frequency only

✓ the resulting transverse magnetisation is completely dephased using a spoiler gradient

✓ Therefore there is no fat magnetisation for the subsequent excitation pulse to nutate

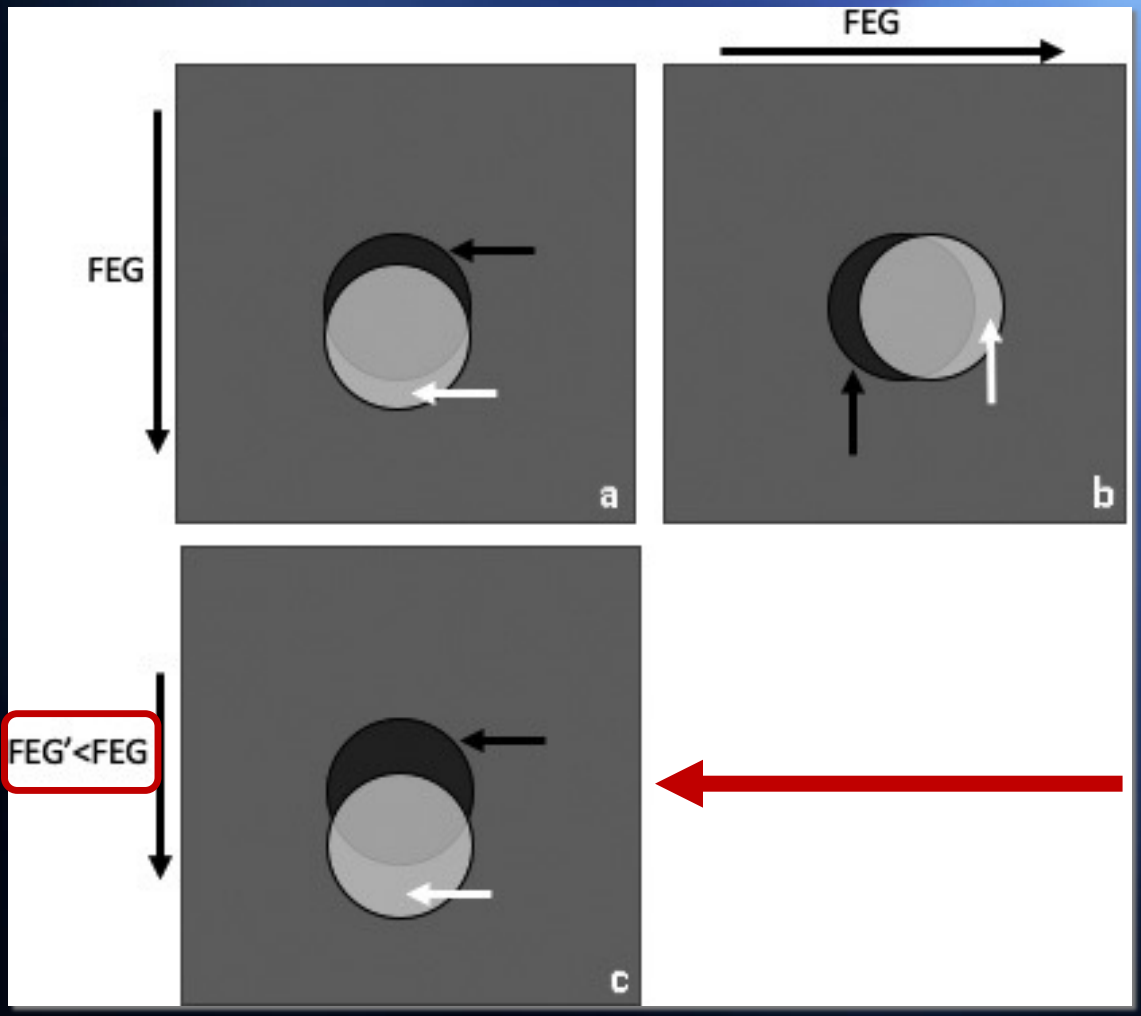
- hence no fat signal

Water and Fat Frequency Shift artefacts

- ✓ The water–fat shift is a source of an artefact in the frequency encoding direction at the interface between water and fat
  - e.g. kidney and surrounding adipose tissue
- ✓ Fat and water signals are displaced from each other along the frequency encoding direction
- ✓ Resulting in a hyperintense edge where the signals from water and fat overlap and a dark edge on the opposite side of the organ
  - Due to a signal void

Water and Fat Frequency Shift

This artefact is known as the chemical shift artefact of the first kind



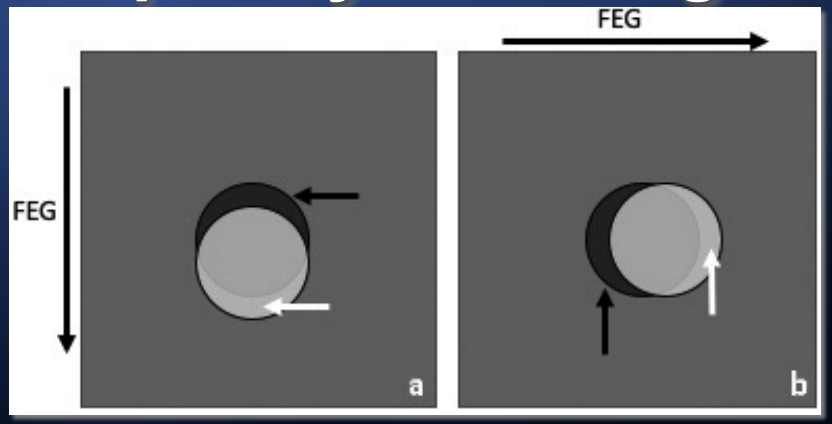
larger displacement with a weaker gradient and hence smaller pixel bandwidth

Water and Fat Frequency Shift

- ✓ The displacement may be expressed in pixels
- ✓ It is calculated as the ratio between the water–fat shift and the pixel bandwidth
  - the range of frequencies contained in each pixel
    - ❖ which depends on the gradient strength used
- ✓ The pixel bandwidth influences the signal to noise ratio (SNR) of the image
- ✓ Using a smaller bandwidth improves the SNR, but also results in a larger water–fat shift artefact

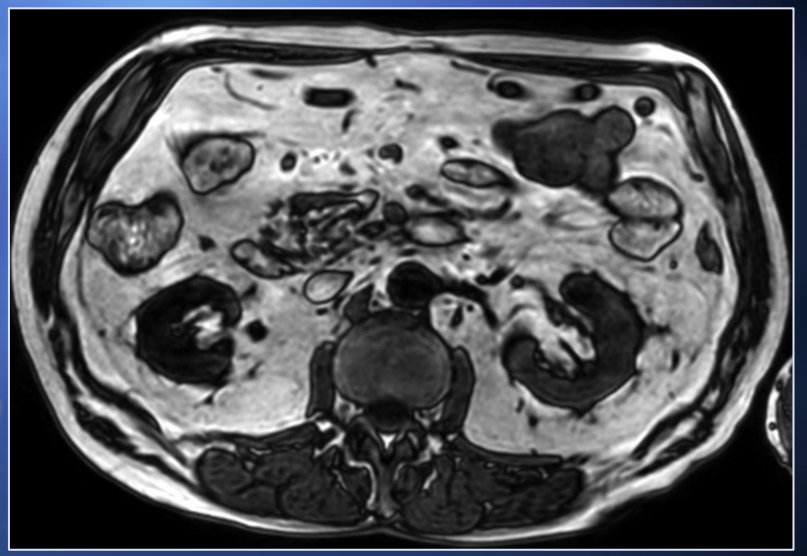
Water and Fat Frequency Shift

- ✓The balance between these effects must be optimised by the user taking into account the anatomical region
  - for example, water–fat shift is crucial in abdominal imaging but negligible in brain studies
- ✓If there is doubt as to whether a feature is a water–fat shift artefact, the simple way to solve the impasse is to re-acquire the image switching phase and frequency encoding directions



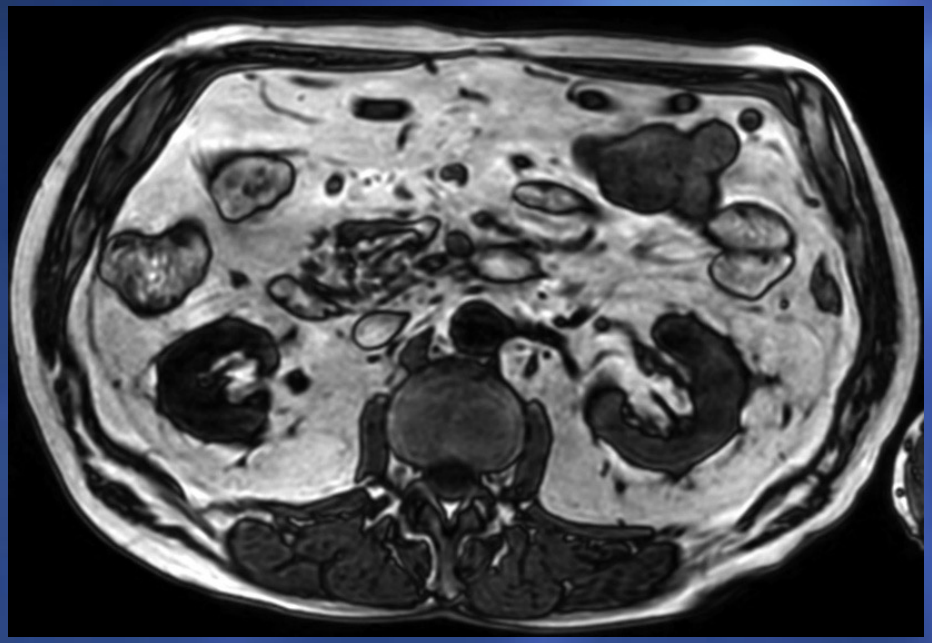
Chemical shift artefact of the second kind

When both water and fat are present in the same voxel, the signal acquired depends on the relative phase of water and fat signals at the echo time



- ✓ **if the relative phase is zero the signal is maximum**
- ✓ **if the relative phase is 180° the signal is the difference between water and fat signal intensities**

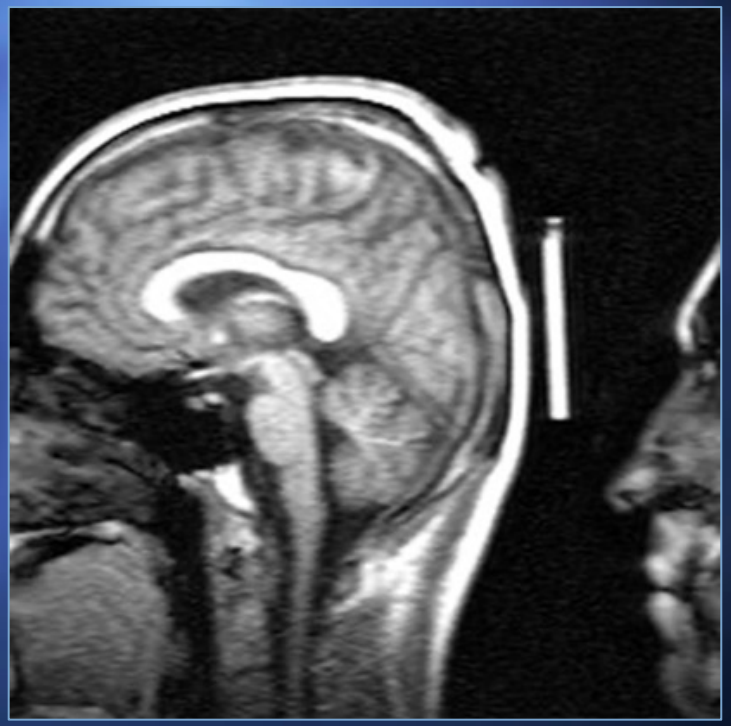
Quantification of fat content



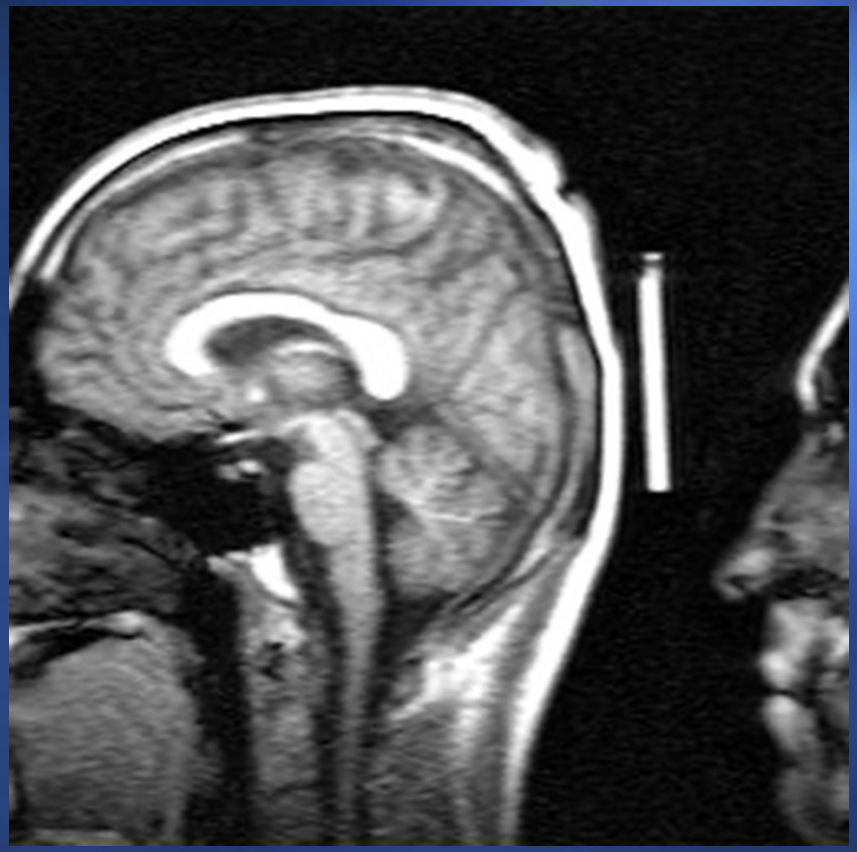
- ✓ **The echo time needed to obtain in-phase or opposed-phase signals depends on B_0**
  - **At 1.5 T, in phase signals occur at TE = 4.55n ms and opposed phase at TE = (2.3 + 4.55n) ms n is an integer**
- ✓ **Comparing in-phase and opposed-phase imaging allows quantification of the fat component in tissue**
  - **known as the Dixon method**

Wrap-Around Artefacts

- ✓The spatial encoding process in MRI is known as frequency and phase encoding
- ✓Phase is a periodic variable between 0° and 360°
- ✓When the phase value reaches 360° it starts again from 0°, and in general phase $\phi > 360°$ maps to a value $\phi - 360°$



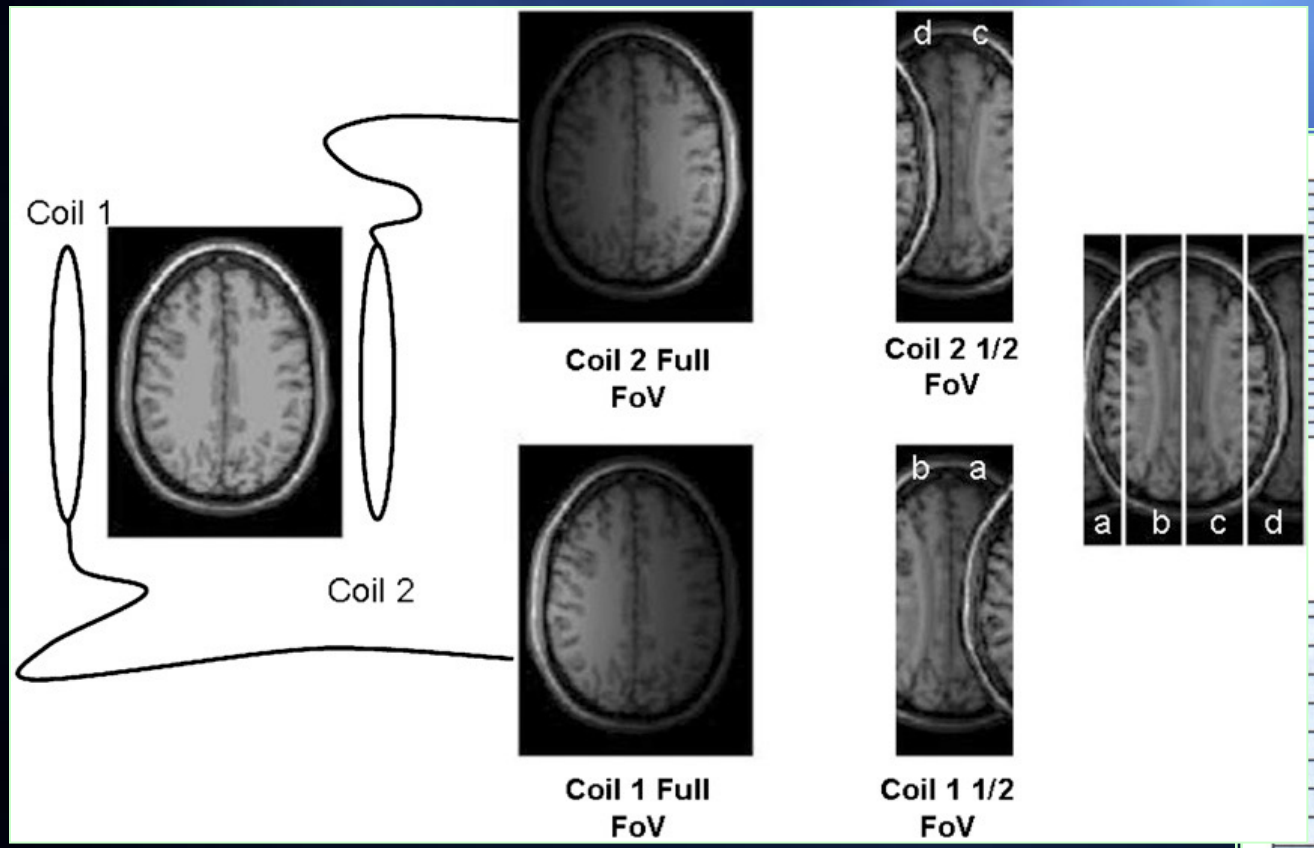
Wrap-Around Artefacts

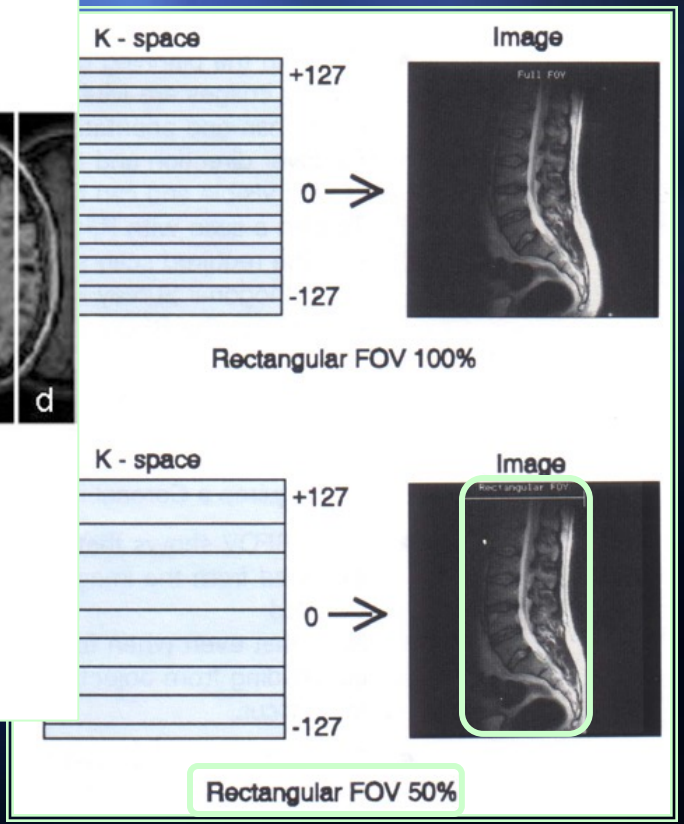


- ✓ **in parallel imaging the acquisition of ‘folded’ images using a reduced FOV is done intentionally to reduce acquisition time**
  - **fewer k-space lines**

Parallel imaging

- ✓In this example two local receiver coils are used for spatial discrimination
- ✓But images are acquired using ½ FOV

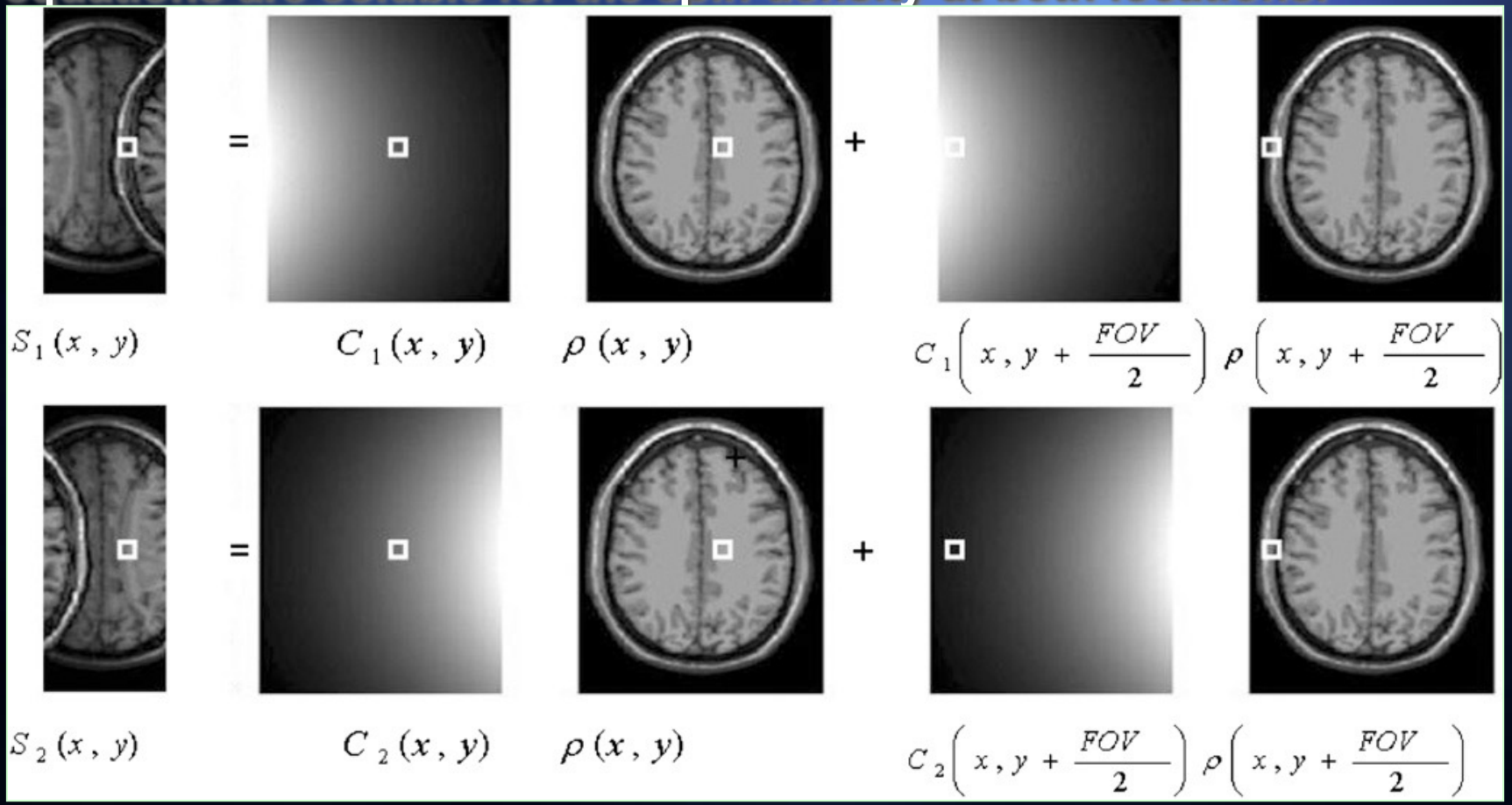




Parallel imaging (image domain)

The aliased pixel in the image from coil 1, marked by a white square, S1 contains the sum of the spin density at location 1 multiplied by the coil sensitivity at location 1 and the spin density at location 2 multiplied by the coil sensitivity at location 2, likewise for coil 2.

If the coil sensitivities are known (the maps shown) then these equations are soluble for the spin density at both locations.

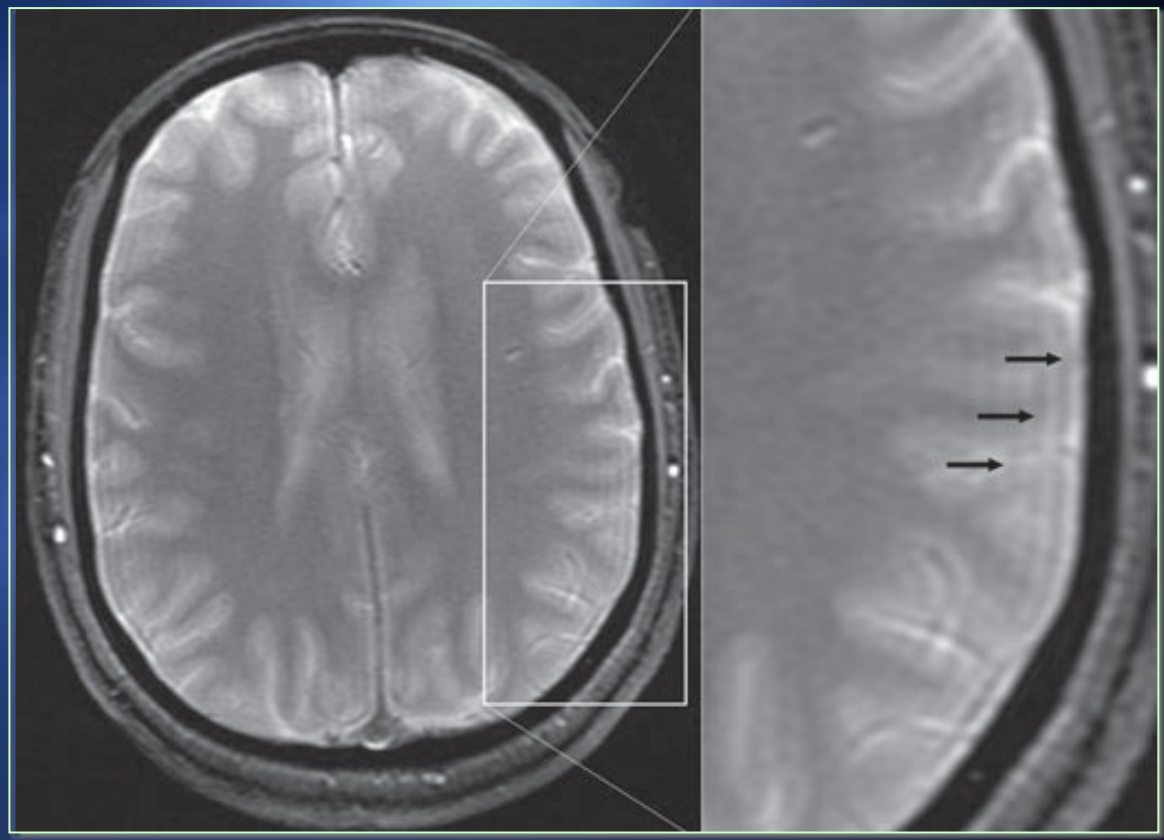


http://www.imaios.com/en/e-Courses/e-MRI/Parallel-imaging/sense

Truncation Artefacts

Truncation or Gibbs artifacts:

- ✓ **appear as parallel lines adjacent to high-contrast interfaces**
- ✓ **due to the Fourier transform from a finite sampled signal**



Gallager et al AJR 2008; 190:1396–1405

http://www.imaios.com/en/e-Courses/e-MRI/Image-quality-and-artifacts/truncation

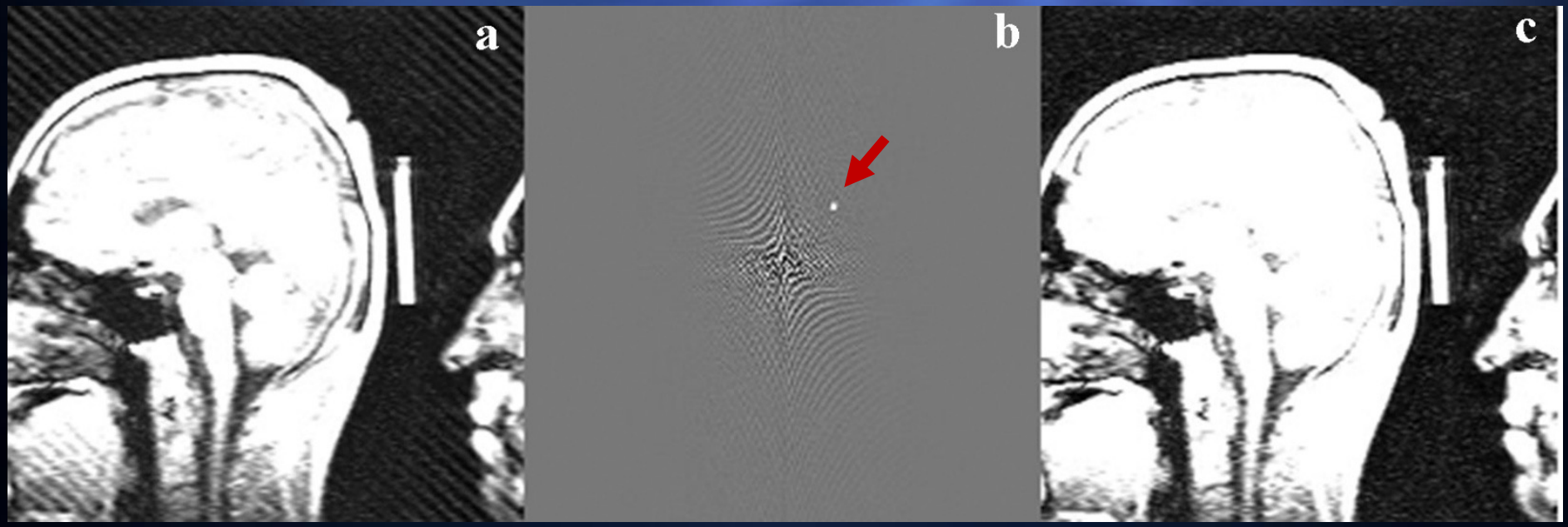
Zipper and 'Corduroy' Artefacts

- ✓ Data errors in k-space, or detection of unwanted RF signals due to external interference, result in characteristic artefacts related to the Fourier transform
- ✓ A single abnormal bright pixel in k-space is transformed into sinusoidal noise in image space: this is the source of the corduroy (or herring-bone) artefact, often caused by static electrical discharge
  - One possible cause the humidity in the scanner room being too low

Zipper and ‘Corduroy’ Artefacts

a zipper artefact due to an abnormal bright pixel in k-space visible in (b)

(c) is the image reconstructed with this bright pixel removed



Equipment-Related Artefacts

- ✓There is another family of artefacts that arise when some component of the scanner is not working optimally
- ✓If these artefacts are very evident, clinical use of the scanner may have to be stopped until it is repaired
- ✓A good programme of quality assurance (QA) may prevent this through early detection of small deterioration in image quality which can be addressed without interruption of clinical activity