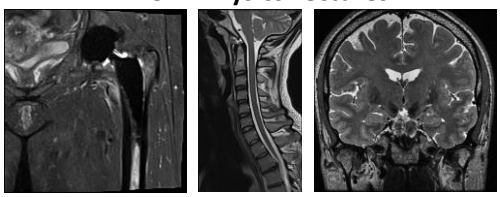
Magnetic Resonance Imaging

F.R.C.R. Physics Lectures



Lawrence Kenning PhD

FRCR MRI Syllabus

Magnetic Resonance Imaging (MRI)

- Spatial Misregistration
- Chemical Shift
- Susceptibility
- Motion
- Flow
- Other Artefacts

MRI Artefacts

- Image artefact is MRI is any unwanted image feature that does not represent the true anatomical structure or physiological information on the subject/object being scanned
- May degrade image or be more subtle
- Often can be related to a particular encoding direction

MRI Artefacts

- Causes of artefacts broadly divided into three groups:
  - **Patient-related artefacts** tend to appear as ghosts along the phase-encoding direction. May be produced by physiological motion or involuntary movement by the patient.
  - **Physics and Hardware artefacts** usually cause signal intensity changes and image distortions, and are due to hardware imperfections and to the susceptibility effects within the human body; for example, air in the sinuses or blood breakdown products.
  - **Image reconstruction artefacts** have a variety of appearances, and include phase wrap-around artefacts and problems arising from the Fourier transform

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Motion

- Most common artefact in MRI is patient motion
- Causes a range of ghosting artefacts depending on the severity of the motion
- Continuous movement during the scan causes a generalized blurring, often making the scan useless
- A few twitches or only small movements cause a few subtle ghosts which may leave an acceptable image
- In some cases, it is necessary to sedate or anesthetise the patient order to produce a diagnostic quality study

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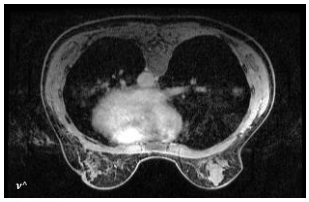
Motion

- Part of anatomy changes its location relative to encoding resulting in spatial blurring
- Ghosts can be discrete (periodic motion: cardiac beats, arterial pulsations, respiration) or diffuse (non-periodic), e.g. bowel peristalsis
- Principally occurs in **phase encoding** direction due to disparity in sampling times for frequency (msec) and phase (sec) encoding times
  - Also, motion along any magnetic field gradient results in abnormal phase accumulation, which mismaps the signal along the phase encoding gradient.

Motion

- To minimise the number of phase encoding steps (scan time), it is often desirable to orientate the phase-encoding direction to the shortest dimension of the patients anatomy
- However, consideration should always be given to potential sources of motion.



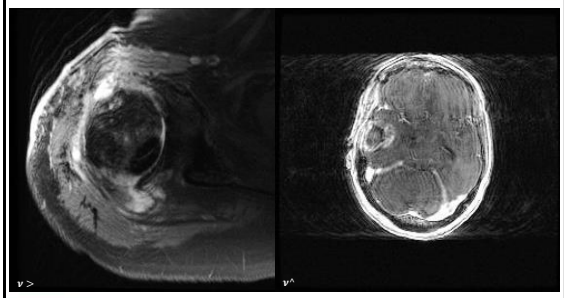
nu (ν) denotes the frequency encoding direction

^ or >

Remarkable people. Extraordinary place.

Motion

Motion/Ghosting Examples



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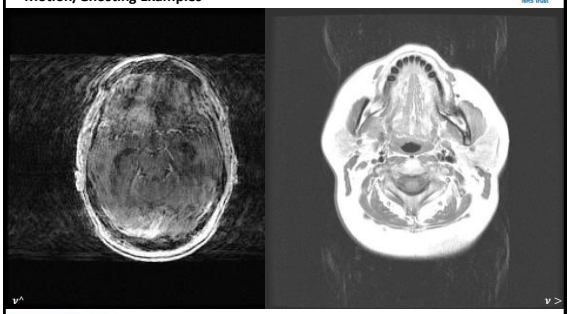
Motion

Motion/Ghosting Examples



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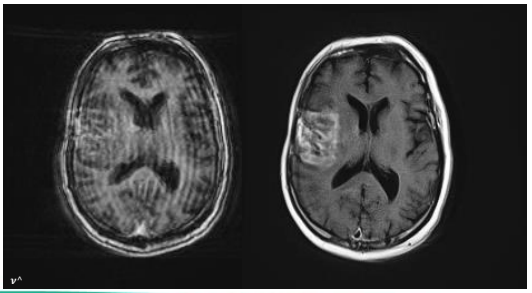
Motion

PROPELLER/BLADE



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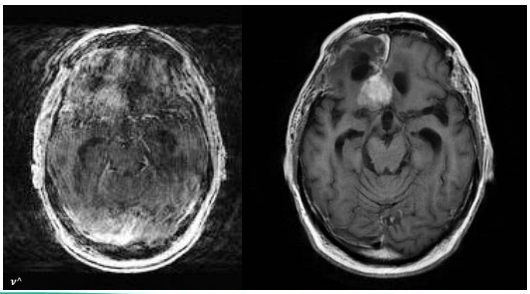
Motion

PROPELLER/BLADE



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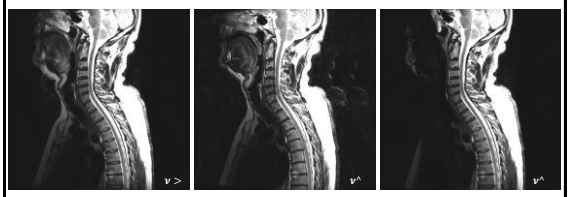
Motion

Phase/Frequency Direction



No anterior saturation band

anterior saturation band

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Motion

Motion/Ghosting: Elimination

- Restrict patient motion (pads / sedation)
- Periodic motion can be 'gated'
  - Cardiac/respiratory triggered scanning / Longer scan times
- Alternatively use 'breath hold' or 'single shot' techniques
  - Modern scanners have very fast acquisition times
- Non-periodic motion more difficult
  - Anti-peristalsis drugs (buscopan)
- Optimise PE & FE direction
- Saturation bands
  - Suppress the signal from moving tissues with signal suppression techniques

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Flow

Flow artefacts

- Constitute a particular subset of physiological motion artefacts.
- The pulsatile motion of blood within the vascular system can produce ghosting in the image.
- Occur in the phase encoding direction
  - Separation of the ghosts detected by the frequency of the pulsating blood
- Same principle at motion/ghosting artefacts

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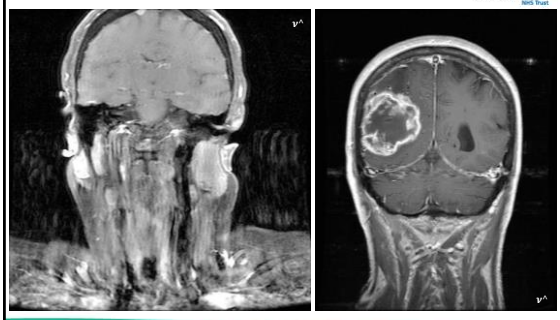
Flow



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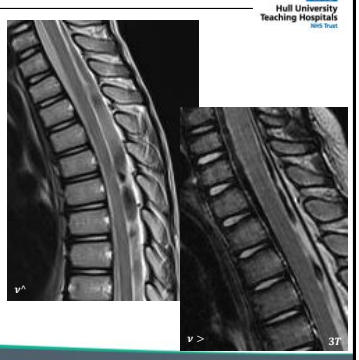
Flow

CSF flow related dephasing

- Flow-related dephasing is greater in sequences with longer TEs
  - exaggerates the dephasing, as there is a longer delay before the echo is measured
- Turbulent flow is too unpredictable to compensate even with flow compensation



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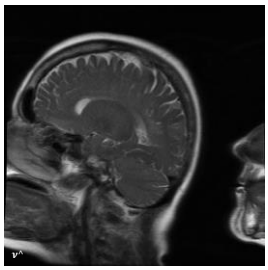
Spatial Misregistration

Phase Wrap

- Also know as: wrapping / aliasing / 'foldover' / 'wrap around'
- Occurs when signal is detected from outside of the FOV in the **phase encoding direction**
- Regions outside FOV excited with RF are indistinguishable from those inside FOV
- These regions manifest within the image on the opposite side – "wrapping around"



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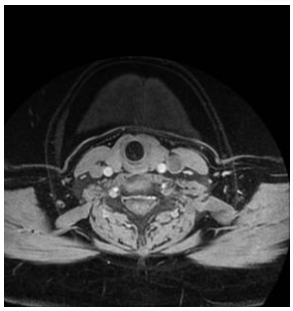
Spatial Misregistration

Phase Wrap

- For 3D sequences, phase wrap can occur in 2 directions
- In-plane and through-plane



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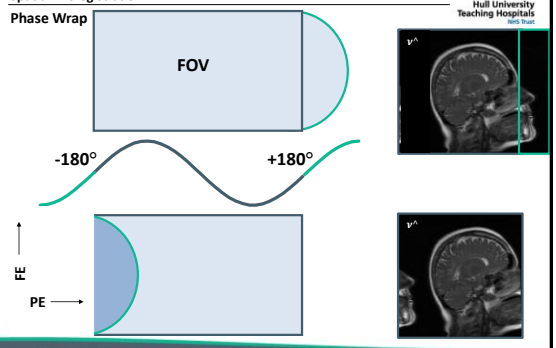
Spatial Misregistration

Phase Wrap



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Spatial Misregistration

Phase-wrap: Elimination

- Increase the size of the FOV
  - Reduces spatial resolution (unless matrix is adjusted)
- Saturation of pulses from outside the FOV (not 100% effective)
- Selective excitation (3D)
- Use of 'No Phase-Wrap' (NPW) / Phase Oversampling
  - Doubles FOV in PE direction
  - Doubles no. of PE steps (to maintain spatial resolution, doubles scan time)
  - Halving no. of averages (same scan time, but lower SNR)

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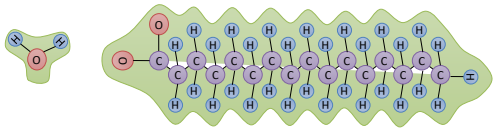
Tissue Suppression Methods

Water and Fat

Water molecule H_2O Fat molecule $–CH_2–$



- Fat has a shorter T_1 relaxation rate than water
- The two dominate fat peaks (1.3ppm and 0.9ppm) experience a lower local magnetic field (B_0) due to the electron shielding compared to water (4.7ppm)
- Fat precesses at a lower frequency than water

Tissue	T_1 1.5T (ms)
Fat	260
Liver	500
Grey Matter	900
CSF	2400

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Chemical Shift

Water and Fat Molecules – Chemical Shift Effect

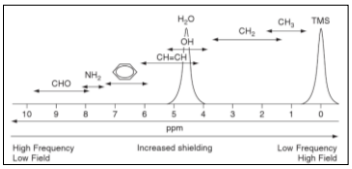
- electron cloud around an atom shields the nucleus from the magnetic field (σ):
- different resonant frequencies for different molecules

$$\omega_0 = \gamma(1-\sigma)B_0$$

γ = gyromagnetic ratio

B_0 = magnetic field strength,

ω_0 = resonant frequency



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Chemical Shift

Water and Fat Molecules

$$\omega = \gamma.\beta$$

- Not all protons experience the same magnetic field and therefore precessional frequency
- Electron shielding either adds or subtracts from the main magnetic field for protons within molecules

$$\omega_{lower} = \gamma.\beta_{lower}$$

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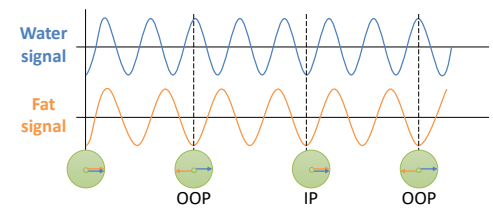
Chemical Shift

Phase Cycling

- Differences in precessional frequencies of water and fat cause signals to move in phase (IP) and out of phase (OOP) with one another.



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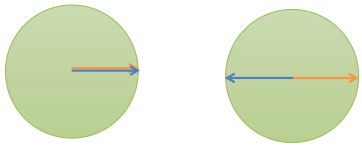
Chemical Shift

Phase Cancellation

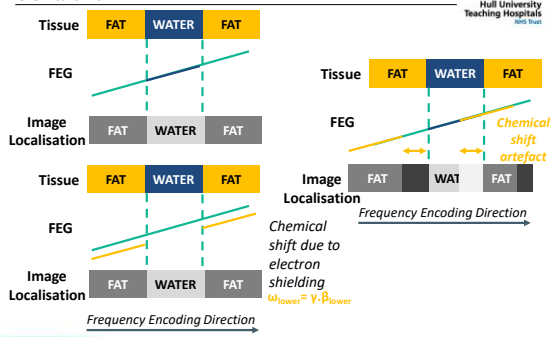
- Due to different precessional frequencies water and fat become IN and OUT of phase over time



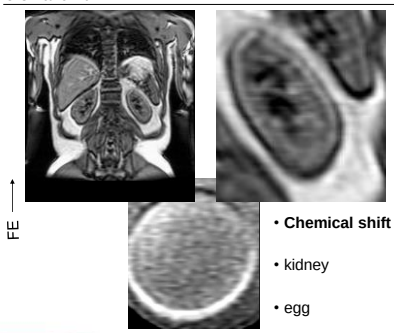
In Phase = Water + Fat

Out of Phase = Water – Fat

Chemical Shift



Chemical Shift



- **Chemical shift effect:**
- kidney
- egg

Chemical Shift

Chemical Shift (1st kind)

- Difference in resonant frequency of water and fat (chemical-shift)
- @ 1.5 T the difference = 220Hz, @ 3T = 440Hz
- Spatial location in frequency encoding direction assumed to be consequence of FE gradient
- Due to chemical shift, voxels containing fat will not have the expected frequency and will be spatially misregistered.
- Results in signal void and build-up on opposite sides of the anatomy
- Chemical shift is increased by Higher B_0 and deceased bandwidth (BW)
- If we decrease BW→ lower BW / pixel and thus fewer frequencies / pixel
- Example: BW ↓ from 32 to 16 kHz.
  - BW/ pixel = 16000/256= 62.5 Hz per pixel
  - 220 Hz/ 62.5 Hz/ pixel ~ 4 pixels misregistration, as opposed to ~ 2pixels at 32kHz BW

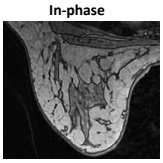
Chemical Shift

Chemical Shift (2nd kind)

- Occurs in gradient echo sequences
- The absence of 180° refocusing pulse causes phase shift between fat and water when echo is formed.
- Difference in resonant frequency of water and fat leads to phase differences when echo is formed.
- At 1.5T - every 4.4ms fat/water will be in-phase
- At 2.2 ms fat/water are exactly out of phase
- For OOP TE's → out of phase voxels containing similar amounts of fat & water will cancel and produce a black line at tissue/fat borders



In-phase



Out-of-phase

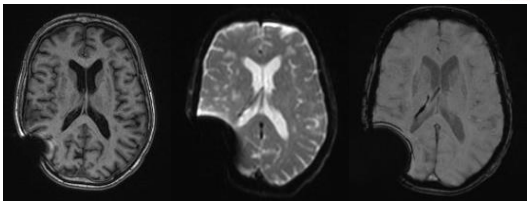
Susceptibility

Magnetic Susceptibility Artefact

- Although the magnetic susceptibility of tissues is small, the differences between the tissues & air are large enough generate local magnetic field gradients.
  - Hydrogen atoms on either side of the boundary will be in different magnetic fields & will relax more quickly as they interact with each other
- Artefacts occur at interfaces between materials of very different susceptibilities as local distortions are caused in the magnetic field.
  - Natural boundaries e.g. air / tissue or tissue/bone
  - Also any metal (not just ferromagnetic)
- Results in local distortions
  - Local field distortion can lead to precessional frequency shift → when G_{ss} is performed there is an absence of spin excitation and absence of signal
  - When signal is acquired → shift of spatial localisation which causes signal loss and/or image distortion.

Susceptibility

Susceptibility Examples



- Shunt producing a large susceptibility artefact
  - Signal void
  - distortion of anatomy
- Artefact worse at long TE (short TE allows less time for signal loss)

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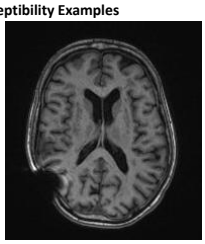
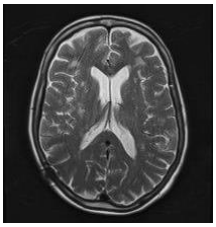
Susceptibility

Susceptibility Examples





- Can be reduced by using SE (not GRE) or high bandwidths
- Special metal artefact reduction sequences (MARS) e.g. MAVRIC SL / SEMAC

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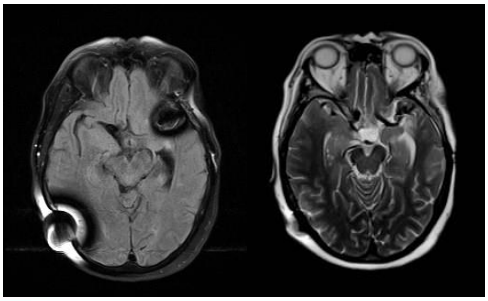
Susceptibility

Susceptibility Examples



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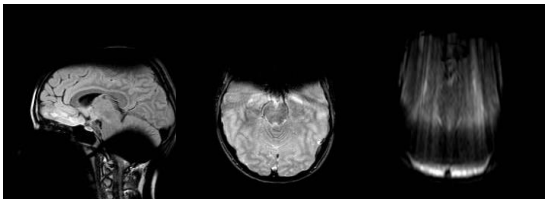
Susceptibility

Braces



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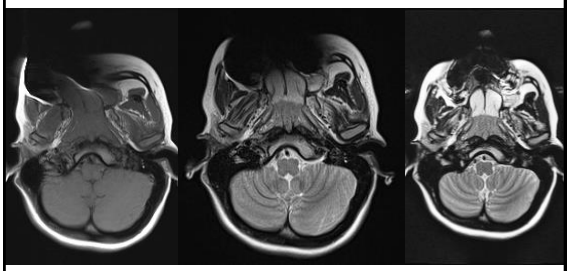
Susceptibility

Braces



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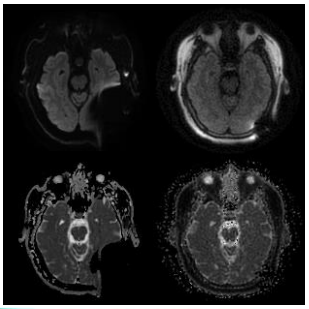
Susceptibility

Susceptibility Examples

EPI-DWI

FSE-DWI



EPI-DWI ADC

FSE-DWI ADC

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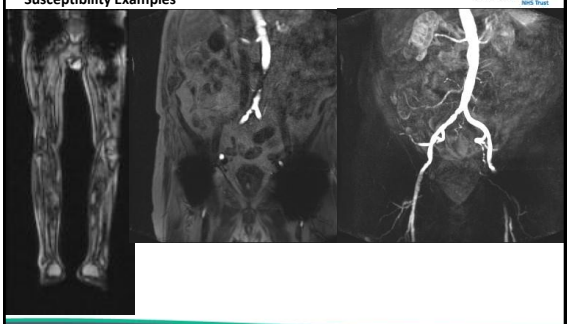
Susceptibility

Susceptibility Examples



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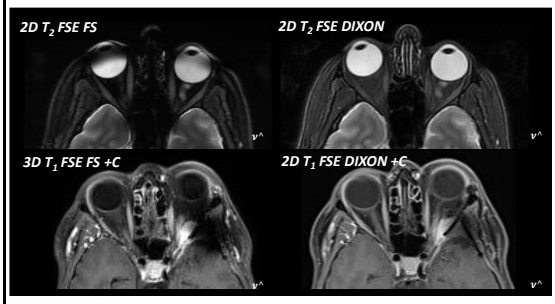
Susceptibility

DIXON



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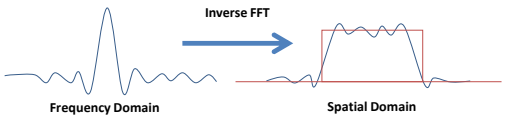
Other Artefacts

Gibbs Artefact (ringing or truncation artefact)

- Appears as parallel lines adjacent to high contrast interfaces (cord/CSF).
- Inability to approximate a step like change in signal intensity
- Consequence of using FT to reconstruct signals
  - Signal represented by infinite sum of sine waves (Fourier theory)
  - Series is truncated due to finite sampling
  - FT produced with ripples→ parallel bands



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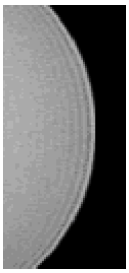
Other Artefacts

Gibbs Artefact

- Artefact appears at the edge of objects
- Reduced by
  - increasing the number of PE steps (256→ 320)
  - Increase sampling time
- Common in spine, where it can mimic appearance of syringomyelia



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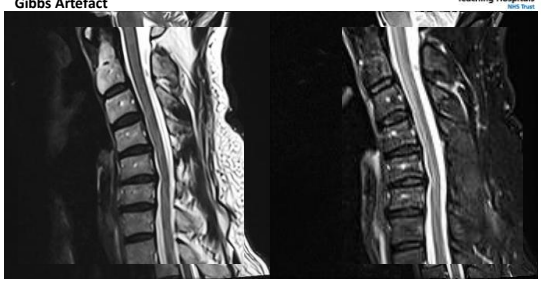
Other Artefacts

Gibbs Artefact



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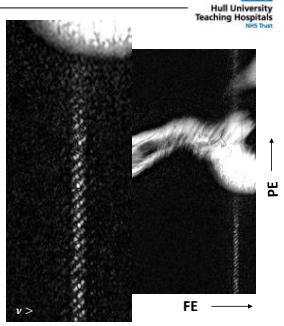
Other Artefacts

Radiofrequency/ 'Zipper' Artefact

- MR signal is very weak, thus RF receiver is very sensitive
- Causes a discrete zip-like line in PE direction
- Caused by <u>continuous</u> RF interference
- Usually a breakdown in RF integrity of system
  - Break in RF Cage
  - Faulty patient monitoring
- LED Lightbulbs can interfere with MRI
- Artefact reduced by changing centre frequency or reducing bandwidth



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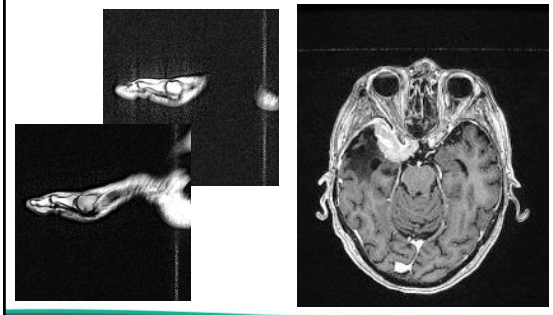
Other Artefacts

RF or 'Zipper' Artefact



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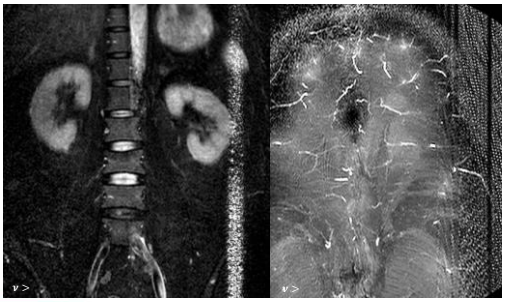
Other Artefacts

RF or 'Zipper' Artefact



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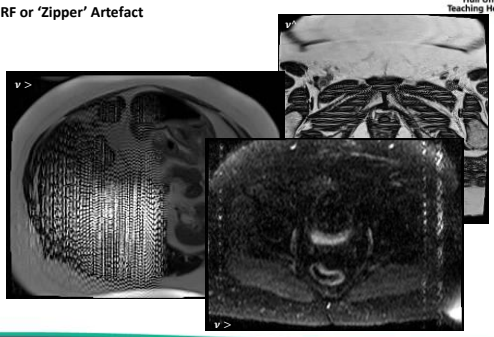
Other Artefacts

RF or 'Zipper' Artefact



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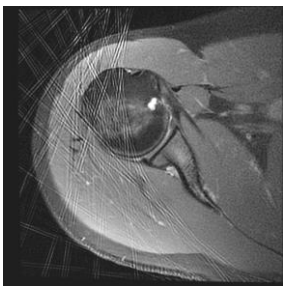
Other Artefacts

PROPELLER/BLADE – RF Interference



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Other Artefacts

Herringbone artefact (Instantaneous RF Interference)

- Also known as "corduroy" artefact
- Series of high and low intensity stripes across the image
- Often appears on just one or two images in a multi-slice dataset
- Caused by spike noise in the raw data, whose FFT is then convolved with all the image information (instantaneous RF interference)
- A single image with this artefact could be bad luck (static electricity discharge), but issues with several different scans is a symptom of breakdown of either the RF coils or the decoupling system

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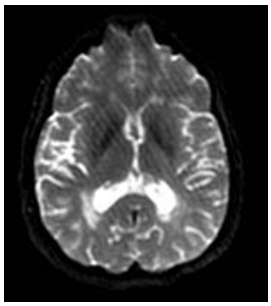
Other Artefacts

Herringbone artefact

- Due to short RF spike whilst filling k-space during read-out
- RF spikes lead to points in k-space having higher intensities than the centre of k-space
- The spatial frequency of the pattern depends on which points of k-space were affected



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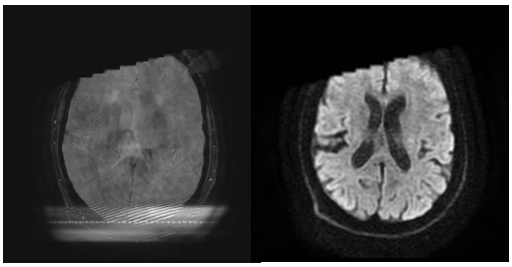
Other Artefacts

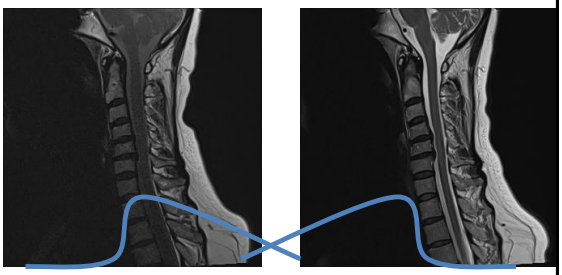
Calibration scan and RF artefacts



Remarkable people. Extraordinary place.

Other Artefacts

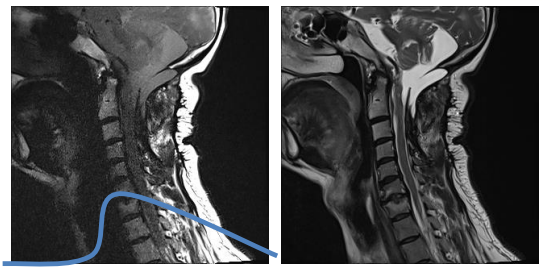
Asymmetric Saturation band



Remarkable people. Extraordinary place.

Other Artefacts

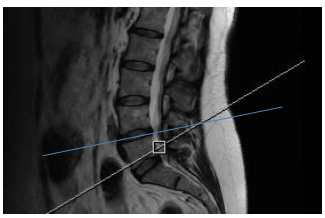
Asymmetric Saturation band



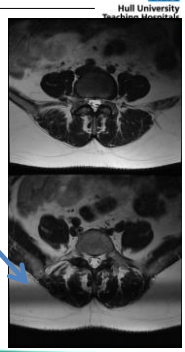
Remarkable people. Extraordinary place.

Other Artefacts

Cross-Talk



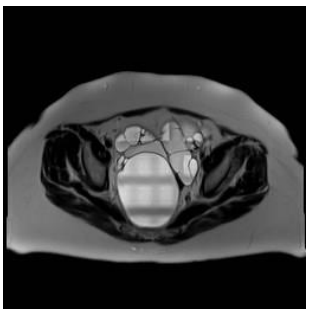
When multislice acquisitions overlap, the protons belonging to more than one slice become overly saturated.



Remarkable people. Extraordinary place.

Other Artefacts

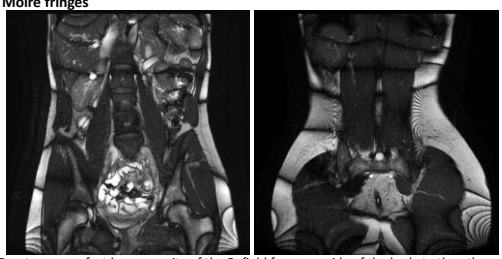
Cross-Talk



Remarkable people. Extraordinary place.

Other Artefacts

B_0 Field out of specification
Moiré fringes

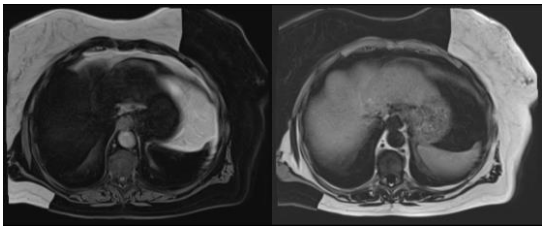


Due to non-perfect homogeneity of the B_0 field from one side of the body to the other, aliasing of one side of the body to the other results in superimposition of signals of different phases that alternatively add and cancel on gradient echo imaging.

Remarkable people. Extraordinary place.

Other Artefacts

DIXON swap artefact



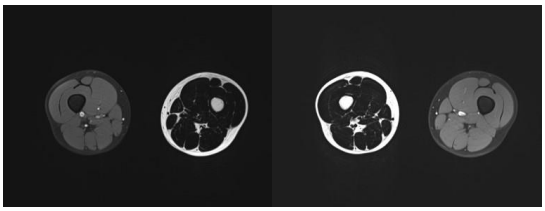
DIXON swap artefact

Local or global swap depending on vendor algorithm

Remarkable people. Extraordinary place.

Other Artefacts

DIXON swap artefact



WATER **FAT**

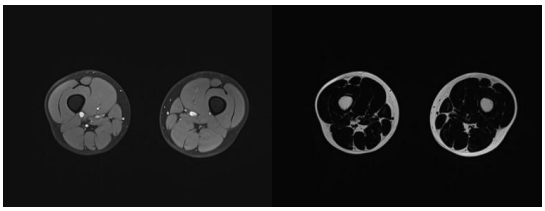
DIXON swap artefact

Local or global swap depending on vendor algorithm

Remarkable people. Extraordinary place.

Other Artefacts

Correct DIXON swap artefact



WATER **FAT**

DIXON swap artefact

Local or global swap depending on vendor algorithm

Remarkable people. Extraordinary place.

Other Artefacts

DIXON & B_0 Field out of specification

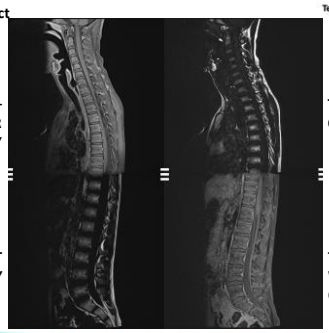


- Due to non-perfect homogeneity of the B_0 field

Remarkable people. Extraordinary place.

Other Artefacts

DIXON swap artefact



T1+C – WATER ONLY

T1+C – FAT ONLY

T1+C – FAT ONLY

T1+C – WATER ONLY

Remarkable people. Extraordinary place.

Other Artefacts

Coil Selection



Remarkable people. Extraordinary place.

Other Artefacts

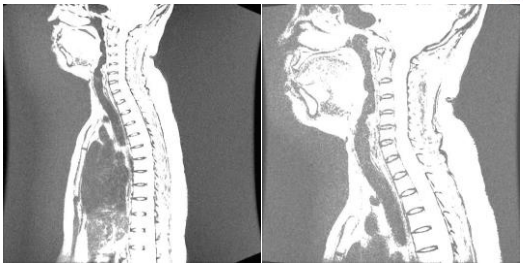
Gradient Field Nonlinearity

- Gradient coils produce linear magnetic field gradients over a limited distance
- Scanning with large FOVs may include regions of gradient nonlinearity
  - i.e. whole spine imaging
- Produces image distortions, compressing image information at the FOV edge
- Unlike geometric distortions arising from B_0 magnetic field inhomogeneities or susceptibility differences, gradient field nonlinearities are predictable
- Most vendors apply a correction (2D/3D) to the images to stretch out the pixels resulting in a curved edge to large FOV images

Remarkable people. Extraordinary place.

Other Artefacts

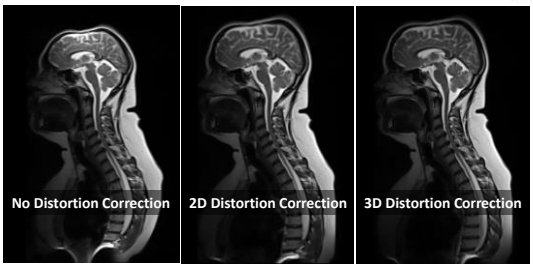
2D/3D Geometry Correction



Remarkable people. Extraordinary place.

Other Artefacts

2D/3D Geometry Correction – 45cm FOV



Remarkable people. Extraordinary place.

Questions

Question

Artefacts in MRI:

A. Chemical shift is displaced in the frequency encoding direction

B. Chemical shift is more apparent at lower static field strength

C. Ferrous metal implants cause streak artefact

D. Cardiac motion artefact can be reduced by triggering the pulse sequence with the electrocardiogram (ECG)

E. Aliasing occurs if the FOV is too large

Remarkable people. Extraordinary place.

Questions

Question

Artefacts in MRI:

A. Chemical shift artefacts are due to chemical differences and thermal movement in free fluid and oedema

B. Chemical shift artefacts are in the phase encoding direction

C. Aliasing may be apparent in the phase encoding direction, where part of the image is wrapped to the wrong side

D. Motion artefact occurs because the phase encoding steps are spread of time and therefore any movement causes a misregistration of position

E. Ferrous metallic objects can cause localised distortion and degradation of the image

Remarkable people. Extraordinary place.