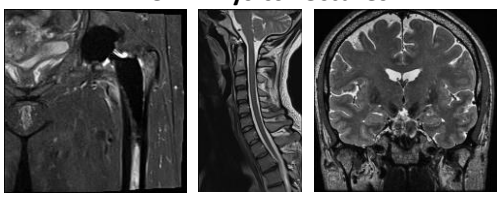
Magnetic Resonance Imaging

F.R.C.R. Physics Lectures

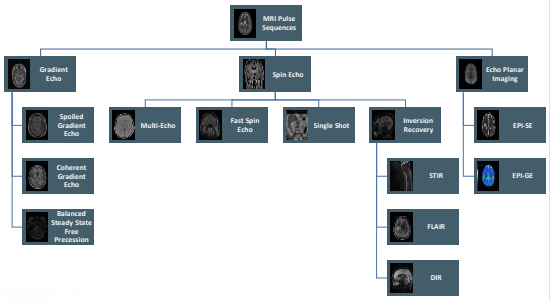


Lawrence Kenning PhD

Magnetic Resonance Imaging

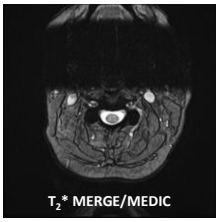
Magnetic Resonance Imaging (MRI) [2]

- Gradient Echo Sequences
- Susceptibility Weighted Imaging (SWI) [Extra]
- Magnetic Resonance Angiography



Gradient Echo Sequences

- GE sequences are generally:
  - Lower SNR
  - Faster
  - More susceptible to metallic artefacts
  - **Generally used to produce T_1 and T_2^* weightings**



T_2* MERGE/MEDIC

Multiple **E**cho **R**ecombined **G**radient **E**cho
Multi-**E**cho **D**ata **I**mage **C**ombination

Gradient Echo (GE) Pulse Sequences

T_2/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

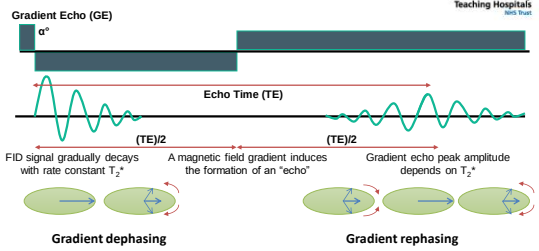
Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

- Gradient echo (GE/GRE) sequences utilise magnetic field gradients 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**

Remarkable people. Extraordinary place.

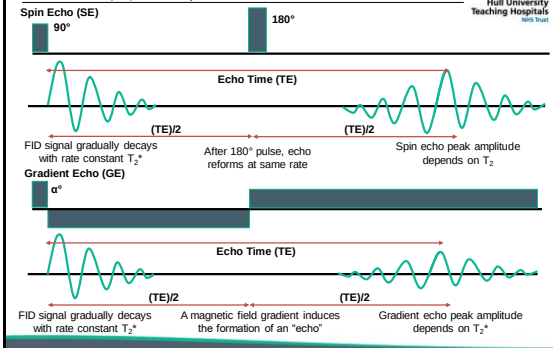
Gradient Echo (GE) Pulse Sequences



- 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

Remarkable people. Extraordinary place.

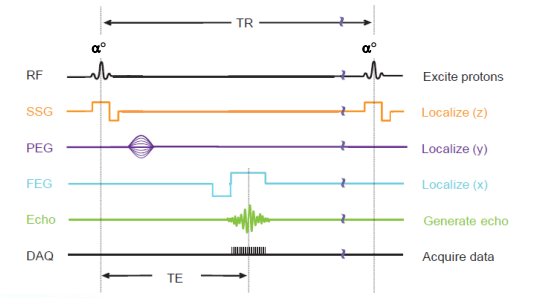
Gradient Echo (GE) Pulse Sequences



Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

Gradient Echo Sequence



Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

T_2/T_2^*

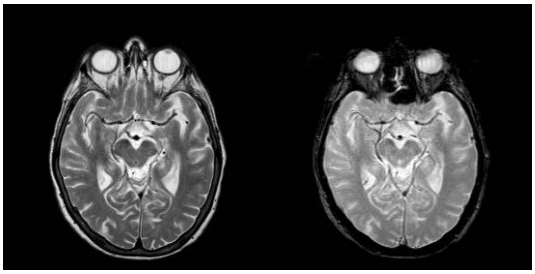
- In the absence of a 180° rephasing pulse, field inhomogeneities are maintained and images are T_2^* (not T_2) weighted
- GE sequences are thus more sensitive to magnetic susceptibility artefacts than spin echo sequences


Gradient Echo Localiser

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

T_2* Weighted Imaging

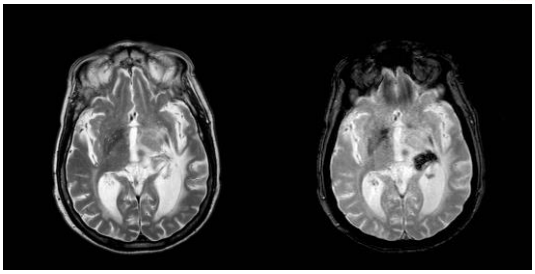


Spin Echo T_2 | Gradient Echo T_2*

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

T_2* Weighted Imaging



Spin Echo T_2 | Gradient Echo T_2*

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

Gradient Echo vs. Spin Echo

- Flip angle is usually less than 90˚
- Absence of a 180˚ rephasing pulse
- Lower flip angle decreases amount of magnetisation tipped to transverse plane
- Faster recovery of longitudinal magnetisation
- Shorter TR/TE decreases scan time
- GE particularly useful as a rapid imaging technique. i.e. breath-hold studies, dynamic contrast examinations and angiography
- Allows new tissue contrasts (T_2*)
- Magnetic field inhomogenieties maintained!

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

Gradient Echo Image Contrast

- Flip angle (α):
  - Small α → reduced T_1 weighting
  - Large α → increased T_1 weighting

  *** Small flip angles minimise T_1-weighting because the longitudinal magnetisation (M_z) of tissues are less well differentiated*

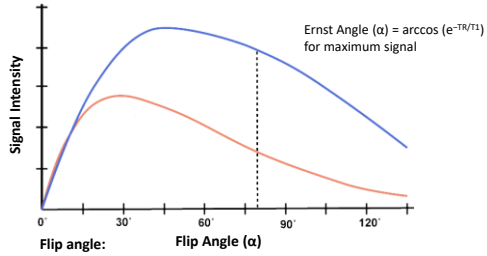
- TE:
  - Short TE → reduced T_2* weighting
  - Long TE → increased T_2* weighting.

- TR:
  - Short TR → reduced T_1 weighting
  - Long TR → increased T_1 weighting

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

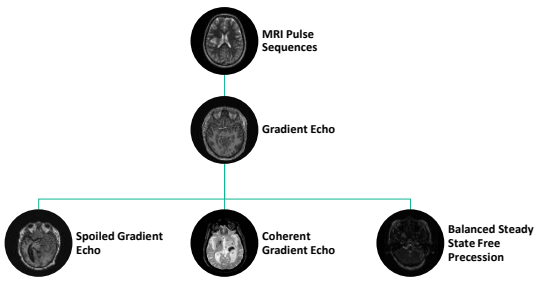
Gradient Echo Image Contrast



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

Remarkable people. Extraordinary place.

MRI Pulse Sequences



Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

- Two main classes of GE sequence depending on how residual transverse magnetisation (RTM) is managed:
  - **Coherent or Rewound GE** (GRE/FISP/FFE)
    - M_{ss} conserved. Rewinder gradient applied to PE direction at end of cycle to reverse effects
    - By maintaining residual transverse magnetisation excitation pulses will produce new echoes (Hahn echoes, stimulated echoes) in addition to the GE
  - **Spoiled or incoherent GE** (SPGR/FLASH/T_1FFE/RAGE)
    - M_{ss} eliminated by use of RF / gradient spoiling
  - ***M_{ss} = steady state magnetisation***

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

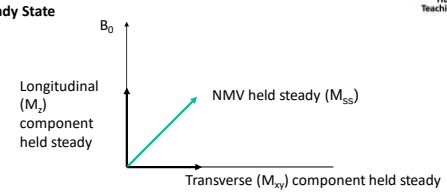
Steady State

- Using a RF pulse, longitudinal magnetisation (M_z) is tilted into the transverse plane (M_{xy})
- *The net magnetisation vector (NMV) is the sum of M_z and M_{xy}*
- "Steady State" is where the TR is shorter than the T_1 and T_2 relaxation times of the tissue being imaged
- No time for the transverse (M_{xy}) magnetisation to decay, before the pulse sequence is repeated
- Therefore there is coexistence of both longitudinal (M_z) and transverse (M_{xy}) magnetisation
- Flip angle and TR can maintain the "steady state" which holds the longitudinal and transverse components stationary during data acquisition

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

Steady State



- When steady state is maintained, the transverse component does not have time to decay during pulse sequence
- This transverse magnetisation, produced as a result of previous excitations is called the residual transverse magnetisation (RTM)

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

Steady State

- The residual transverse magnetization (RTM) affects image contrast as it results in tissues with long T_2 times, appearing bright on the image
- Most gradient echo sequences use "steady state" approach since shorter scan times can be achieved (shorter TR)
- Gradient echo sequences are classified according to whether the residual transverse magnetisation is in phase (coherent) or out of phase (incoherent)

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

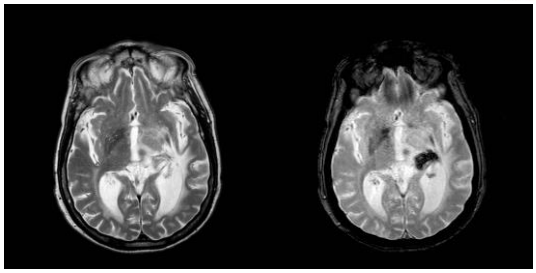
Coherent Gradient Echo (GRASS, FISP, FAST, FFE)

- This type of pulse sequence uses a variable flip angle excitation pulse followed by gradient rephasing, to produce a gradient echo
- Steady state is maintained by selecting TR shorter than T_1 and T_2
- There is therefore RTM left over when the next excitation pulse is applied
- The RTM is kept coherent by a process known as rewinding
- Rewinding is achieved by reversing the slope of the phase encoding gradient after readout
- This results in RTM rephasing, so that it is in phase at the beginning of the next repetition. This allows the RTM to build up so that tissues with a long T_2 time produce a high signal

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

T_2* Weighted Imaging

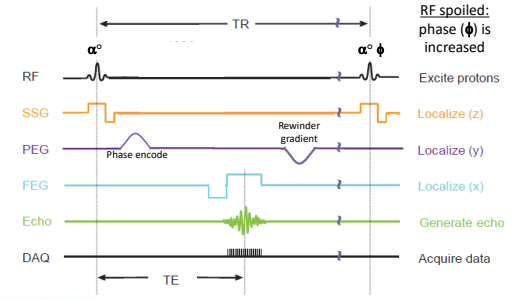


Spin Echo T_2 **Gradient Echo T_2***

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

Coherent Gradient Echo Sequence



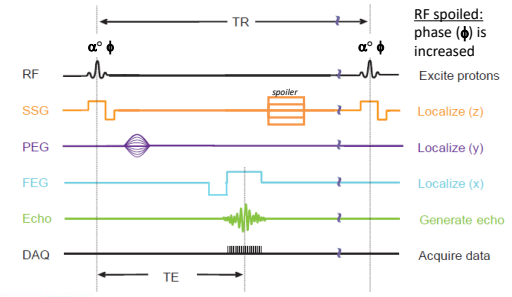
Gradient Echo (GE) Pulse Sequences

Spoiled Gradient Echo (SPGR/FLASH/T1FFE/RAGE)

- Incoherent gradient echo (gradient spoiled) is a type of sequence that uses continuous shifting of the RF pulse to spoil (destroy) the remaining transverse (M_{xy}) magnetisation
- The transverse (M_{xy}) magnetisation is spoiled by a magnetic field gradient resulting in more T_1 weighting
- Gradient spoiling occurs after each echo using strong gradients in the slice-select direction after the frequency encoding and before the next RF pulse
- Because spins in different locations in the magnet thereby experience a variety of magnetic field strengths, they will precess at differing frequencies; as a consequence they will quickly become dephased

Gradient Echo (GE) Pulse Sequences

Spoiled Gradient Echo Sequence



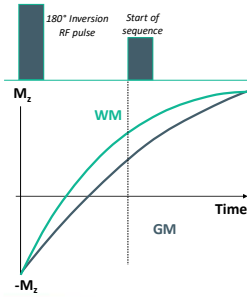
Gradient Echo (GE) Pulse Sequences

SPGR SPGR



Gradient Echo (GE) Pulse Sequences

Inversion Recovery Prepped T_1

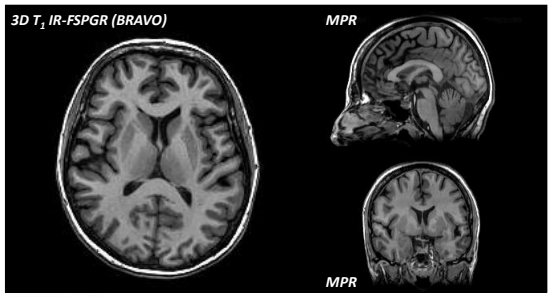


Inversion Recovery Preparation

1. Initial 180° inversion pulse
2. WM and GM signal begin T_1 relaxation from $-M_z$
3. GM signal recovers slower due to longer T_1 relaxation time (900 vs 780ms)
4. When M_z is greatest, imaging sequence begins (TI~450ms)

Gradient Echo (GE) Pulse Sequences

Inversion Recovery Prepped T_1

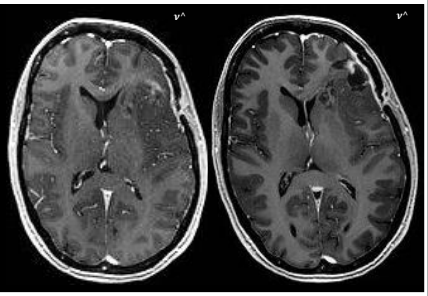


Gradient Echo (GE) Pulse Sequences

Inversion Recovery Prepped T_1

3D T_1 FSPGR +C
FOV = 30cm
Matrix = 256x256
TR/TE = 8.3/3.1ms
SL Thick = 1.3/0mm
Scan Time = 4:17

3D T_1 IR-FSPGR +C
FOV = 25.6cm
Matrix = 256x256
Phase FOV = 0.8
TR/TE = 8.2/3.2ms
TI = 450ms
SL Thick = 1/0mm
ARC = 2 x 1
Scan Time = 3:42



Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

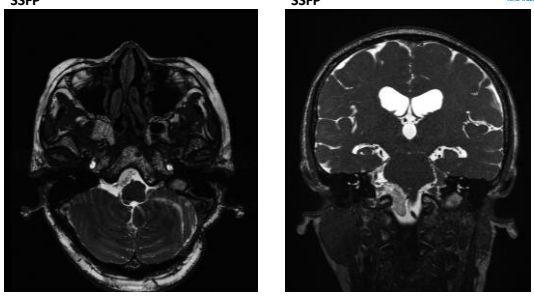
Gradient Echoes: Steady State Free Precession (SSFP/PSIF)

- Images give a T_2 weighted appearance but with advantage of faster acquisition than spin echo
- Sensitive to motion (still quicker than spin echo)
- Relatively low SNR
- Used a lot before 3D T_2 FSE became available

Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

SSFP SSFP



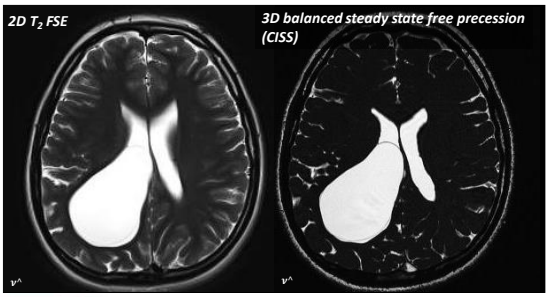
Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

TSE vs SSFP

2D T_2 FSE

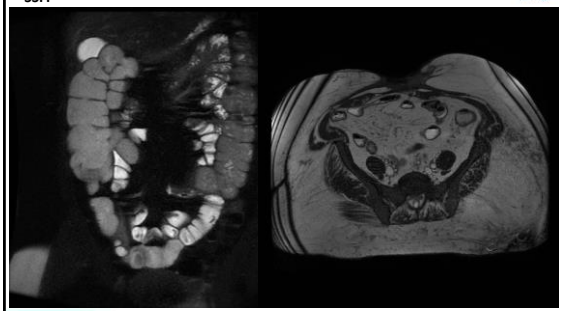
3D balanced steady state free precession (CISS)



Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

SSFP

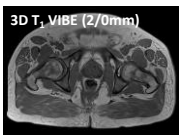


Remarkable people. Extraordinary place.

Gradient Echo (GE) Pulse Sequences

BASG	Balanced SARGE (Steady-state Acquisition Rewound Gradient Echo)
BRAVO	Brain Volume imaging
CISS	Constructive Interference in the Steady Steady State
COSMIC	Coherent Oscillatory State Acquisition for Manipulation of Imaging Contrast
DESS	Double Echo Steady State
FAME	Fast Acquisition with Multiphase Elliptical fast gradient echo
FE	Field Echo
FFE	Fast Field Echo
FIESTA	Fast Imaging Employing Steady State Acquisition
FIESTA-C	Fast Imaging Employing Steady State Acquisition - Constructive Interference
FISP	Fast Imaging with Steady Precession
FLASH	Fast Low Angle Shot
GE, GRE	Gradient Echo/ Gradient Recalled Echo
GEIR	Gradient Echo Inversion Recovery
GRASE	Gradient And Spin Echo
GRASS	Gradient Recalled Acquisition in the Steady State
LAVA	Liver Acquisition with Volume Acceleration
MEDIC	Multi-Echo Data Image Combination
MENSA	Multi-Echo iN Steady-state Acquisition
MERGE	Multiple Echo Recombined Gradient Echo
M-FFE	Multiple Fast Field Echo
MP-RAGE	Magnetization Prepared Rapid Gradient Echo
PBSG	Phase Balanced SARGE
PSIF	Time-reversed FISP
RGE	Rapid Gradient Echo
RSSG	RF-Spoiled SARGE
SARGE (SG)	Steady-state Acquisition Rewound Gradient Echo
SSFP	Turbo Gradient Spin Echo
TGSE	Steady State Free Precession
THRIVE	T1-weighted High Resolution Isotropic Volume Examination
TIGRE	T1-weighted Gradient Echo
TRSG	Time-Reversed SARGE
VIBE	Volumetric Interpolated Breath-hold Examination

3D T_1 VIBE (2/0mm)



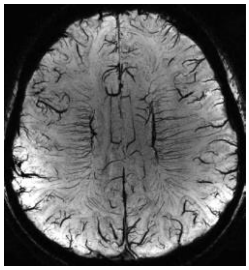
Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

Remarkable people. Extraordinary place.

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*)



Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

- Conventional diagnostic MR imaging relies only on magnitude information $\sqrt{(Real^2+Imaginary^2)}$
- Phase information is ignored and usually discarded during image reconstruction
- 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)

Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

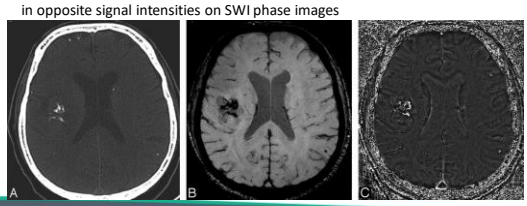
- SWI combines a T_2*-weighted magnitude image with a filtered phase image acquired using a gradient echo sequence in a multiplicative relationship
- While T_2*-weighted imaging provides some susceptibility contrast, SWI further enhances the contrast between tissues of differing susceptibility
- Phase 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

Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

Intratumoral Calcifications

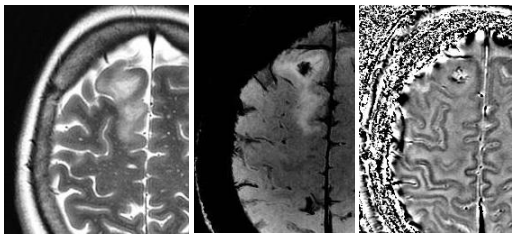
- Calcification cannot be definitively identified by GRE imaging since haemorrhage also cause local magnetic field changes and appears as hypointensities
- Phase images can differentiate calcification from haemorrhage because calcification is diamagnetic, whereas haemorrhage is paramagnetic, resulting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



Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

Calcification – Low Grade Glioma



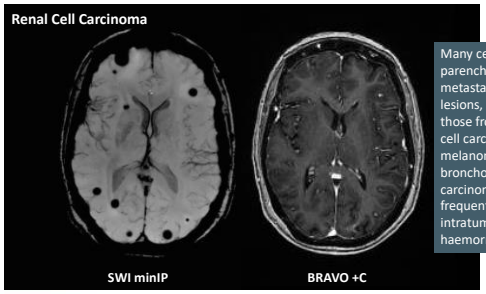
T2 FSE | 3D SWI minIP | Filtered Phase Map (r.h.s)

Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

Haemorrhagic Lesions

Renal Cell Carcinoma



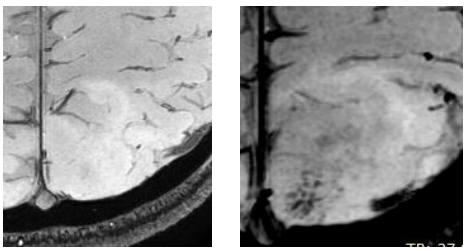
SWI minIP BRAVO +C

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

Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

Low Grade Glioma Transformation

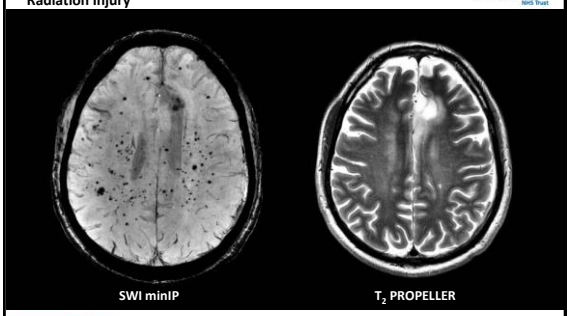


2013 SWI minIP 2015

Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

Radiation Injury



SWI minIP T_2 PROPELLER

Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

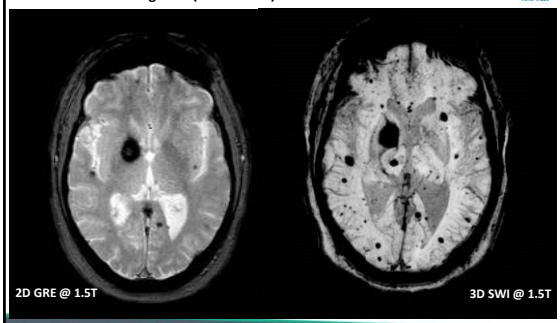
Cavernous haemangioma (Cavernoma)

- Type of blood vessel malformation or haemangioma, where a collection of dilated blood vessels form a benign tumour
- Blood flow through the cavities, or caverns, is slow
- Cells that form the vessels do not form the necessary junctions with surrounding cells
- Leakage of blood, known as a haemorrhage from these vessels that causes a variety of symptoms known to be associated with this disease

Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

Cavernous haemangioma (Cavernoma)



2D GRE @ 1.5T 3D SWI @ 1.5T

Remarkable people. Extraordinary place.

Susceptibility Weighted Imaging (SWI)

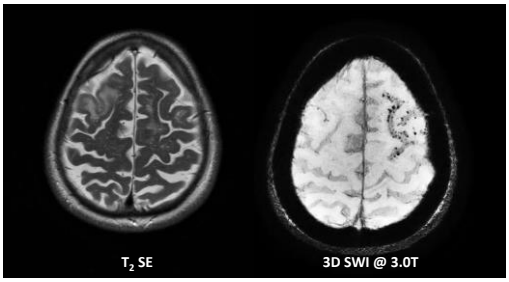
Cerebral amyloid angiopathy

- amyloid deposits form in the walls of the blood vessels of the central nervous system
- amyloid material is only found in the brain and as such the disease is not related to other forms of amyloidosis
- caused by the same amyloid protein that is associated with Alzheimer's dementia, brain bleeds are more common in people who suffer from Alzheimer's, however they can also occur in those who have no history of dementia
- The bleeding within the brain is usually confined to a particular lobe

Remarkable people. Extraordinary place.

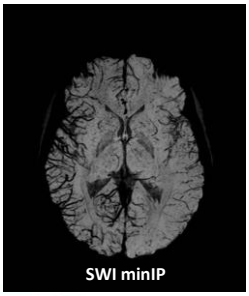
Susceptibility Weighted Imaging (SWI)

Cerebral amyloid angiopathy



Susceptibility Weighted Imaging (SWI)

Transient Changes

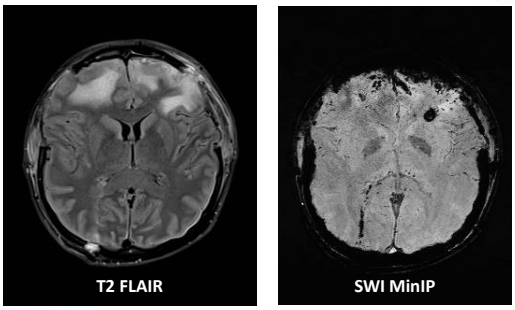


Blood Oxygen Level Dependent (BOLD) Contrast

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

Susceptibility Weighted Imaging (SWI)

RTA - Contusion

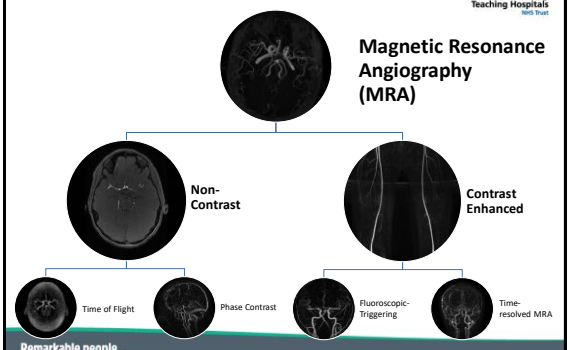


Susceptibility Weighted Imaging (SWI)

- More sensitive than conventional T_2* weighted imaging
- Able to resolve venous vasculature, haemorrhage, and iron
- High-resolution images able to depict neoangiogenesis in tumours
- Differentiate calcification and haemorrhage using phase maps

Magnetic Resonance Angiography

Magnetic Resonance Angiography

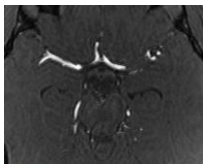


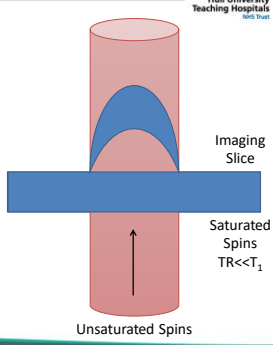
Magnetic Resonance Angiography

Hull University Teaching Hospitals NHS Trust

Time of Flight (TOF)

- TOF MRA utilises gradient echo sequences with short TE/TR to saturate the signal from stationary spins
- Spins flowing into the imaging slice with full magnetisation have high signal





Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

Hull University Teaching Hospitals NHS Trust

Time of Flight (TOF)

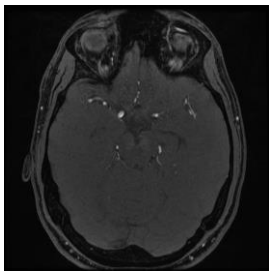
- Based on the phenomenon of **flow-related enhancement** of spins entering into an imaging slice.
  - As a result of being unsaturated, these spins give more signal that surrounding stationary spins.
- The strength of the vascular signal depends on:
  - Flow velocity and type
  - The length and orientation of the vessel
- Limitations
  - Signal loss from spin dephasing when flows are complex or turbulent (stenosis), when flow is too slow
  - Poor signal suppression of the stationary tissues with short T_1 relaxation time (fat, atheroma, haematoma, thrombus)

Remarkable people. Extraordinary place.

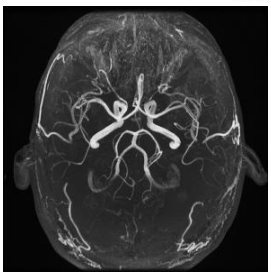
Magnetic Resonance Angiography

Hull University Teaching Hospitals NHS Trust

MR Angiography: Time of Flight (TOF)



TOF Source Data



TOF MIP

Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

Hull University Teaching Hospitals NHS Trust

MR Angiography: Time of Flight (TOF)



TOF MIP

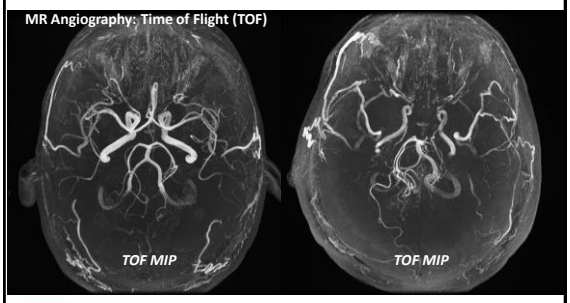


TOF MIP

Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

Hull University Teaching Hospitals NHS Trust



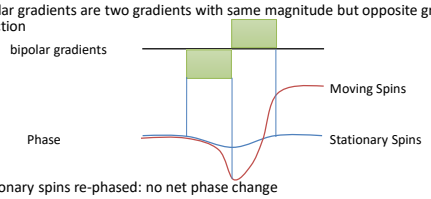
Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

Hull University Teaching Hospitals NHS Trust

Phase-Contrast (PC) MRA

- Bipolar gradient pair used to sensitise flow (flow encoding in 1 direction)
- bipolar gradients are two gradients with same magnitude but opposite gradient direction



- Stationary spins re-phased: no net phase change
- Moving spins experience net phase shift proportional to blood velocity leading to loss of signal flow appears dark

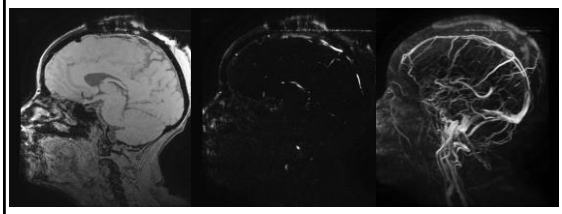
Remarkable people. Extraordinary place.

MRI Physics: Flow Related Effects in MRI
http://xrayphysics.com/mr_flow.html

Magnetic Resonance Angiography

Phase-Contrast (PC) MRA

- This information can be used directly to determine the velocity of the spins. Alternatively, the image can be subtracted from one acquired without the velocity encoding gradients to obtain an angiogram



PC Source Data | PC Subtraction Data | PC MIP

Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

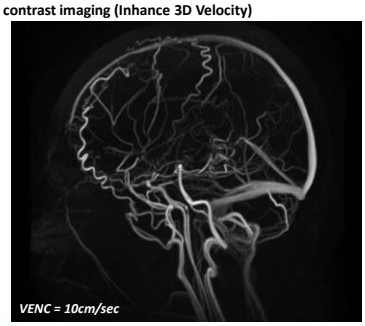
Phase-Contrast (PC) MRA

- Velocity Encoding (VENC) is a parameter that must be specified before performing a phase-contrast study
- Units of cm/sec, should be chosen to encompass the highest velocities likely to be encountered within the vessels of interest
- If VENC is set to 50 cm/sec, for example, flows in the range of ±50 cm/sec can be accurately represented by a set of phase shifts spanning from −180° to +180°
- If the selected VENC is set too high, the range of flows imaged will span only a limited phase shift range
- Generally: Arterial imaging => VENC=40-50cm/sec
  Venous imaging => VENC=5-10cm/sec

Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

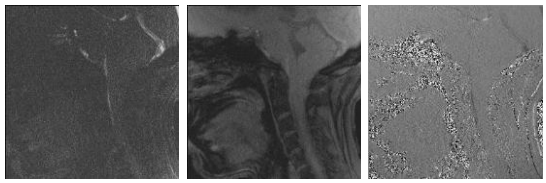
MIP Phase contrast imaging (Inhance 3D Velocity)



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

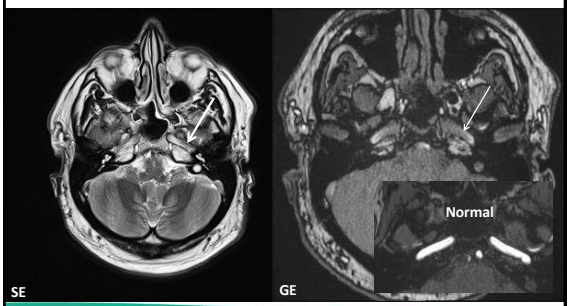
Phase Contrast CSF Flow Studies



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

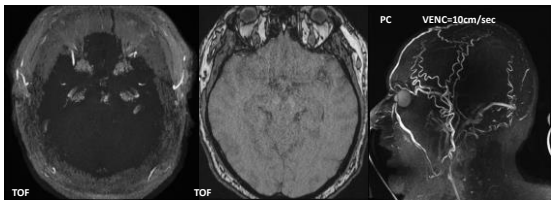
Abnormal flow



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

MR Angiography: Multimodal Imaging

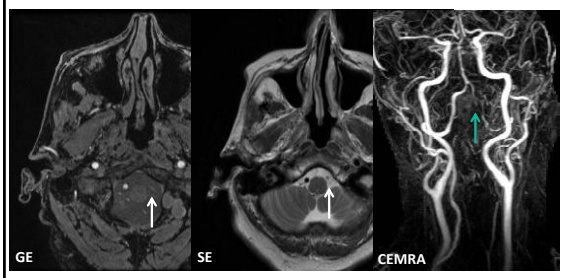


SWI

Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

MR Angiography: Multimodal Imaging



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

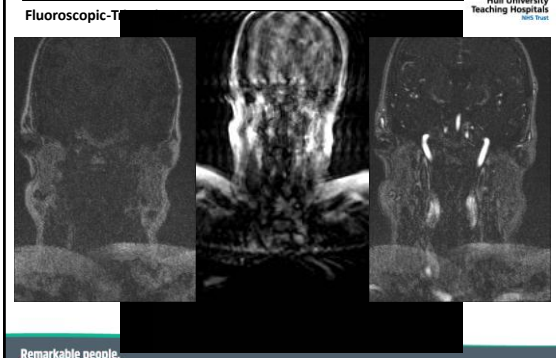
Contrast Enhanced (CE) MRA

- Contrast agent shortens relaxation time of blood
- Not reliant on saturation effects, relatively independent of flow dynamics
- Short TR reduces background signal and scan time
- Timing of arterial bolus and acquisition important

Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

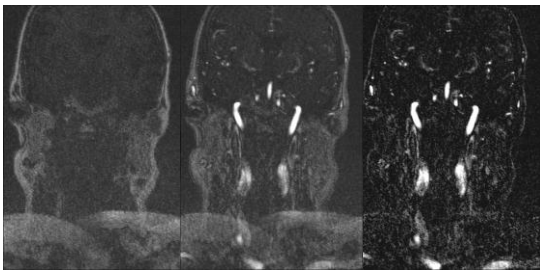
Fluoroscopic-T[redacted]



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

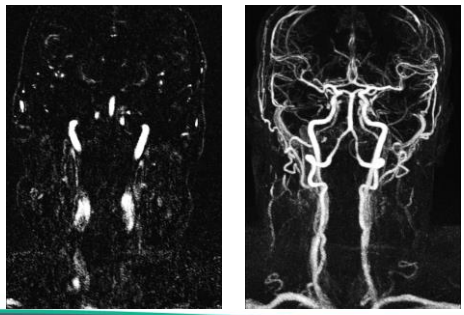
Fluoroscopic-Triggering



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

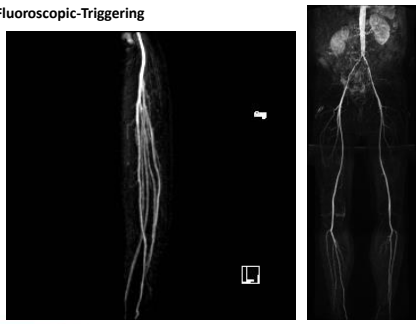
Fluoroscopic-Triggering



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

Fluoroscopic-Triggering



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography



A: Single-dose (0.1 mmol/kg body weight) high-resolution (0.8 x 0.8 x 0.8 mm³) MR angiography in coarctation of the aorta (CoA). B: 3-tesla dynamic MR angiography performed at high temporal and spatial resolution. Images courtesy of Dr. Bernd Winterspeger.

Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

Contrast Enhanced (CE) MRA: Time-resolved MRA

- Time-resolved MRA sequences, known under acronyms such as TRICKS and TWIST, obtain a series of images displaying passage of the contrast bolus
- Typical time-resolved MRA study temporal resolution =1-2 seconds
- An inherent trade-off exists between spatial and temporal resolution
- The centre of k-space contains information about basic image contrast, while edges and details are encoded in the k-space periphery
- Increasing spatial resolution requires that more k-space points be sampled. However, sampling more points requires additional imaging time, adversely impacts temporal resolution.

Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

Contrast Enhanced (CE) MRA: Time-resolved MRA

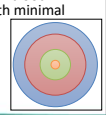
- Time-resolved MRA techniques balance these competing resolution requirements through a process known as view-sharing
- Although the details of these methods vary, all begin by acquiring a non-contrast, full-resolution image (all of k-space) of the area of interest
- During passage of the contrast bolus, the centre of k-space is sampled more frequently than the periphery, which is updated only periodically
- The data from the different partial k-space samplings are combined to create a series of time-resolved images with satisfactory spatial resolution.
- The original non-contrast image can be used as a mask for subtraction to improve vascular conspicuity.

Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

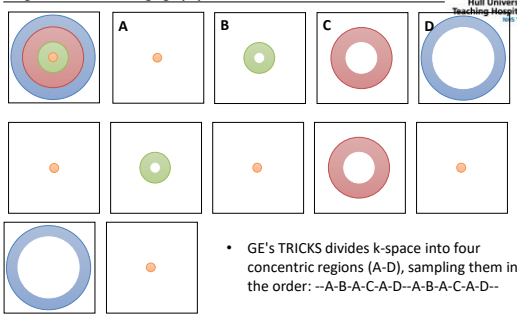
Contrast Enhanced (CE) MRA

- Time Resolved Imaging of Contrast KineticS (TRICKS) technology provides MR Angiography imaging with excellent spatial and temporal resolution.
- An intricate temporal sampling and complex data recombination helps accelerate the temporal domain of 3D dynamic imaging – without compromising spatial resolution.
- An elliptical-centric data sampling helps further increase efficiency.
- Easy to set up, TRICKS rapidly generates time resolved 3D images of blood vessels to meet the challenge of capturing peak arterial phases with minimal venous contamination.



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

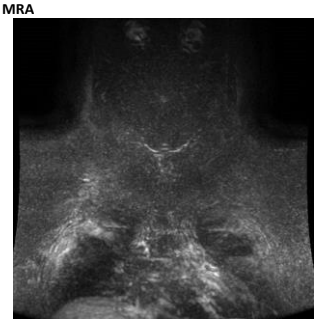


- GE's TRICKS divides k-space into four concentric regions (A-D), sampling them in the order: --A-B-A-C-A-D--A-B-A-C-A-D--

Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

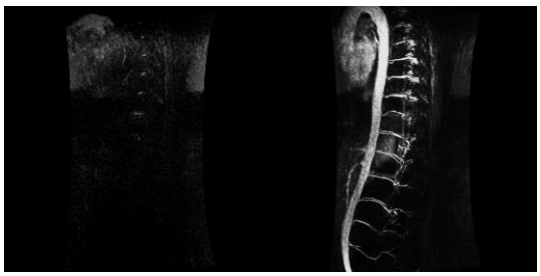
Time Resolved MRA



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

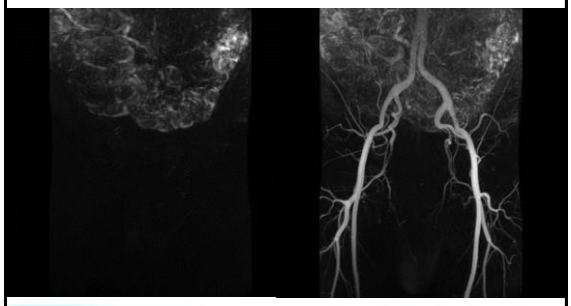
Time Resolved MRA



Remarkable people. Extraordinary place.

Magnetic Resonance Angiography

Time Resolved MRA



Remarkable people. Extraordinary place.

Question

In gradient echo sequences use in magnetic resonance imaging (MRI)

A. a gradient replaces the 90 degree rephasing pulse used in spin echo imaging

B. Higher flip angles (30-50°) provide more T_1 weighting

C. Flow is sensitively detected and this is exploited for magnetic resonance angiography

D. TR is characteristically shorter than spin echo sequences

E. Resultant images are affected by T_2* information

Remarkable people. Extraordinary place.

Question

T_2 Decay

A. Occurs due to spin-lattice relaxation

B. Is referred to as T_2* when an initial 180° pulse used in spin echo sequencing

C. T_2 relaxation time increases with an increase in magnet field strength

D. In a SE a sequence is affected by magnetic field inhomogeneities

E. When 63% of the transverse signal is lost, this is referred to as time T_2

Remarkable people. Extraordinary place.

Question

A. T_2 always has a longer decay time than T_2*

B. A reduced flip angle can be used to decrease the scan time at the expense of signal strength.

C. In MR angiography flow blood normally appears dark

D. In time of flight MR angiography, flowing blood shows as high signal because its movement prevents longitudinal relaxation

E. Flowing blood can appear bright on GE sequences

Remarkable people. Extraordinary place.

Question

Concerning MR Angiography

A. On a SE sequence, slow flowing blood appears dark (flow void)

B. In GRE flow blood appears bright only after administration of intravenous gadolinium

C. Vessel calcification will produce a high signal which can mask a stenosis

D. Turbulent flow shows high signal on a SE sequence

E. Gradient recalled echo (GRE) sequences are used for their speed of acquisition

Remarkable people. Extraordinary place.