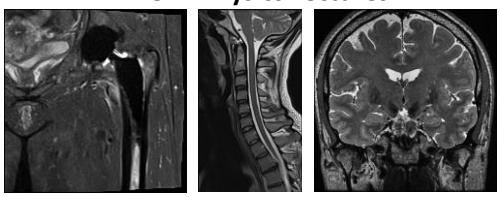
Magnetic Resonance Imaging

F.R.C.R. Physics Lectures



Lawrence Kenning PhD

Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) [2]

- Tissue suppression methods – STIR, FLAIR and Fat saturation
- Standard gadolinium contrast agents

Tissue Suppression Methods

Why Suppress?

- Remove bright signal from normal tissue i.e. fat or CSF
- Improve tissue contrast i.e. white-grey matter in the brain
- Improve appearance of contrast agents
- Confirm tissue characterisation i.e. fat vs. blood



Water and Fat Molecules

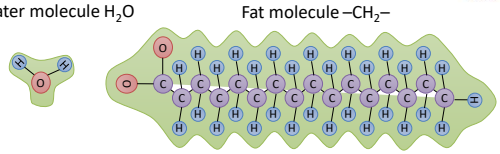
- Signal from water and fat both originate from **PROTONS** but there are differences:
- Relaxation
- Chemical Shift



Water and Fat Molecules

Water molecule H_2O

Fat molecule $-CH_2-$



- Water molecules are small and therefore tumble quickly
- Triglyceride molecules are large and tumble much slower
- Molecules with tumbling rates close to the Larmor frequency are more efficient at transferring their energy to the surrounding lattice
- Fat has a shorter T_1 relaxation rate than water

Water and Fat Molecules – Chemical Shift

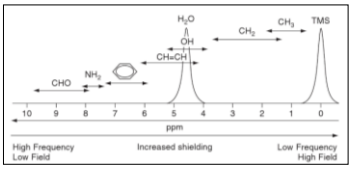
- electron cloud around an atom shields the nucleus from the magnetic field (σ):
- different resonant frequencies for different molecules

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

γ = gyromagnetic ratio

B_0 = magnetic field strength

ω_0 = resonant frequency



Water and Fat Molecules

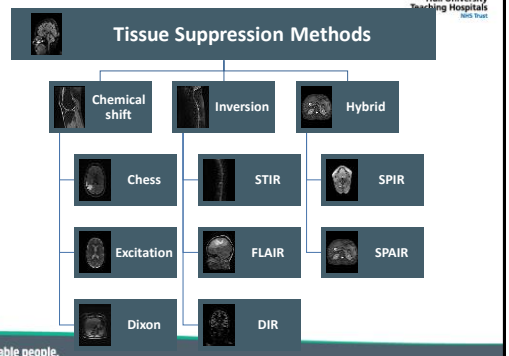
- The two dominate fat peaks (1.3ppm and 0.9ppm) experience a lower local magnetic field (B_0) due to the electron shielding compared to water
- Fat precesses at a lower frequency than water
- Chemical shift is 3.5ppm

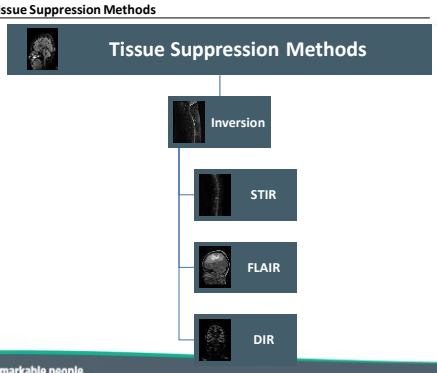
1.5T scanner the fat-water frequency difference (Δf)

$\Delta f = (64\ MHz)(3.5\ ppm) = (64 \times 10^6\ Hz)(3.5 \times 10^{-6}) \approx$ **220 Hz**

3.0T scanner the fat-water frequency difference (Δf)

$\Delta f = (128\ MHz)(3.5\ ppm) = (128 \times 10^6\ Hz)(3.5 \times 10^{-6}) \approx$ **440 Hz**



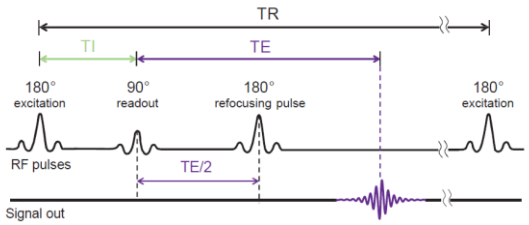


Inversion Recovery (IR)

- IR emphasises T_1 relaxation times of the tissues by extending the amplitude of the longitudinal recovery by a factor of 2
- Selection of an appropriate TI can thus suppress tissue signals (e.g., fats/lipids, CSF) depending on their T_1 relaxation times
- Initial 180° RF pulse inverts M_z to $-M_z$
- After a predefined delay, the time of inversion (TI), a 90° RF pulse rotates the recovered fraction of M_z into the transverse (M_{xy}) plane to generate the FID
- A second 180° pulse at TE/2 produces an echo
- The TR for IR is the time between 180° initiation pulses.

Tissue Suppression Methods

Inversion Recovery (IR)



Remarkable people. Extraordinary place.

Tissue Suppression Methods

Short Tau Inversion Recovery (STIR)

- Short Tau Inversion Recovery (STIR), is a pulse sequence that uses a very short inversion time (TI) to supress fat
- The signal null (M_z=0) occurs at TI=*ln*(2)xT_1
- T_1 for fat at 1.5T is approximately 260 ms, therefore TI selected is 0.693 x 260ms = 180 ms
- Typical STIR sequences uses TI of 140-180ms and TR of approximately 2,500ms
- In STIR, T_1 weighting from the inversion recovery process
- T_2 weighting generated by using longer TE values

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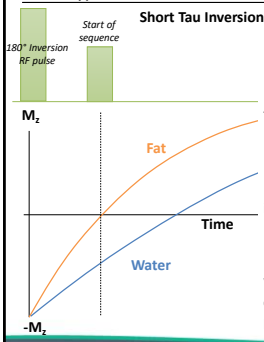
Tissue Suppression Methods

Short Tau Inversion Recovery (STIR)



Initial 180° inversion pulse

Fat and water signals begin T_1 relaxation from $-M_z$

Due to a shorter T_1, fat recovers faster

Fat passes through the zero line at an inversion time TI = T_1 ln(2)

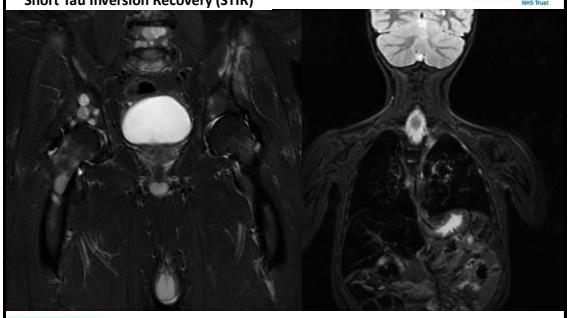
Imaging sequence begins at this point

Water still has a longitudinal (reduced) component (negative) but is displayed as a positive in a magnitude image

Remarkable people. Extraordinary place.

Tissue Suppression Methods

Short Tau Inversion Recovery (STIR)



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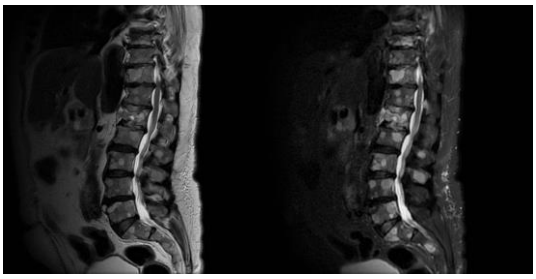
Tissue Suppression Methods

Short Tau Inversion Recovery (STIR)



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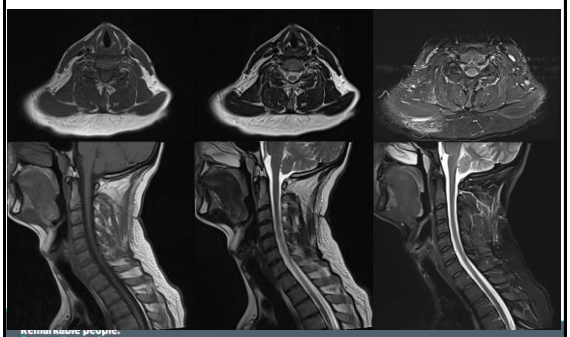
Tissue Suppression Methods

Short Tau Inversion Recovery (STIR)



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Tissue Suppression Methods

Short Tau Inversion Recovery (STIR)

Advantages	Disadvantages	Suggested applications
Insensitive to B_0 and B_1 inhomogeneities	Inefficient, long scan times	Anywhere CHESS or water excitation fail
Robust fat nulling even over large FOV's	Low SNR Water signal reduced by ~40-50%	Especially good for large FOV, unfavourable anatomy or in the presence of metal
	Suppresses all short T_1 species (Gad)	
	Mixed image weighting (T_1)	
	Limited to T_2 and P.D.	

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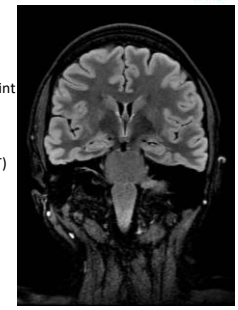
Tissue Suppression Methods

Fluid Attenuated Inversion Recovery (FLAIR)

- Fluid attenuated inversion recovery (FLAIR) sequence, nulls the CSF signal and other water-bound anatomy in the MR image by using a TI selected at or near the bounce point of CSF to permit better evaluation of the surrounding anatomy
- Reducing the CSF signal (T_1<2,500ms @ 1.5T) requires TI=0.693x2500ms =1700ms.



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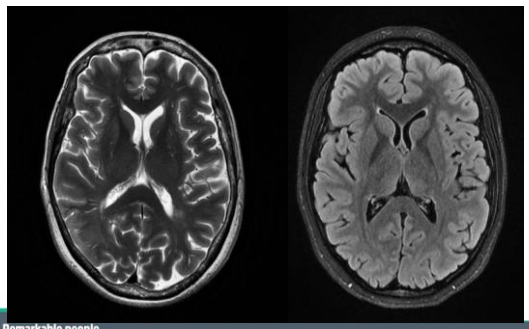
Tissue Suppression Methods

Fluid Attenuated Inversion Recovery (FLAIR)



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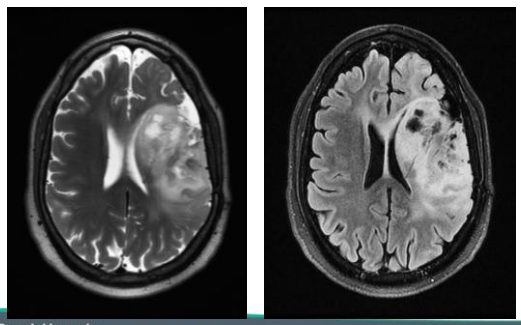
Tissue Suppression Methods

Fluid Attenuated Inversion Recovery (FLAIR)



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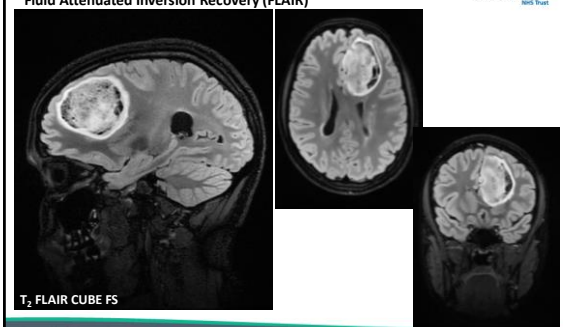
Tissue Suppression Methods

Fluid Attenuated Inversion Recovery (FLAIR)



T_2 FLAIR CUBE FS

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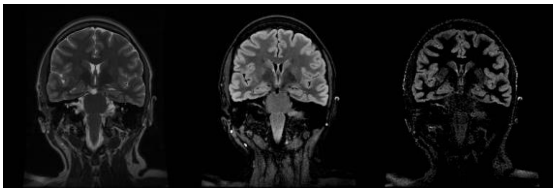
Tissue Suppression Methods

FLAIR and DIR (Double Inversion Recovery)



T2 | FLAIR (T2 IR) | DIR (T2 IR IR)

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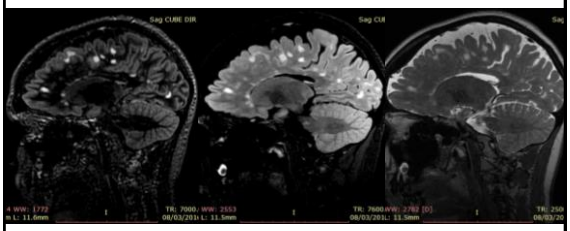
Tissue Suppression Methods

FLAIR and DIR - Visualisation of MS Lesions



T_2 DIR CUBE | T_2 FLAIR CUBE | T_2 CUBE

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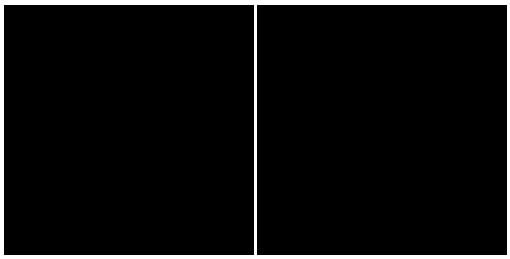
Tissue Suppression Methods

FLAIR and DIR - Visualisation of MS Lesions



DIR CUBE | T2 FLAIR CUBE

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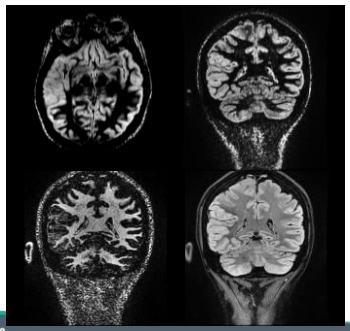
Tissue Suppression Methods

FLAIR and DIR - Cortical Dysplasia

CUBE DIR | CUBE DIR



CUBE DIR | T_2 FLAIR CUBE

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Tissue Suppression Methods

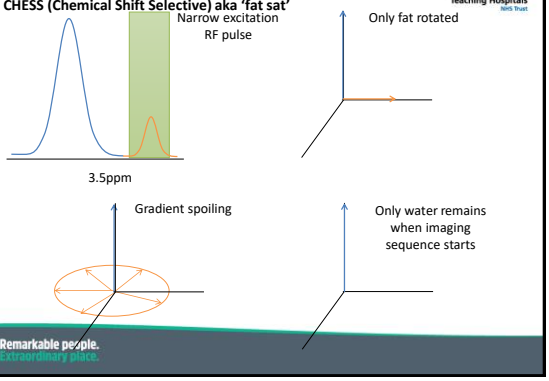
Tissue Suppression Methods

- Chemical shift
  - CHESS
  - Excitation
  - Dixon

Remarkable people. Extraordinary place.

Tissue Suppression Methods

CHESS (Chemical Shift Selective) aka 'fat sat'



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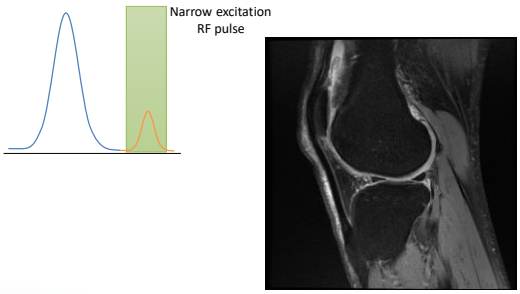
Tissue Suppression Methods

CHESS (Chemical Shift Selective) aka 'fat sat'



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Tissue Suppression Methods

CHESS (Chemical Shift Selective) aka 'fat sat'



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Tissue Suppression Methods

CHESS (Chemical Shift Selective) aka 'fat sat'



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Tissue Suppression Methods

CHESS (Chemical Shift Selective) aka 'fat sat'

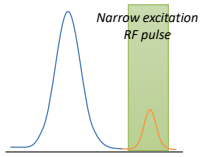
B_0 inhomogeneity – a lack of a homogeneous main magnetic field

- Different locations within the imaging volume experience a different B_0 and consequently precessional frequency
- The bandwidth of the initial narrow RF pulse may not excite all fat within the field

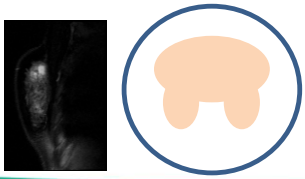
Remarkable people. Extraordinary place.

Tissue Suppression Methods

CHESS (Chemical Shift Selective) aka 'fat sat'



On centre frequency



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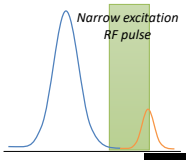
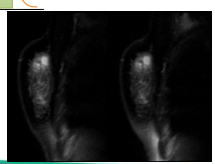
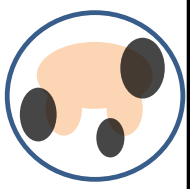
Tissue Suppression Methods

CHESS (Chemical Shift Selective) aka 'fat sat'



Off centre frequency
fat signal not nulled





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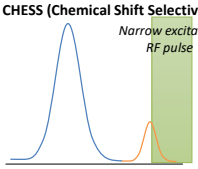
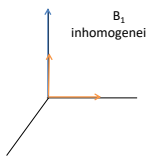
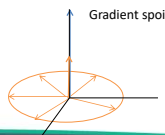
Tissue Suppression Methods

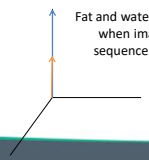
CHESS (Chemical Shift Selective) aka 'fat sat'



3.5ppm







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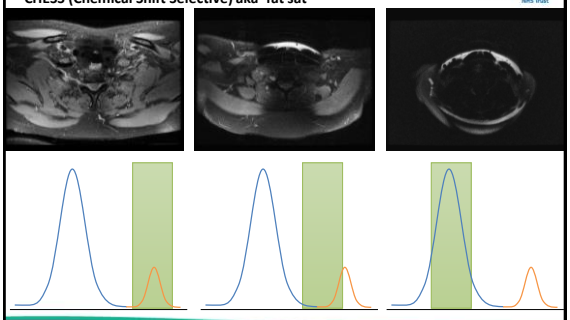
Tissue Suppression Methods

CHESS (Chemical Shift Selective) aka 'fat sat'



Remarkable people. Extraordinary place.

Tissue Suppression Methods

CHESS (Chemical Shift Selective) aka 'fat sat'

B_1 inhomogeneity – a variable flip angle across the imaging field.

- Different locations within the imaging volume experience a different flip angle
- A significant longitudinal component remains for fat resulting in non saturation of all fat signal

Remarkable people. Extraordinary place.

Tissue Suppression Methods

CHESS (Chemical Shift Selective) aka 'fat sat'

Advantages	Disadvantages	Suggested applications
Versatile	Sensitive to B_0 and B_1 inhomogeneities	Most applications except areas with poor homogeneity*
Applicable to most pulse sequences	Low sequence efficiency	
Relatively fast		

*off isocentre imaging, metal implants, anatomy with large shape differences e.g. breast, head and neck

Remarkable people. Extraordinary place.

Tissue Suppression Methods

Water Excitation

Binomial pulses - A sequence of two or more RF pulses.

- The 45º-45º pulse pair simplest binomial pulses, known as 1-1.
- Other more complicated binomial pulses available
- 1-2-1 (22.5º-45º-22.5º)
- 1-3-3-1 (11.25º-33.75º-33.75º-11.25º)
- More complicated binomial pulses result in superior fat nulling BUT take longer

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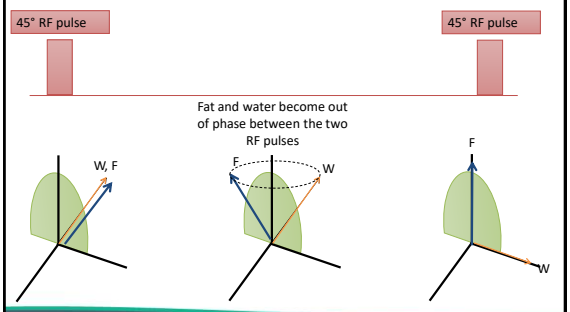
Tissue Suppression Methods

Water Excitation



Remarkable people. Extraordinary place.

Tissue Suppression Methods

Water Excitation

Advantages	Disadvantages	Suggested applications
Insensitive to B_1 inhomogeneities	Sensitive to B_0 inhomogeneities	Most applications except areas with poor homogeneity*
Versatile	Longer excitation pulses	Especially good for GE 3D cartilage imaging
Applicable to most pulse sequences (except FSE)	Low sequence efficiency	
Relatively fast		

*off isocentre imaging, metal implants, anatomy with large shape differences e.g. breast, head and neck

Remarkable people. Extraordinary place.

Tissue Suppression Methods

Water Excitation

Insensitive to B_1 inhomogeneities but.....



http://mri-q.com/water-excitation.html



.....still sensitive to B_0 inhomogeneities

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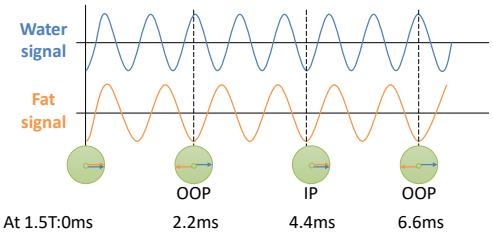
Tissue Suppression Methods

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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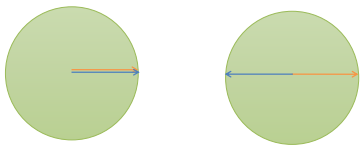
Tissue Suppression Methods

Dixon Technique

- 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

Remarkable people. Extraordinary place.

Tissue Suppression Methods

Dixon Technique

InPhase = Water + Fat

OutPhase = Water – Fat

½ [IP + OP] = ½ [(W+F) + (W–F)] = ½ [2W] = W

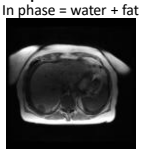
½ [IP – OP] = ½ [(W+F) – (W–F)] = ½ [2F] = F

Remarkable people. Extraordinary place.

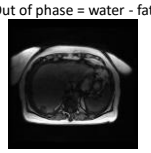
Tissue Suppression Methods

Dixon Technique

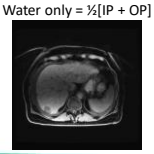
In phase = water + fat



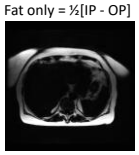
Out of phase = water - fat



Water only = ½[IP + OP]



Fat only = ½[IP - OP]



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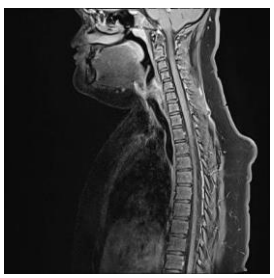
Tissue Suppression Methods

DIXON fat-nulling technique





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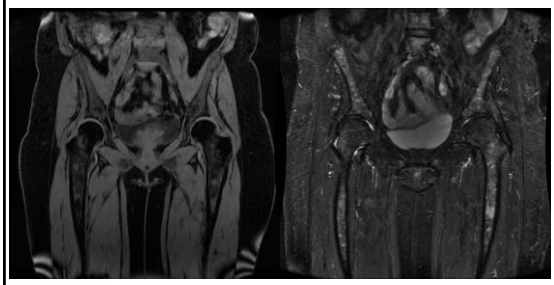
Tissue Suppression Methods

Dixon vs. STIR – Fat nulling efficacy



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Tissue Suppression Methods

Dixon Technique

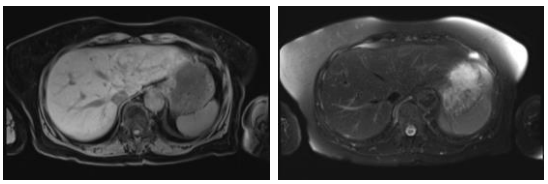
Advantages	Disadvantages	Suggested applications
Insensitive to B_0^* and B_1 inhomogeneities	Long scan times	Anywhere CHESS or water excitation fail
Robust fat nulling even over large FOV's	Complex reconstruction	Especially good for large FOV, unfavourable anatomy or in the presence of metal
High SNR (Vechoes)	Swapping artefact	
Multiple image types		

*three or four point Dixon techniques only

Remarkable people. Extraordinary place.

Tissue Suppression Methods

Dixon Technique



DIXON CHESS

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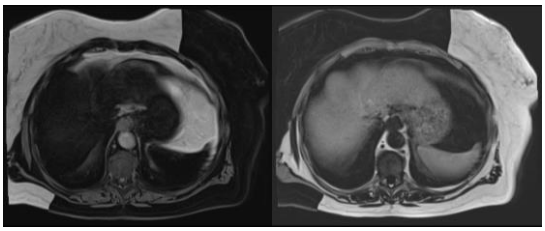
Tissue Suppression Methods

Dixon Technique



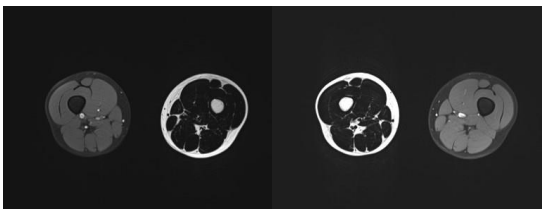
DIXON swap artefact

Local or global swap depending on vendor algorithm

Remarkable people. Extraordinary place.

Tissue Suppression Methods

DIXON swap artefact



WATER FAT

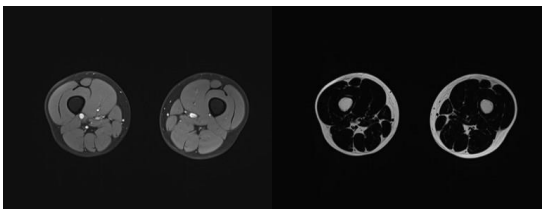
DIXON swap artefact

Local or global swap depending on vendor algorithm

Remarkable people. Extraordinary place.

Tissue Suppression Methods

Correct DIXON swap artefact



WATER FAT

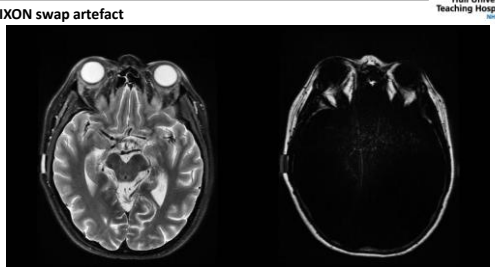
DIXON swap artefact

Local or global swap depending on vendor algorithm

Remarkable people. Extraordinary place.

Tissue Suppression Methods

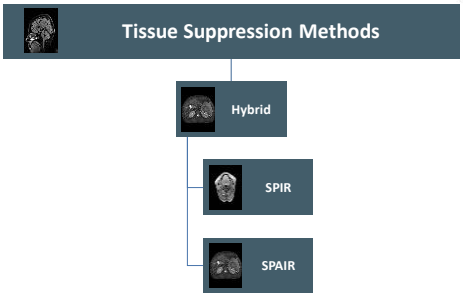
DIXON swap artefact



DIXON swap artefact

Local or global swap depending on vendor algorithm

Tissue Suppression Methods



Tissue Suppression Methods

SPIR & SPAIR

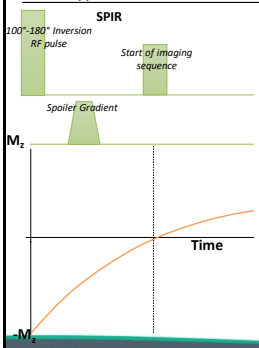
STIR robust uniform nulling of fat signal

BUT

STIR inverts everything leading to a SNR reduction for the remaining water signal

Hybrid techniques only invert the fat so there is no SNR reduction for water

Tissue Suppression Methods



Spectral selective 100 - 180° inversion pulse **only** excites fat protons

Any fat transverse magnetisation is dephased by a spoiler gradient

Fat signals begin T_1 relaxation

Fat passes through the zero line at an inversion time

Imaging sequence begins at this point

Unlike in STIR, water signal not affected by the inversion pulse so water SNR is unaffected and only fat (not all short T_1 species) nulled (Gad)

Tissue Suppression Methods

SPIR - Hybrid Spectral Presaturation with Inversion Recovery

Advantages	Disadvantages	Suggested applications
Higher SNR than STIR	Inefficient, long scan times (not as bad as SPIR if lower inversion pulse used)	Most applications except areas with poor homogeneity*
Only nulls fat not all short T_1 species	Sensitive to B_0 and B_1 inhomogeneities	
Can be used with Gad		

*off isocentre imaging, metal implants, anatomy with large shape differences e.g. breast, head and neck

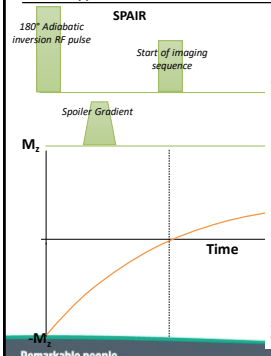
Tissue Suppression Methods

SPAIR - Hybrid SPectral Attenuated Inversion Recovery

- What is the difference between SPIR and SPAIR?
- SPAIR uses an adiabatic inversion pulse
- **What!**
- Amplitude and frequency modulated RF pulses that are *relatively insensitive* to $\mathbf{B_1}$ inhomogeneity

Tissue Suppression Methods

SPAIR



Spectral selective 180° adiabatic inversion pulse only flips fat protons

Any fat transverse magnetisation is dephased by a spoiler gradient

Fat signals begin T_1 relaxation

Fat passes through the zero line at an inversion time

Imaging sequence begins at this point

Unlike STIR, water signal not affected by the inversion pulse so SNR is unaffected and only fat nulled

(Adiabatic inversion pulses are a special type of RF-pulses capable of accurately rotating Mz and M_{xy} magnetisation by exactly 180º)

Remarkable people. Extraordinary place.

Tissue Suppression Methods

SPAIR

Advantages	Disadvantages	Suggested applications
Higher SNR than STIR	Inefficient, long scan times (not as bad as SPIR if lower inversion pulse used)	Most applications except areas with poor homogeneity*
Insensitive to B_1 inhomogeneities	Sensitive to B_0 inhomogeneities	
Only nulls fat not all short T_1 species	High SAR than SPIR due to adiabatic pulse	
Can be used with Gad	Longer scan time than SPIR due to full 180° inversion	

*off isocentre imaging, metal implants, anatomy with large shape differences e.g. breast, head and neck

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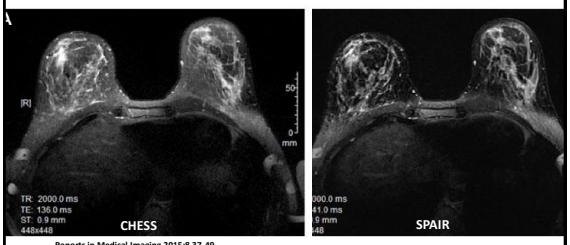
Tissue Suppression Methods

SPAIR vs CHESS

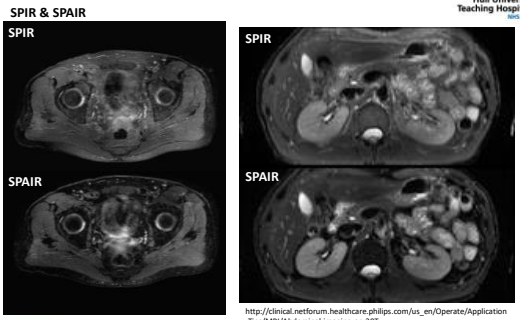


Reports in Medical Imaging 2015:8 37-49

Remarkable people. Extraordinary place.

Tissue Suppression Methods

SPIR & SPAIR



http://clinical.netforum.healthcare.philips.com/us_en/Operate/Application-Tips/MRI/Abdominal-imaging-on-3DT

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http://clinical.netforum.healthcare.philips.com/global/Operate/Application-Tips/MRI/Optimizing-SPIR-and-SPAIR-fat-suppression

Tissue Suppression Methods

Technique	GE	Siemens	Philips
Long IR	FLAIR	Dark Fluid	FLAIR
STIR	STIR	TIRM	STIR
Fat saturation – chemical	Fat Sat	Fat Sat	SPIR
SPAIR	ASPIR	SPAIR	SPAIR
Water Excitation	Water Excitation	Water Excitation	Proset
Dixon Fat-Water separation for FSE	IDEAL	Dixon TSE	mDixon TSE
Dixon Fat-Water separation for 3D GRE	LAVA-Flex	Dixon VIBE	mDixon

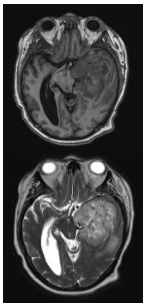
Remarkable people. Extraordinary place.

Contrast Agents

Remarkable people. Extraordinary place.

Contrast Agents

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



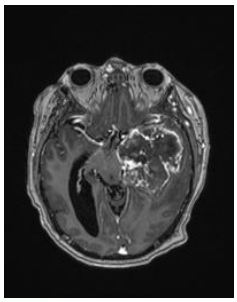
Remarkable people. Extraordinary place.

Contrast Agents

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

Remarkable people. Extraordinary place.

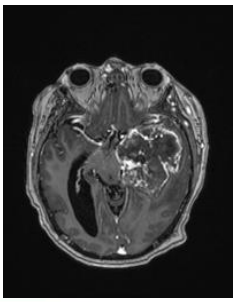
Contrast Agents



- Gadolinium is not directly visible on MRI
- Reduces relaxation times of hydrogen nuclei in the vicinity
  - Unpaired electrons interact with neighbouring water molecules
- Paramagnetic agent
- Shortens T_1 and T_2
  - T_1 effect dominates
- On T_1 weighted MRI => signal increase

Remarkable people. Extraordinary place.

Contrast Agents



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

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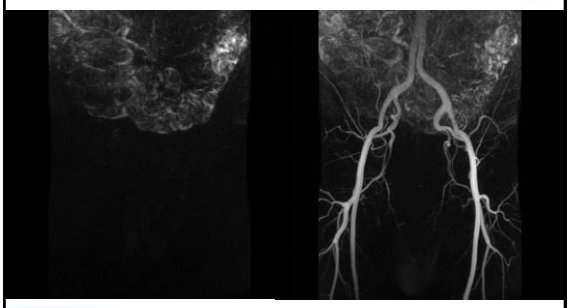
Contrast Agents

Time Resolved MRA



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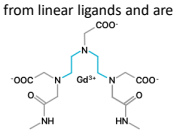
Contrast Agents

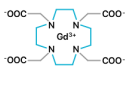
Linear vs Macrocyclic

- There are 2 structurally distinct categories of commercially available GBCAs:
  - linear ("open chain")
  - macrocyclic
- In the macrocyclic structure, the gadolinium ion is "caged" in the preorganized cavity of the ligand
- The rates of dissociation of gadolinium from macrocyclic ligands are slower than dissociation from linear ligands and are thus considered to be the most "stable"



Linear Agents

Linear agents do not fully surround the gadolinium (Gd) ions.



Macrocyclic Agents

Macrocyclic molecules fully enclose gadolinium (Gd) ions with nitrogen (N).

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https://www.drugwatch.com/gadolinium/side-effects/

Contrast Agents

Ionic vs Nonionic

- GBCAs are either **nonionic** (where the number of carboxyl groups is reduced to 3 and neutralizes the 3 positive charges of Gd^{3+}) or **ionic** (where the remaining carboxyl groups are salified with sodium or meglumine)
- The primary difference is that an ionic compound dissociates or dissolves into charged particles when it enters a solution such as blood
- Nonionic contrast media does not dissolve into charged particles when in a solution and have a lower viscosity and osmolality (a measure of the number of molecules and particles in a solution per kilogram of water)
- With nonionic agents, the absence of charged particles means there may be less potential to disrupt the electrical charges associated in brain and heart
- In practice, serious adverse events from extravasation or physiologic effects on the heart or brain with any GBCA are exceedingly rare

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https://www.medscape.org/viewarticle/780675_4

Contrast Agents

Type	Agent	Dissociation half-life
Linear non-ionic	Ominscan	<5s
	Optimark	<5s
Linear ionic	Magnevist	<5s
	Primovist	<5s
	MultiHance	<5s
Macrocyclic non-ionic	Prohance	3.9 hr
	Gadovist	4.3hr
Macrocyclic ionic	Dotarem	338 hr

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Essentials of MRI Safety

Contrast Agents

Nephrogenic systemic fibrosis

The 2015 MHRA risk classification is as follows:

- **High risk**—Omniscan (gadodiamide) *Linear nonionic*, OptiMARK (gadoversetamide) *Linear nonionic*, Magnevist (gadopentetic acid) *Linear ionic*
- **Medium risk**—MultiHance (gadobenic acid) *Linear ionic*, Primovist (gadoxetic acid) *Linear ionic*, Vasovist (gadofosveset) *Linear ionic*
- **Low risk**—Gadovist (gadobutrol) *Macrocyclic nonionic*, ProHance (gadoteridol) *Macrocyclic nonionic*, Dotarem (gadoteric acid) *Macrocyclic ionic*
- The rate of dissociation of gadolinium from macrocyclic ligands is slower than linear ligands and thus considered more stable

Remarkable people. Extraordinary place.

Contrast Agents

European Medicines Agency 2017

Product	Type (formulation)	Recommendation
Artirem / Dotarem (*gadoteric acid*)	macrocyclic (i.v.)	maintain
Artirem / Dotarem (*gadoteric acid*)	macrocyclic (intra-articular)	maintain
Gadovist (*gadobutrol*)	macrocyclic (i.v.)	maintain
Magnevist (*gadopentetic acid*)	linear (intra-articular)	maintain
Magnevist (*gadopentetic acid*)	linear (i.v.)	suspend
Multihance (*gadobenic acid*)	linear (i.v.)	restrict use to liver scans
Omniscan (*gadodiamide*)	linear (i.v.)	suspend
Optimark (*gadoversetamide*)	linear (i.v.)	suspend
Primovist (*gadoxetic acid*)	linear (i.v.)	maintain
Prohance (*gadoteridol*)	macrocyclic (i.v.)	maintain

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Contrast Agents

In Hull 3 gadolinium based contrast agents (GBCA) in use:

- Gadoteric acid 0.5mmol/ml (**Clariscan**) – New to market
  - Standard contrast agent
- Gadobutrol 1mmol/ml (**Gadovist**)
  - Vascular/Cardiac contrast agent
- Gadoxetic acid, disodium 0.5mmol/ml (**Primovist**)
  - Liver characterisation contrast agent
- Normally administered under Patient Group Directive (PGD) by an MR Radiographer
- Radiographers cannot administer GBCA to **paediatric patients**
  - Normally **Radiologist** or **Anaesthetist**

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Contrast Agents

Type	Agent	Molecular Weight (g/mol)	Osmolality (mosm /kg)	Viscosity (mPa/s)	Clearance $t_{1/2}$ (hr)
Linear non-ionic	Ominscan	591.7	789	1.4	1.3
	Optimark	661.8	1110	2.0	-
Linear ionic	Magnevist	938.0	1960	2.9	1.6
	Primovist	684.8	688	1.2	0.93
	MultiHance	1058.1	1970	5.3	1.6
Macrocyclic non-ionic	Prohance	558.7	630	1.3	1.57
	Gadovist	604.7	1603	5.0	1.81
Macrocyclic ionic	Dotarem	753.9	1350	2.0	1.6

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Essentials of MRI Safety

Contrast Agents

Nephrogenic systemic fibrosis (NSF)

- NSF is a serious and life-threatening condition characterised by the formation of connective tissue in the skin which becomes thickened, coarse, and hard, sometimes leading to contractures and joint immobility.
- Patients with NSF can have systemic involvement of other organs including the lungs, liver, muscles, and heart.
- Link to gadolinium based contrast agents discovered around year 2000
  - Gadodiamide (Omniscan®) *Linear non-ionic*
  - Today, NSF is unlikely to be seen due to safer GBCA
- Nine gadolinium-containing contrast agents are authorised in the EU to aid MRI of the body and of the blood vessels (magnetic resonance angiography, MRA)

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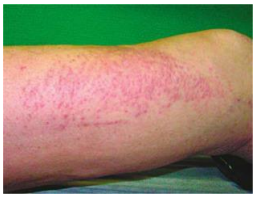
Contrast Agents

Nephrogenic systemic fibrosis (NSF)





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Contrast Agents

Gadolinium deposition disease

Original Research
Neuroradiology

Free Access

High Signal Intensity in the Dentate Nucleus and Globus Pallidus on Unenhanced T1-weighted MR Images: Relationship with Increasing Cumulative Dose of a Gadolinium-based Contrast Material

Tomonori Kanda ✉, Kazunari Ishii, Hiroki Kawaguchi, Kazuhiro Kitajima, Daisuke Takenaka

Author Affiliations

Published Online: Dec 7 2013 | https://doi.org/10.1148/radiol.13131669

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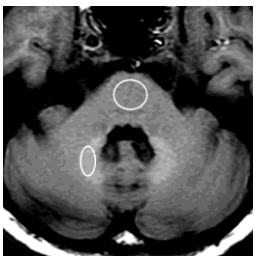
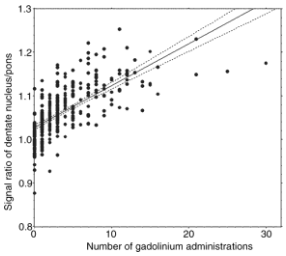
Contrast Agents

Gadolinium deposition disease





Remarkable people. Extraordinary place.

Contrast Agents

Gadolinium deposition disease

› Magn Reson Imaging. 2016 Dec;34(10):1383-1390. doi: 10.1016/j.mri.2016.07.016. Epub 2016 Aug 13.

Gadolinium deposition disease: Initial description of a disease that has been around for a while

Richard C Semelka [1], Joana Ramalho [2], Ami Vakharia [3], Mamdoh AlObaidy [4], Lauren M Burke [3], Michael Jay [5], Miguel Ramalho [6]

Affiliations + expand

PMID: 27530966 DOI: 10.1016/j.mri.2016.07.016

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Contrast Agents

Gadolinium deposition disease

ORIGINAL ARTICLE

Gadolinium-Based MRI Contrast Agents Induce Mitochondrial Toxicity and Cell Death in Human Neurons, and Toxicity Increases With Reduced Kinetic Stability of the Agent

Bower, Danielle V. MD, PhD*,†; Richter, Johannes K. MD*; von Tengg-Kobligk, Hendrik MD*,†; Heverhagen, Johannes T. MD, PhD*,†; Runge, Val M. MD*,†

Author Information

Investigative Radiology: August 2019 - Volume 54 - Issue 8 - p 453-463
doi: 10.1097/RLI.0000000000000567

Remarkable people. Extraordinary place.

Contrast Agents

Gadolinium deposition disease

Review > Clin Toxicol (Phila). 2020 Mar;58(3):151-160. doi: 10.1080/15563650.2019.1681442. Epub 2019 Oct 30.

Gadolinium-based contrast agents – what is the evidence for 'gadolinium deposition disease' and the use of chelation therapy?

Kerry A Layne [1 2 3], David M Wood [1 2 3], Paul I Dargan [1 2 3]

- "There is currently no published information from well-designed clinical studies that support a link between gadolinium deposition and the development of clinical sequelae in patients with normal renal function."
- "Clinicians should exercise caution when considering whether or not gadolinium is of relevance in patients reporting symptoms after administration of gadolinium-based contrast agents."

Remarkable people. Extraordinary place.

Contrast Agents

Gadolinium deposition disease

Gadolinium Tissue Distribution in a Large-Animal Model after a Single Dose of Gadolinium-based Contrast Agents

Henning Richter*, Patrick Bücker*, Louise Françoise Martin, Calvin Dunker, Stefanie Fingerhut, Anna Xia, Agnieszka Karol, Michael Sperling, Uwe Karst, ... Show all authors

* H.R. and P.B. contributed equally to this work.

Author Affiliations

Published Online: Sep 21 2021 | https://doi.org/10.1148/radiol.2021210553

At 10 weeks after injection, linear GBCAs resulted in highest mean gadolinium concentrations in the kidney (502 ng/g [95% CI: 270, 734]) and liver (445 ng/g [95% CI: 202, 687]), while low concentrations were found in the deep cerebellar nuclei (DCN) (30 ng/g [95% CI: 20, 41]). Tissue concentrations of linear GBCAs were three to 21 times higher compared with those of macrocyclic GBCAs. Administered macrocyclic

Ten weeks after one injection of a clinically relevant dose of gadolinium-based contrast agents, the liver and kidney appeared to be reservoirs of gadolinium; however, despite gadolinium presence, no tissue injury was detected.

Remarkable people. Extraordinary place.

Contrast Agents

Screening

Are you allergic to anything? Do you suffer from hay fever?			
Do you have asthma that is not well controlled?			
Do you have any kidney problems?			
Are you waiting for a liver transplant?			

- All relate to the use of gadolinium based contrast agents (GBCA)

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Contrast Agents

Advice for healthcare professionals

The following risk-minimisation measures should be used for gadolinium-containing contrast agents for:

- **Renal-function monitoring** - this should be tested in all patients receiving high-risk agents, and is advisable for patients receiving medium-risk or low-risk agents. Important to screen patients aged 65 years or older
- **Renal Impairment** - for patients with severe renal impairment (glomerular filtration rate [GFR] <30 mL/min/1·73m^2), use of a high-risk agent is contraindicated
- If use of a medium-risk agent cannot be avoided or if it is necessary to use a low-risk agent, a single lowest dose possible can be used and should not be repeated for at least 7 days. For patients with moderate renal impairment (GFR 30–59 mL/min/1·73 m^2), if it is necessary to use a high-risk agent a single lowest dose possible can be used and should not be repeated for at least 7 days

Remarkable people. Extraordinary place.

https://www.gov.uk/government/publications/safety-guidelines-for-magnetic-resonance-imaging-equipment-in-clinical-use

Contrast Agents

Advice for healthcare professionals

- **Perioperative Liver-Transplantation Period** - use of a high-risk agent is contraindicated. If use of a medium-risk agent cannot be avoided or if it is necessary to use a low-risk agent, a single lowest dose possible can be used and should not be repeated for at least 7 days neonates - use of a high-risk agent is contraindicated. For medium-risk or low-risk agents, use a single lowest possible dose and do not repeat for at least 7 days
- **Infants** - use a single lowest dose of agent possible and do not repeat for at least 7 days
- **Breastfeeding** - discontinue for at least 24 hours after use of a high-risk agent
- The decision of whether to continue or suspend breastfeeding for 24 hours after use of a medium-risk or low-risk agent should be at your discretion in consultation with the mother

Remarkable people. Extraordinary place.

https://www.gov.uk/government/publications/safety-guidelines-for-magnetic-resonance-imaging-equipment-in-clinical-use

Contrast Agents

Advice for healthcare professionals

- **Pregnancy** - use of any gadolinium-containing contrast agent is not recommended unless absolutely necessary
- **Haemodialysis** - there is no evidence to support the initiation of haemodialysis for prevention or treatment of NSF in patients not already undergoing haemodialysis
- **Recording of the Agent Used** - when they become available, peel-off tracking labels found on the vials, syringes, or bottles should be stuck onto the patient record to accurately record the name of the gadolinium contrast agent used. The dose used should also be recorded reporting of suspected adverse reactions - on a Yellow Card for any suspected adverse reactions, including NSF, to gadolinium-containing contrast agents

Remarkable people. Extraordinary place.

https://www.gov.uk/government/publications/safety-guidelines-for-magnetic-resonance-imaging-equipment-in-clinical-use

Contrast Agents

NHS Hull University Teaching Hospitals NHS Trust

ESUR Guidelines on **Contrast Agents**

European Society of Urogenital Radiology

2019 ESUR Guidelines V10.0

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Contrast Agents

NHS Hull University Teaching Hospitals NHS Trust

B.8. HOW LONG SHOULD THERE BE BETWEEN TWO GADOLINIUM-BASED CONTRAST AGENT INJECTIONS FOR ROUTINE EXAMINATIONS?

1. **Patients with normal or moderately reduced renal function (GFR > 30 ml/min/1.73 m²).**
   75 % of extracellular gadolinium-based contrast agents are excreted by 4 hours after administration.
   There should be 4 hours between injections of gadolinium-based contrast agent.
2. **Patients with severely reduced renal function (GFR < 30 ml/min/1.73 m²) or on dialysis.**
   There should be 7 days between injections of gadolinium-based contrast agent

Remarkable people. Extraordinary place.

Contrast Agents

NHS Hull University Teaching Hospitals NHS Trust

B.6. CAN IODINE- AND GADOLINIUM-BASED CONTRAST AGENTS SAFELY BE GIVEN ON THE SAME DAY FOR ROUTINE EXAMINATIONS?

Efficient practice may involve giving iodine- and gadolinium-based contrast agents for enhanced CT and MR on the same day. To reduce any potential for nephrotoxicity the following are recommended:

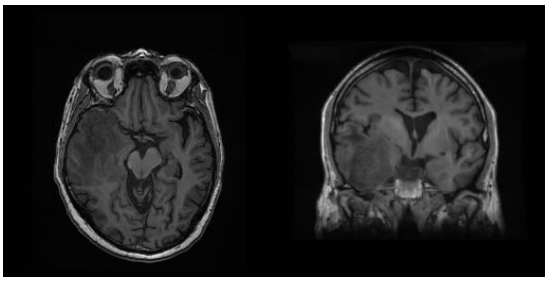
1. **Patients with normal renal function or moderately reduced (GFR > 30 ml/min/1.73 m²).**
   75 % of both gadolinium- and iodine-based contrast agents are excreted by 4 hours after administration. There should be 4 hours between injections of iodine- and gadolinium-based contrast agents.
2. **Patients with severely reduced renal function (GFR < 30 ml/min/1.73 m² or on dialysis).**
   There should be 7 days between injections of iodine- and gadolinium-based contrast agents.

Note: *Gadolinium-based contrast agents attenuate X-rays well and may be misinterpreted on CT when they have been excreted into the urinary tract. For abdominal examinations, enhanced CT should be done before enhanced MR. For chest and brain examinations, either CT or MR may be done first.*

Remarkable people. Extraordinary place.

Contrast Agents

NHS Hull University Teaching Hospitals NHS Trust



T1 Pre-contrast

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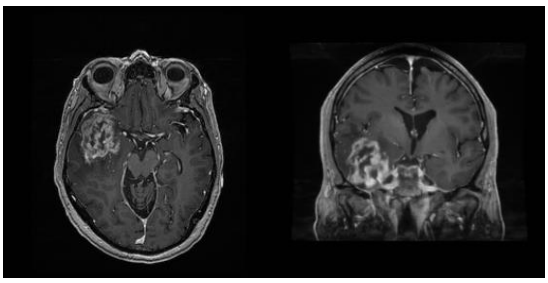
Contrast Agents

NHS Hull University Teaching Hospitals NHS Trust



T1 Post-contrast

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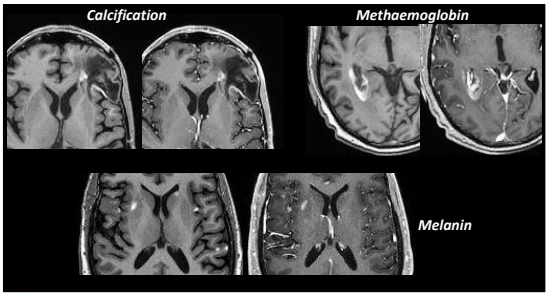
Tissue Contrast

T_1

NHS Hull University Teaching Hospitals NHS Trust



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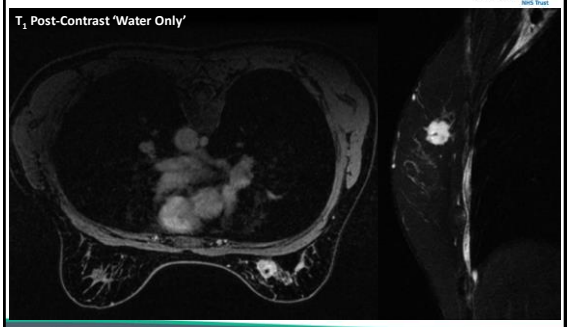
Contrast Agents

T_1 Post-Contrast 'Water Only'



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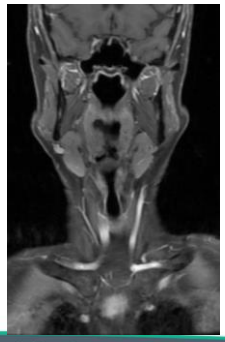
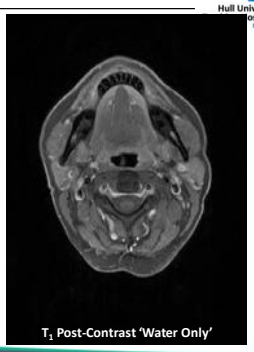
Contrast Agents

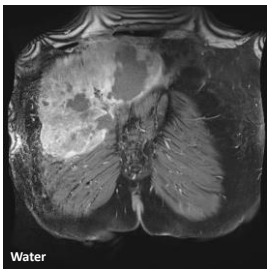




T_1 Post-Contrast 'Water Only'

Remarkable people. Extraordinary place.

Contrast Agents



Water



Fat

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Magnetic Properties

- **Diamagnetic** materials have a weak, negative susceptibility to magnetic fields. Diamagnetic materials are slightly repelled by a magnetic field and the material does not retain the magnetic properties when the external field is removed.
- I.e. calcium

- **Paramagnetic** materials have a small, positive susceptibility to magnetic fields. These materials are slightly attracted by a magnetic field and the material does not retain the magnetic properties when the external field is removed.
- i.e. Gadolinium

- **Ferromagnetic** materials have a large, positive susceptibility to an external magnetic field. They exhibit a strong attraction to magnetic fields and are able to retain their magnetic properties after the external field has been removed.
- Iron, nickel, and cobalt are examples of ferromagnetic materials.

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Contrast Agents

Superparamagnetic Iron Oxide (SPIO)

- These particles have a predominant T_2 effect (magnetic susceptibility) and produce a drop in signal namely in T_2* weighting.

- This hyposignal is found in areas of normal tissue (reticuloendothelial system), which takes up the iron oxide particles, as opposed to zones with metastatic invasion.

- SPIO agent Ferumoxytol (Feraheme®) is approved for the treatment of iron deficiency in adult chronic kidney disease patients.

- Ferumoxytol is comprised of iron oxide particles surrounded by a carbohydrate coat, and it is being explored as a potential imaging approach for evaluating lymph nodes and certain liver tumours.

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Contrast Agents

Superparamagnetic Iron Oxide (SPIO)



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http://mriquestions.com/feridex-and-iron-oxides.html

Question

- Which of the following describes a STIR spin echo sequence?

  A) 90°-180°
  B) 180°- 90°-180°
  C) 90°-180°-180°
  D) 90°-180°-180°-180°

- Should a STIR sequence be used following a gadolinium based contrast agent?

  A) True
  B) False

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Question

In magnetic resonance imaging the following are true:

A. A T_1-weighted image would have a TR of 1000ms and a TE of 100ms

B. A T_2-weighted imager might have a TR of 400 ms and a TE of 15ms

C. Water and fluids such as CSF appear bright on T_2

D. Cortical bone appears white on PD weighted images

E. Short tau inversion recovery (STIR) is a type of fat suppression

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Question

In magnetic resonance imaging the following are true:

A. Within a single TR, following collection of PD-weighted data the echo can be re-sampled after another TE to provide T_2-weighted data

B. Inversion recovery is used to accentuate subtle differences in T_1 weighted between tissues

C. STIR sequencing is used to enhance tissue boundaries

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Question

The following are true about Gadolinium DPTA :

A. is largely excreted by glomerular filtration

B. reduces both the T_1 and T_2 relaxation time

C. gives an increased signal from arteries

D. has a half-life in blood of less than 60 minutes

E. is a superparamagnetic agent

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