Quantifying brain structure and function with MRI

Turku PET Centre Brain Imaging Course 4.-5.10.2017
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Outline

- Basics of NMR
- Imaging techniques:
  - fMRI
  - MR perfusion
  - Diffusion
  - T1 and T2 Mapping

What is MR imaging?

The **patient** is placed in a **magnet**,

A radio wave is sent in

The radio wave is turned off

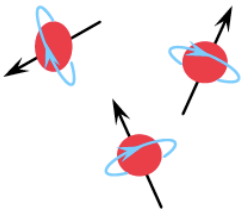
The patient **emits a signal** which is received

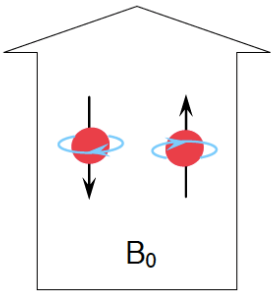
Picture is reconstructed

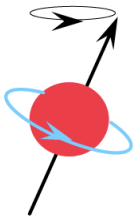
MRI friendly elements

Isotope	Symbol	Spin Quantum number	Gyro Magnetic Ratio (MHz/T)
Hydrogen	1H	1/2	42.6
Carbon	13C	1/2	10.7
Oxygen	17O	5/2	5.8
Fluorine	19F	1/2	40.0
Sodium	23Na	3/2	11.3
Magnesium	25Mg	5/2	2.6
Phosphorus	31P	1/2	17.2
Sulphur	33S	3/2	3.3
Iron	57Fe	1/2	1.4

What happens to the protons when we put a patient in the scanner?

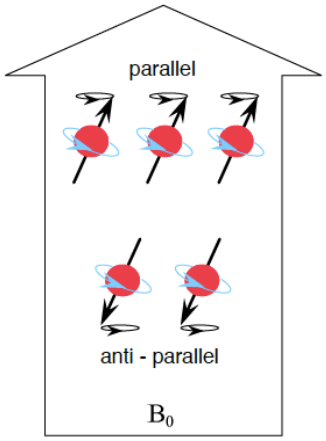


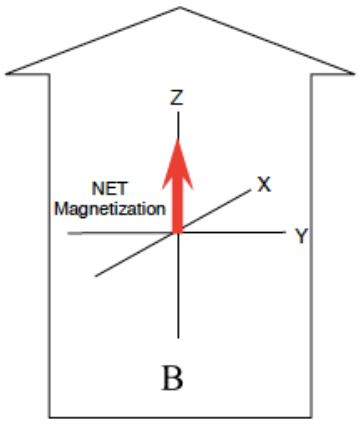




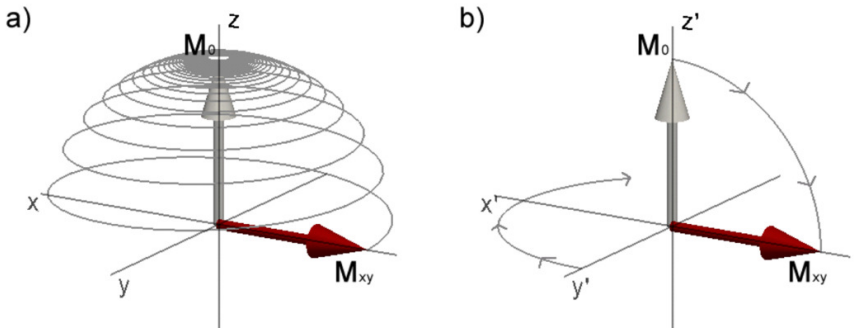
precess at the Larmor frequency

$$\omega_0 = \gamma B_0$$

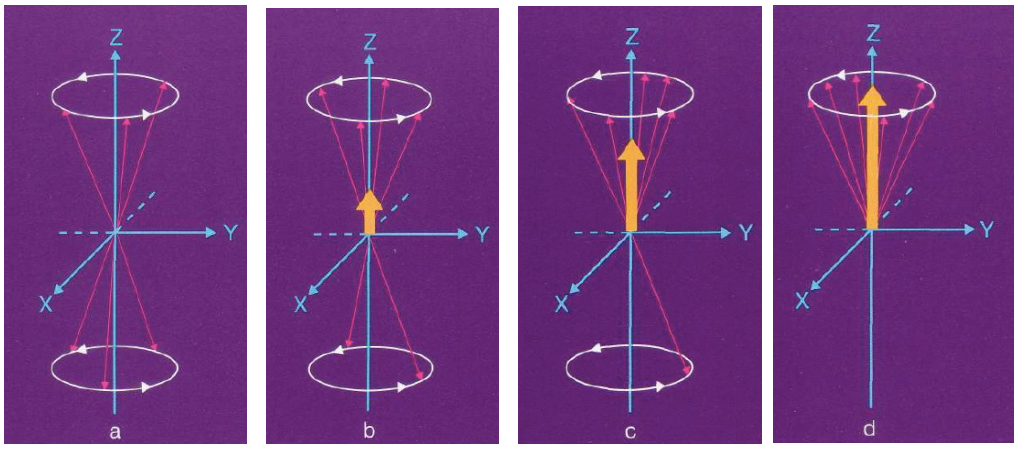




Excitation (A radio wave is sent in)

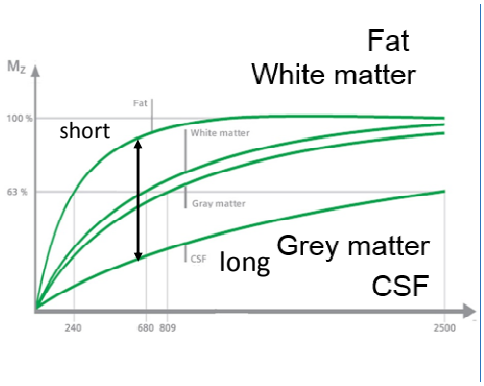


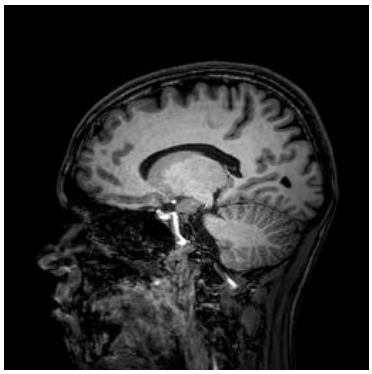
T1 relaxation (spin –lattice relaxation)



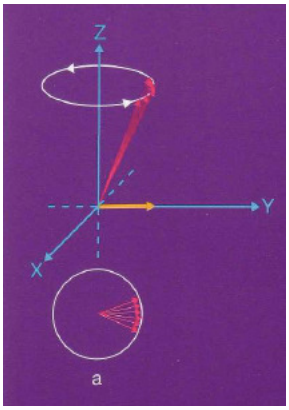
T1 contrast

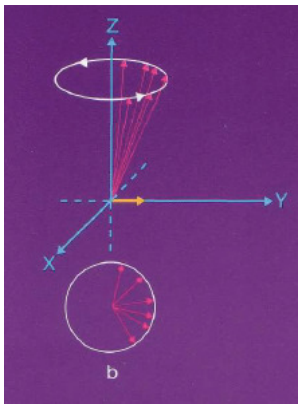
contrast

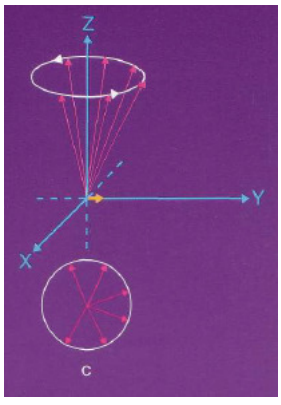




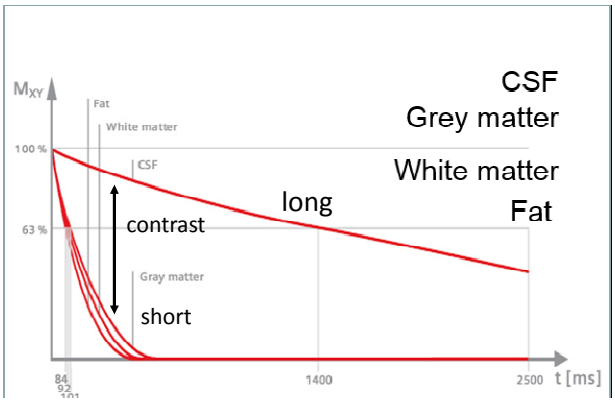
T2 relaxation (spin – spin relaxation)

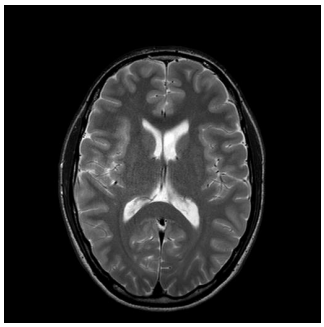






T2 contrast

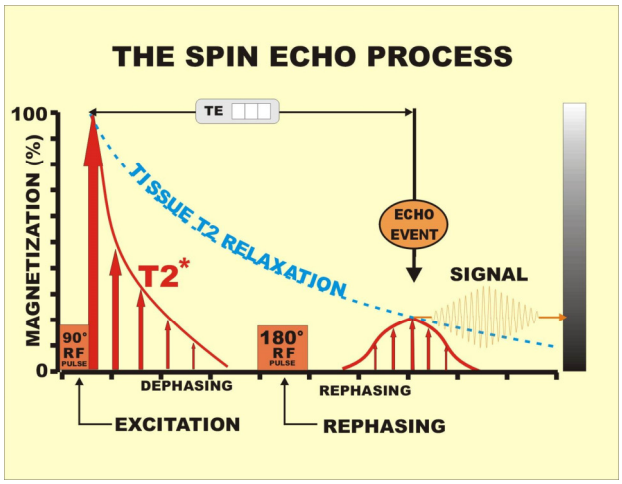




Two reasons for dephasing in x-y plane

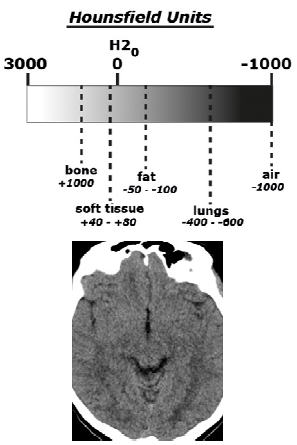
Spin-spin interaction →
T2 contrast

Local magnetic field inhomogeneities →
T2* contrast (even faster decay)

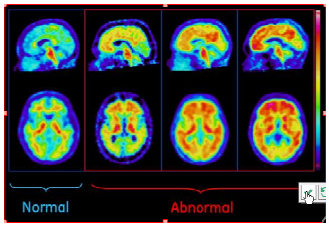


MR image units?

CT

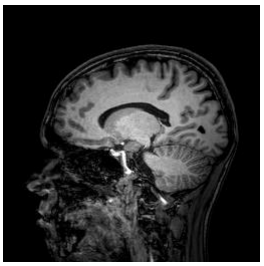


PET



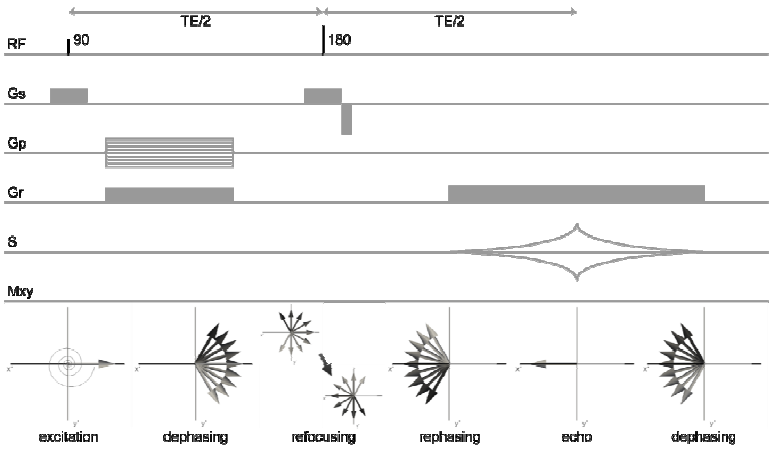
Bq/ml

MRI



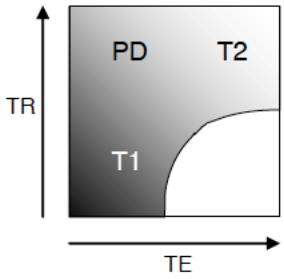
a.u.

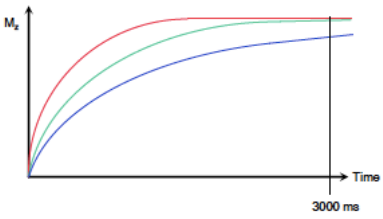
The basic spin echo sequence

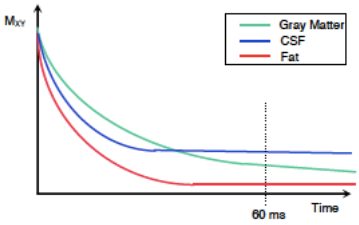


Spin Echo contrast

- A short TR & short TE = T1 weighted contrast
- A long TR & short TE = PD contrast
- A long TR & long TE = T2 weighted contrast.





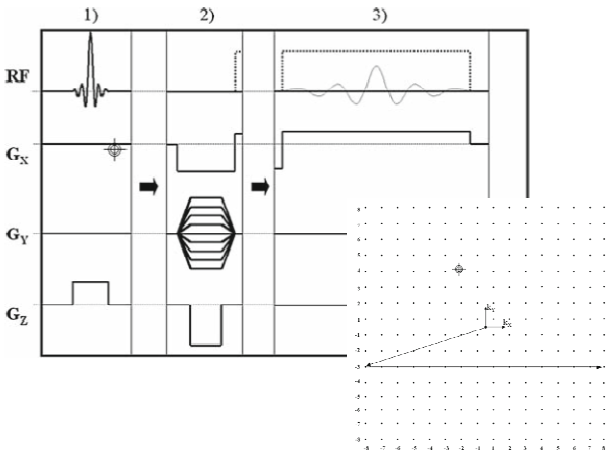


GRE -sequence

1) A slice selective RF excitation pulse

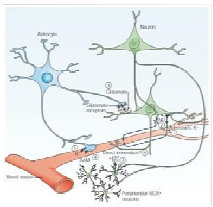
2) Phase encoding

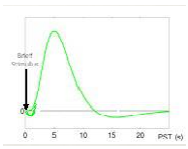
3) readout



fMRI

fMRI acquisitions utilize the fact that regional brain activation results in a local increase in blood oxygenation





Neural Activity

Metabolism + energy consumption

Regional brain activation results in a local increase in blood oxygenation

Functional imaging

What is the difference between deoxyHb and oxyHb?

DeoxyHb paramagnetic

strong field inhomogeneities

→ Fast dephasing

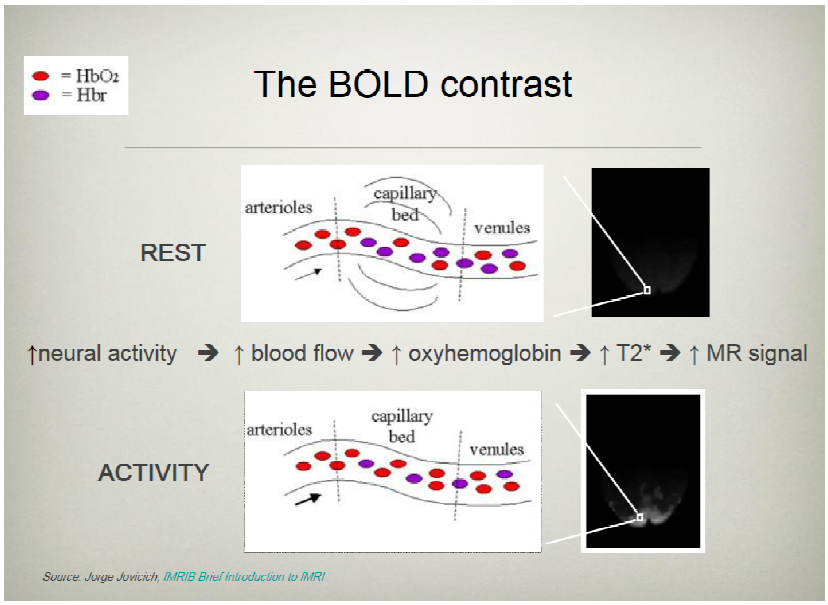
Fast T2*

OxyHb diamagnetic

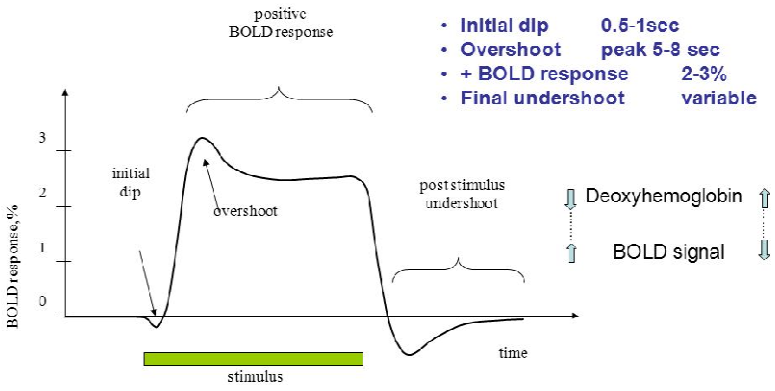
weak field inhomogeneities

→ Slower dephasing

slower T2*

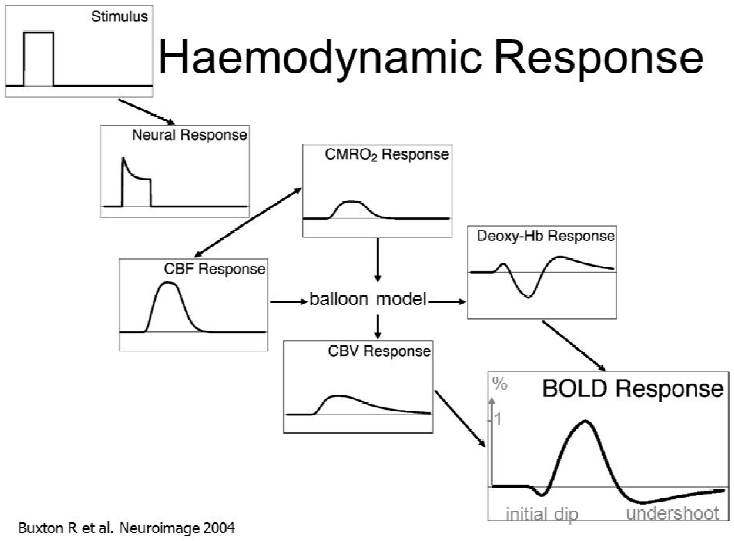


fMRI Bold Response Model



- **Initial dip** 0.5-1sec
- **Overshoot** peak 5-8 sec
- **+ BOLD response** 2-3%
- **Final undershoot** variable

Figure 8.1. from textbook.

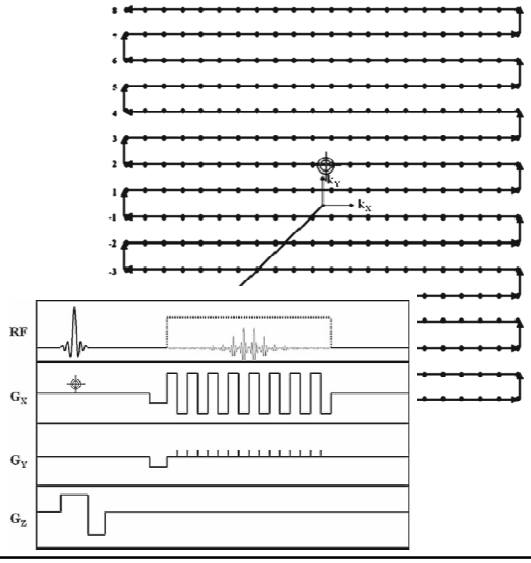


fMRI – how to image

Single-shot sequences: an entire slice are acquired in one readout window after one excitation.

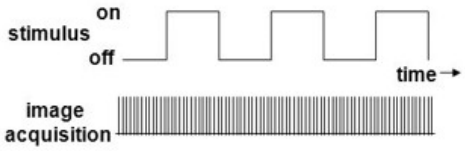
Blipped echo-planar imaging (EPI) pulse sequence. Readout gradients are reversed following readout of each kx line, along with a small increment of k-space in ky direction, or a "blip" in Gy.

Limited resolution from T2 and T2∗ signal decay during the signal readout

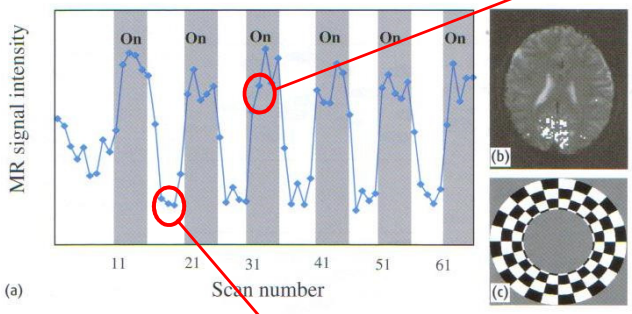


fMRI Study Designs

- Main types of study design:
  - Block design
    - Consecutive tasks in pre-defined time intervals
  - Event-related
    - Stimuli (events or trials) are presented
    - Higher image acquisition rates (1/sec)



Example of fMRI Protocol

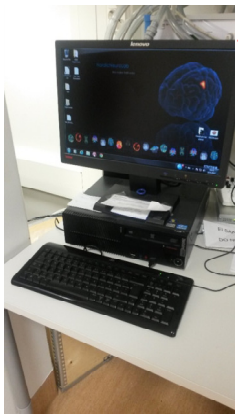


Delay between the stimulus and the vascular changes – might take up to 6 secs

Initial "Dip" – decrease in BOLD signal due to O_2 consumption

Christoph Korn and Andrea Dantas presentation:
Basis of the BOLD Signal
Method for dummies 2008

Set-up in Turku PET centre



presentation

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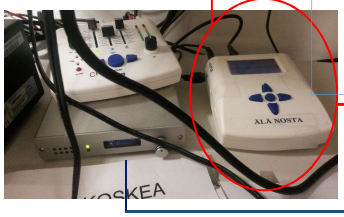
audio

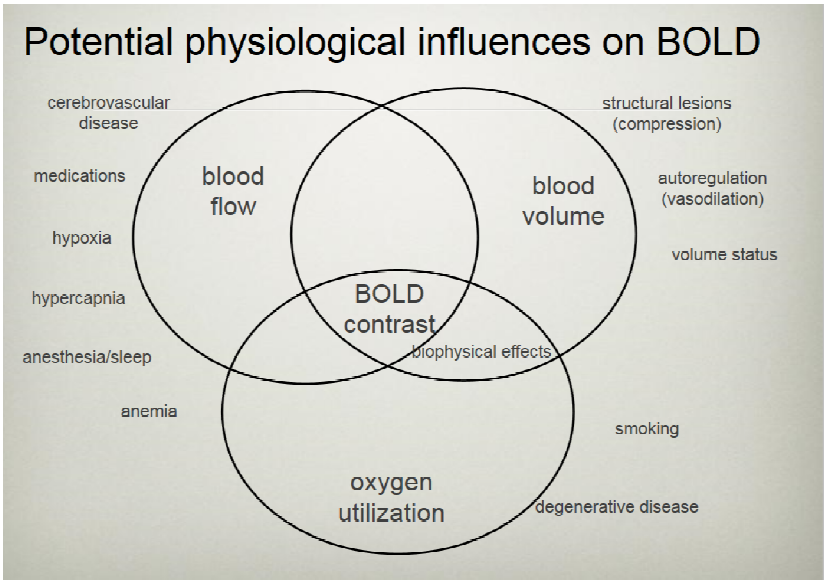


Sync.
simulation

sync

MRI

Response devive



Preuschoff K. Physiological Basis of the BOLD signal

Perfusion Imaging

- Perfusion MRI measures the rate at which blood is delivered to tissue
- Cerebral blood flow (CBF) is the blood supply to the brain in a given time (units: **milliliters per 100 gram per minute**).
- In an adult, CBF is typically 750 millitres per minute or 15% of the cardiac output. This equates to 50 to 54 millilitres of blood per 100 grams of brain tissue per minute
- How to measure:
  - DCE (Dynamic contrast enhanced) = T1 perfusion

    Image dynamically before, during, and after bolus injection of a contrast agent
  - DSC (Dynamic Susceptibility Contrast MRI with bolus tracking of gadolinium chelate) = T2* perfusion

    serial measurement of signal loss during the passage of the bolus through the tissue
  - ASL (Blood is the endogenous contrast agent)

Perfusion MRI Techniques

	DSC	DCE	ASL
Full term	Dynamic susceptibility contrast	Dynamic contrast enhanced	Arterial spin labeling
Bolus handling	Bolus tracking	Bolus passage	Bolus tagging
Acquisition point	First pass of contrast agent	Accumulation of contrast agent	Accumulation of tagged blood
Exogenous or endogenous	Exogenous method	Exogenous method	Endogenous method
Contrast media	Intravenous bolus injection of Gd-based contrast agent	Intravenous bolus injection of Gd-based contrast agent	Without contrast agent
Tracer	Non-diffusible blood pool tracer	Flow or permeability-limited diffusible tracer	Diffusible tracer
Relaxation mechanism	T_2/T_2^* relaxation	T_1 relaxation	Magnetic labeled blood T_1 relaxation
Effect	Increased susceptibility effect	T_1 shortening effect	Blood magnetization inversion
Signal behaviors	Decreased signal	Increased signal	Subtracted signal

Korean J Radiol. 2014 Sep-Oct; 15(5): 554–577.

DSC (Dynamic Susceptibility Contrast)

- Rapid imaging during the first pass of contrast agent.
- T2*-weighted echo-planar imaging (EPI) sequence.
  Acquire the entire brain in 1 or 2 seconds.
- acquisitions is performed before, during, and after injection of contrast agent.

case:

- Gadovist, 0.1ml/kg, 5 ml/s
- EPI: TR 1500ms, 15 slices (4/1.2 mm), FOV 230, matrix 128

(1.5 s interval)

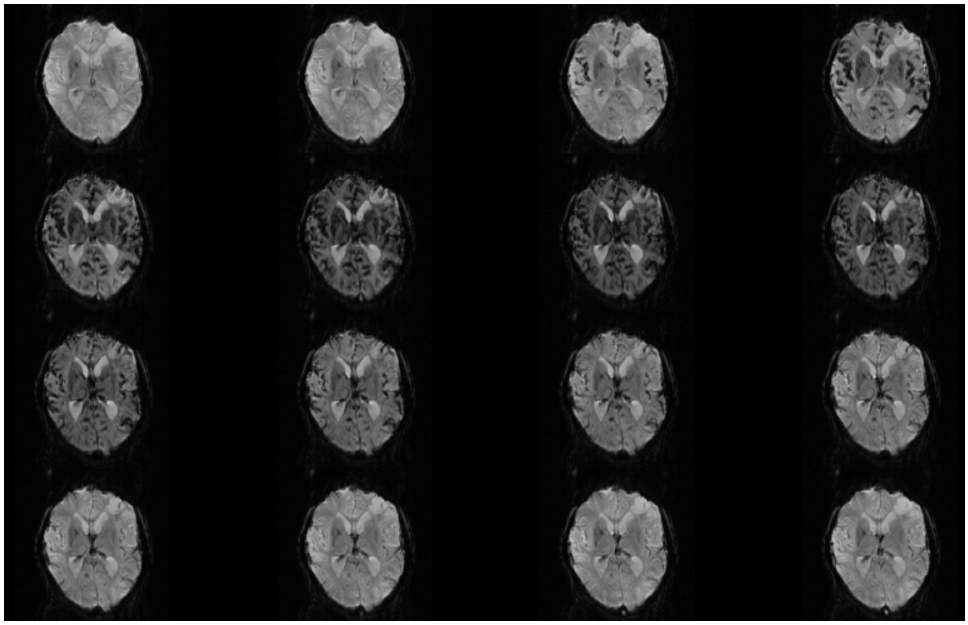
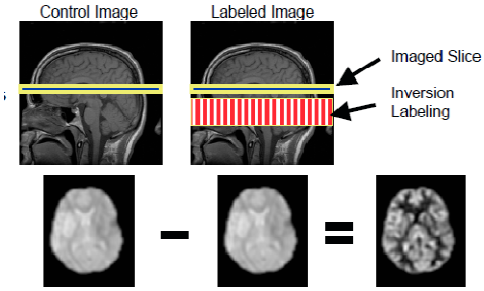


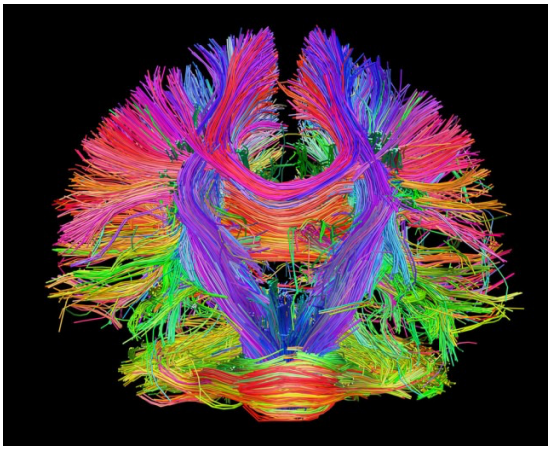
Image Jani Saunavaara

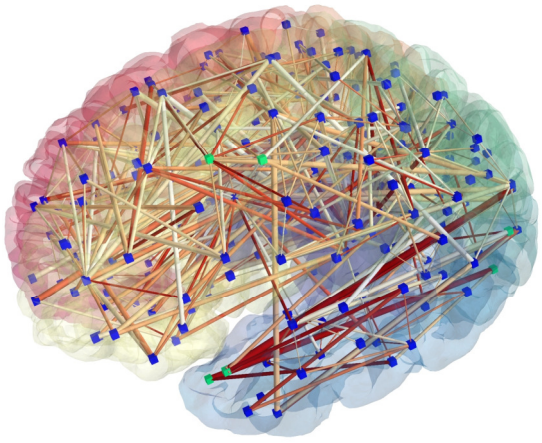
ASL

1. Set-up imaging volume and a label volume (inversion)
2. Wait
3. Image normally
4. Subtract & kinetic modeling



Diffusion tensor imaging

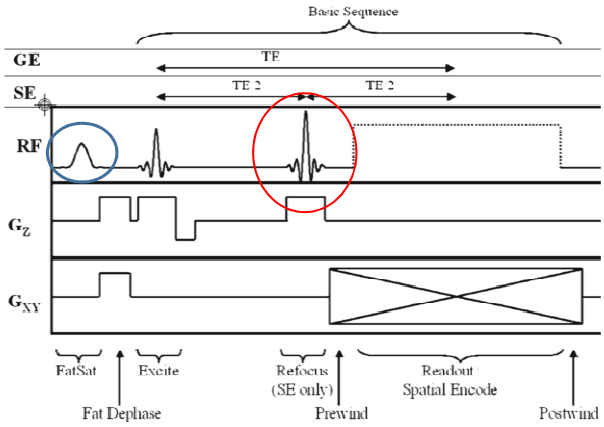




DTI– how to image

A fat saturation pulse

Excitation and refocus pulse



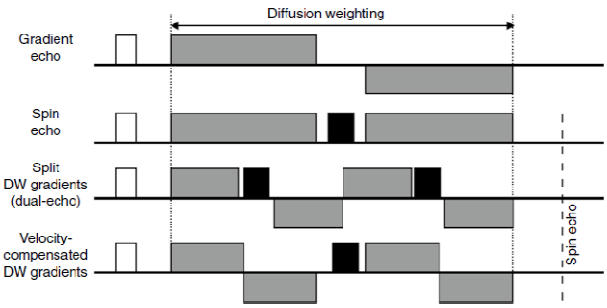
DWI sequence

Rf excitation: white rectangles

Refocusing: black rectangles

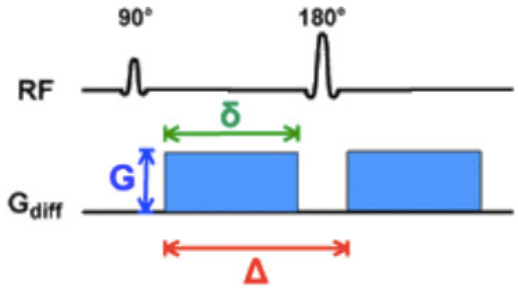
DW gradients are shown in gray.

Basic spin echo sequences add a refocusing pulse, which requires that one DW gradient amplitude be reversed



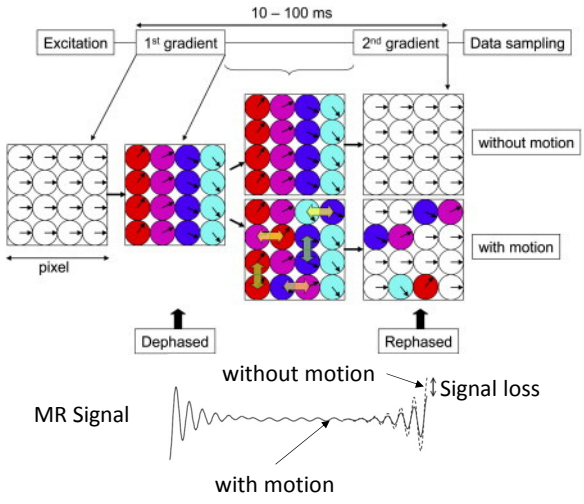
Pipe J. 2009. Pulse Sequences for Diffusion-weighted MRI. In: Johansen-Berg, Behrens ed. Diffusion MRI. Academic Press, p. 21

DW gradients



Stejskal-Tanner pulsed gradient diffusion method.

$$b = \gamma^2 G^2 \delta^2 (\Delta - \delta/3)$$



Susumu M, Jiangyang Z. **Principles of Diffusion Tensor Imaging and Its Applications to Basic Neuroscience Research.** null, Volume 51, Issue 5, 2006, 527–539 http://dx.doi.org/10.1016/j.neuron.2006.08.012

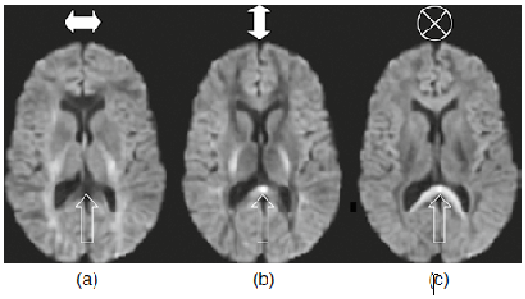
DTI - contrast formation

Dark areas = high apparent diffusivity

lighter areas represent lower apparent diffusivity.

Unfilled arrows: splenium of the corpus callosum

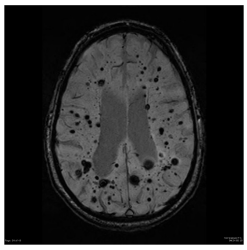
- LR (a): the apparent diffusivity is high
- AP(b) and FH(c): low



Jones D. 2009. Gaussian Modeling of the Diffusion Signal. In: Johansen-Berg, Behrens ed. Diffusion MRI. Academic Press, p. 41

Quantitative Susceptibility Mapping (QSM)

- Local tissue magnetic susceptibility
- traditional hypointensity contrast in SWI or T2* weighted images allow detection of the presence of tissue susceptibility (hypointensity, regional effect, contaminated by blooming artifact.
- The term 'blooming' refers to the fact that lesions appear larger than they actually are
- Blooming is seen:
  - hemosiderin from prior haemorrhage
  - calcification etc.



Case courtesy of Royal Melbourne Hospital, Radiopaedia.org, rID: 13743

QSM in MS (relapsing-remitting MS)

relapsing-remitting MS

Time 1

A) T2-weighted image

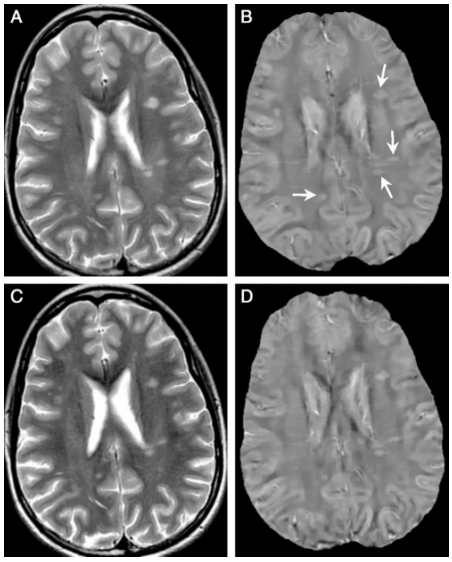
B) QSM at QSM1.

Time 2

C) T2-weighted image

D, QSM at QSM2 (6 months later).

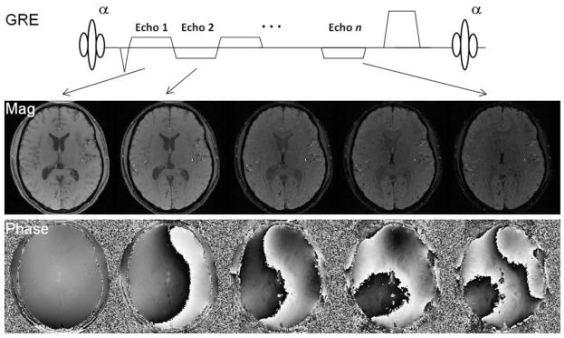
All lesions (arrows) were QSM hyperintense at both Time 1 and Time 2, which indicated that their susceptibilities were higher than normal appearing WM.



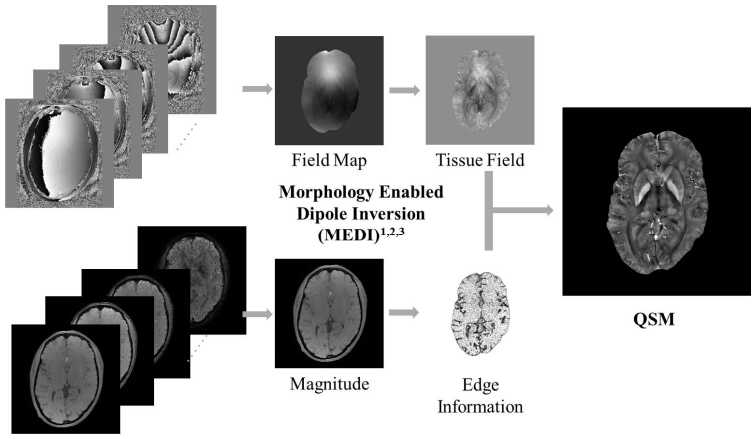
QSM

Sequence:

- 3D multi-echo gradient echo
- flow compensation ON
- The real & imaginary images or magnitude & phase images
- Parallel imaging can be turned on to reduce scan time

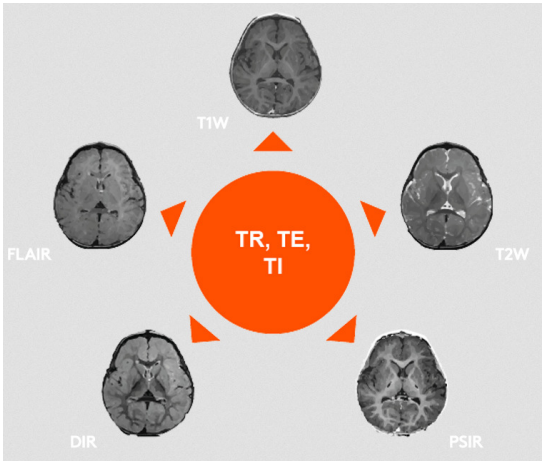


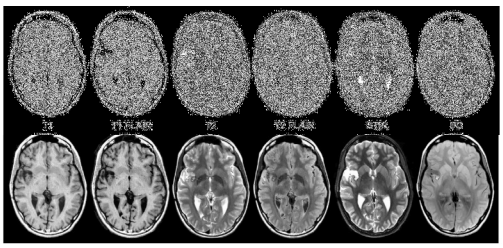
QSM



1. de Rochefort et al, MRM 2010;63(1):194-206; 2. Liu et al, Neuroimage 2012;59(3):2560-8; 3. Liu et al, MRM 2013:69(2):467-76

T1 and T2 mapping (syntheticMR)



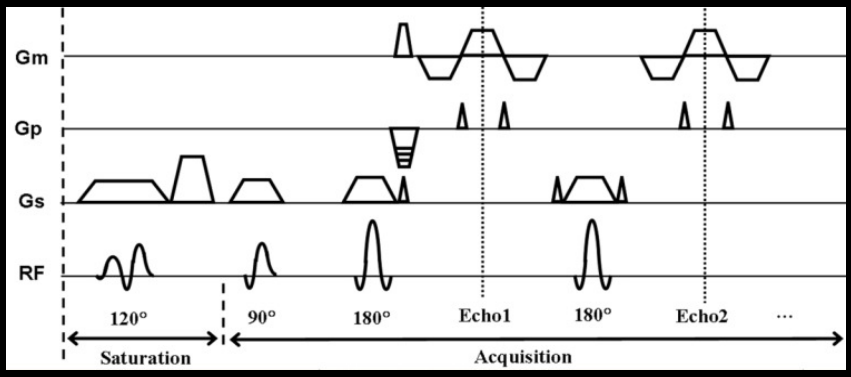


ON-LINE FIG 2. Resection with chronic hemorrhage shown on conventional (*upper row*) and synthetic (*lower row*) views of similar legibility and quality in a 23-year-old woman.

www.syntheticmr.com

MAGiC … **MAG**netic resonance **i**mage **C**ompilation

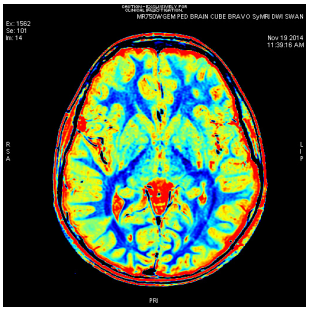
Datan keräys erikoissekvenssillä



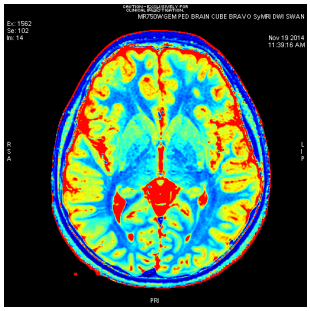
- MDME (multi-delay multi-echo) FSE sequence acquires raw MDME images

Kiitokset diasta: GE Healthcare

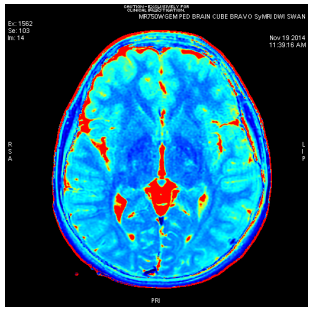
Quantitative information



Magic PD map



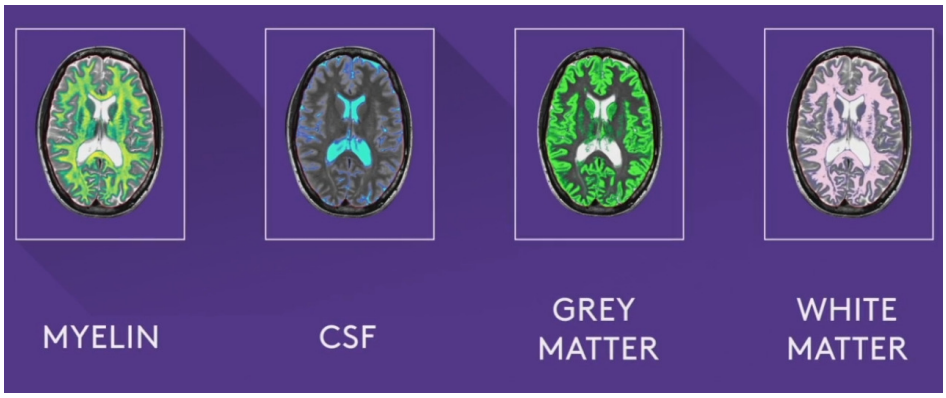
Magic T1 map



Magic T2 map

Thanks for the images
Jani Saunavaara

Anatomical information



Thanks for the images
Jani Saunavaara