Advanced MRI techniques

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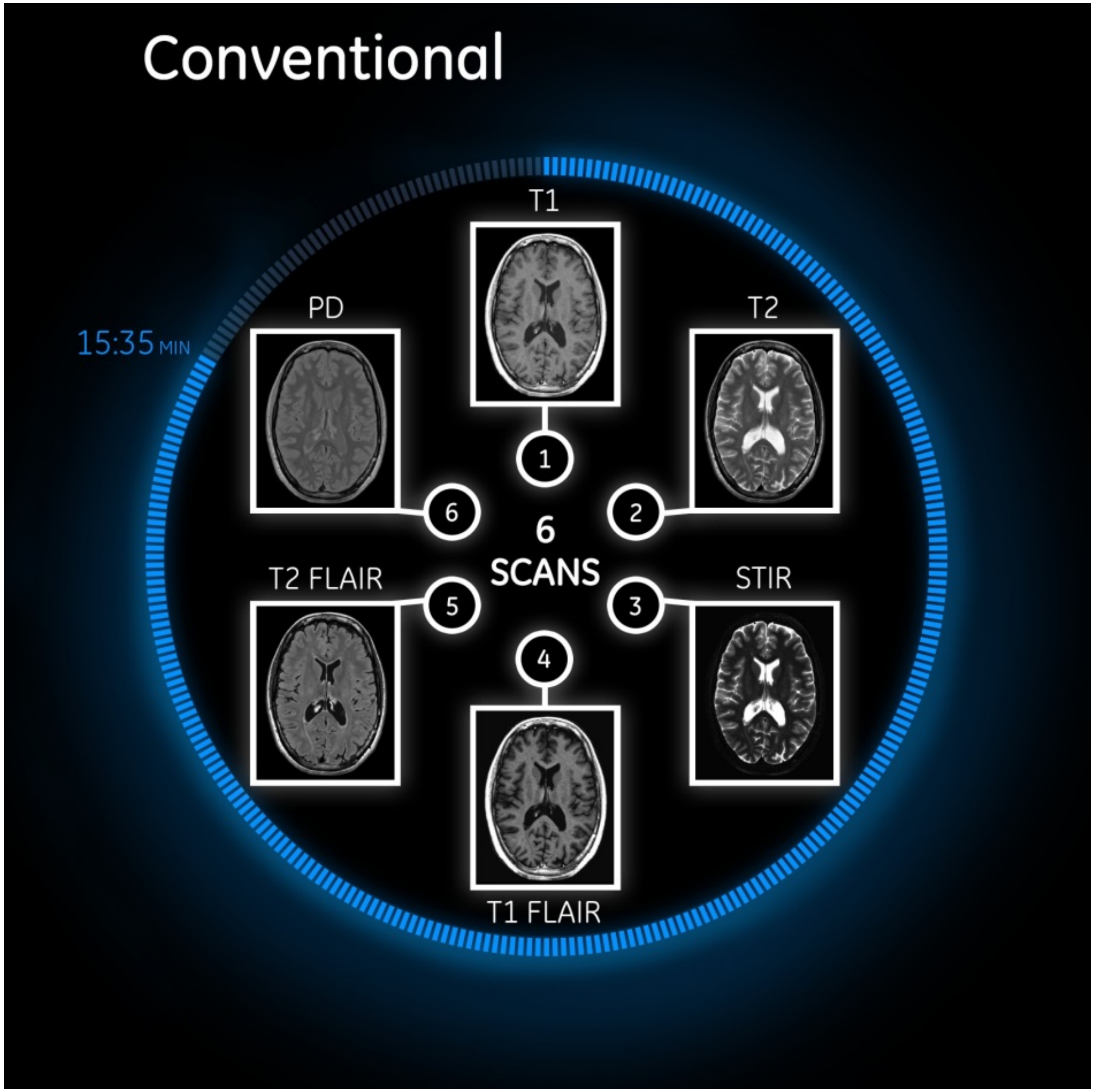
MAGnetic resonance image Compilation (MAGiC)

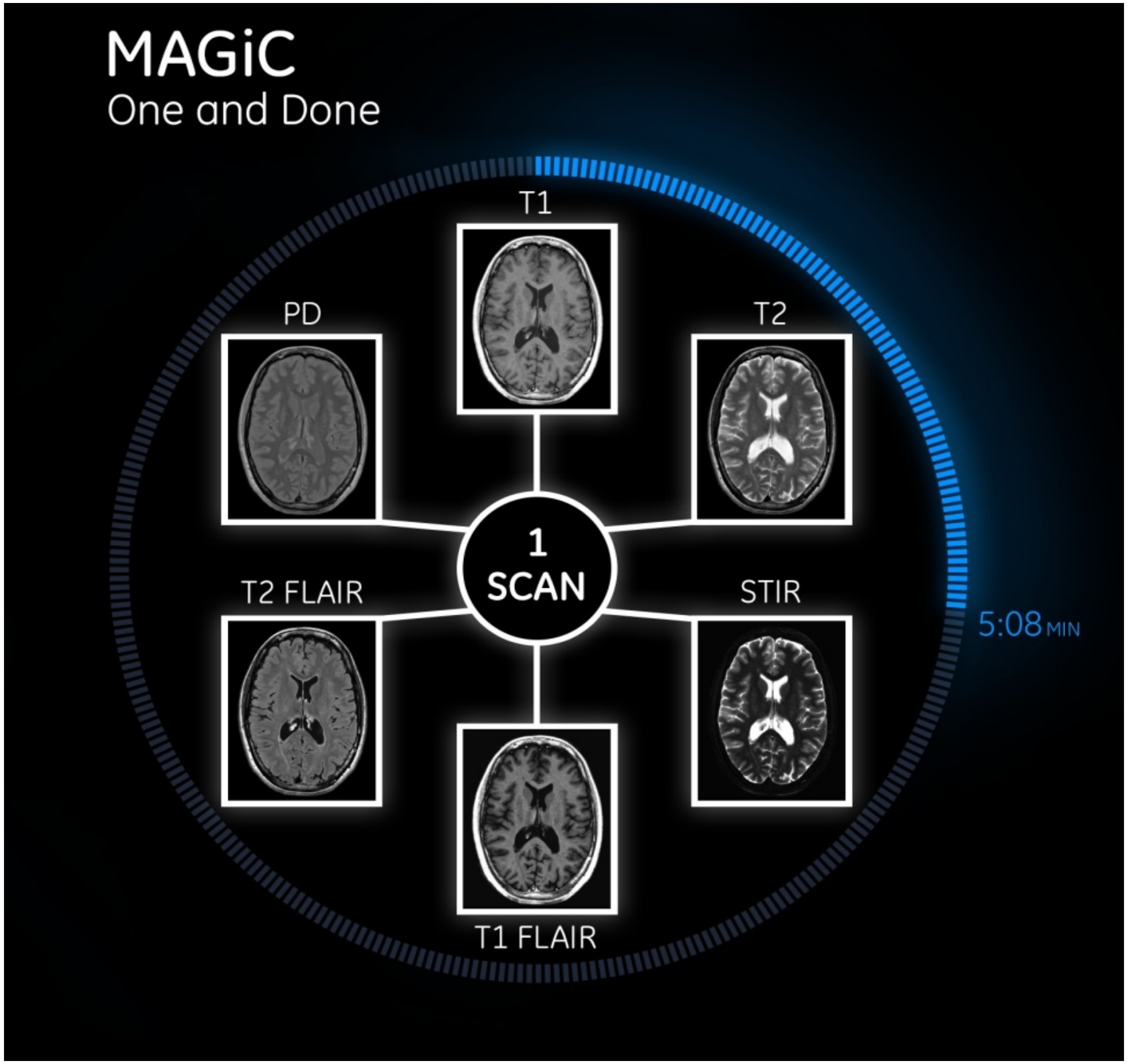
- Product from Swedisch company called SyntheticMR AB:n and GE uses a product name MAGiC
- Currently optimized for brain imaging.

- *Synthetic MRI is general name for technique*

Traditional way

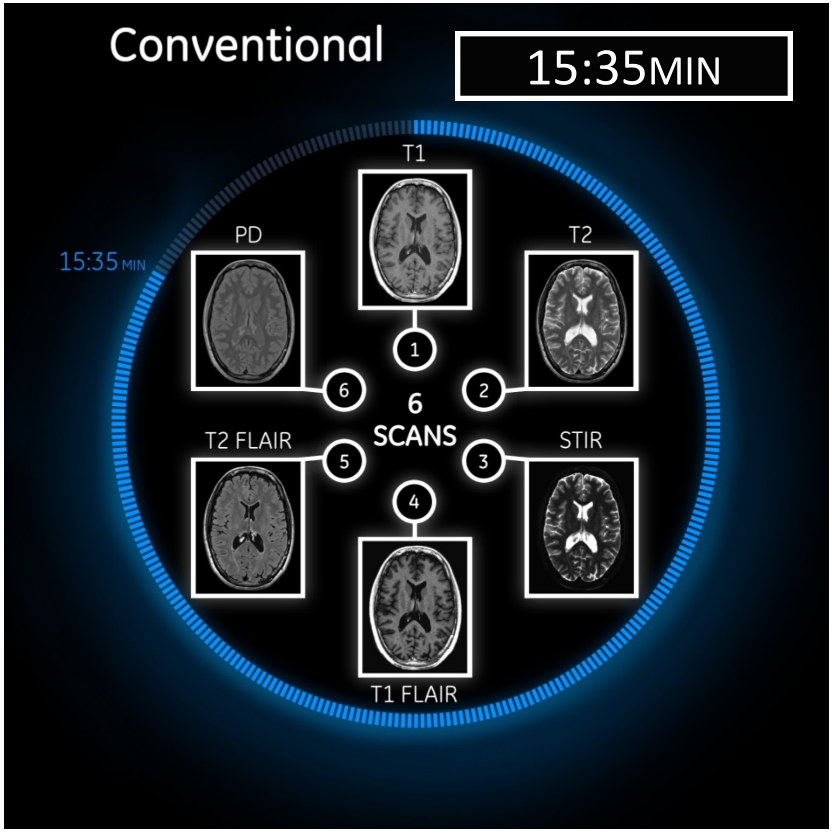


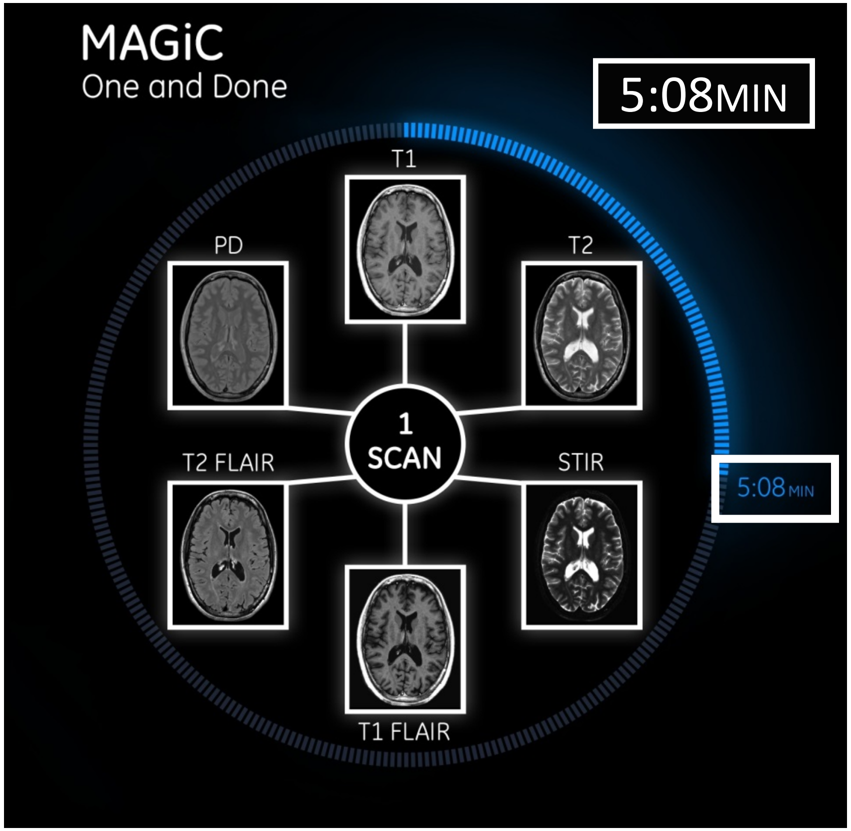
“New way”



MAGiC
One and Done
T1
PD
T2
1
SCAN
T2 FLAIR
STIR
5:08 MIN
T1 FLAIR

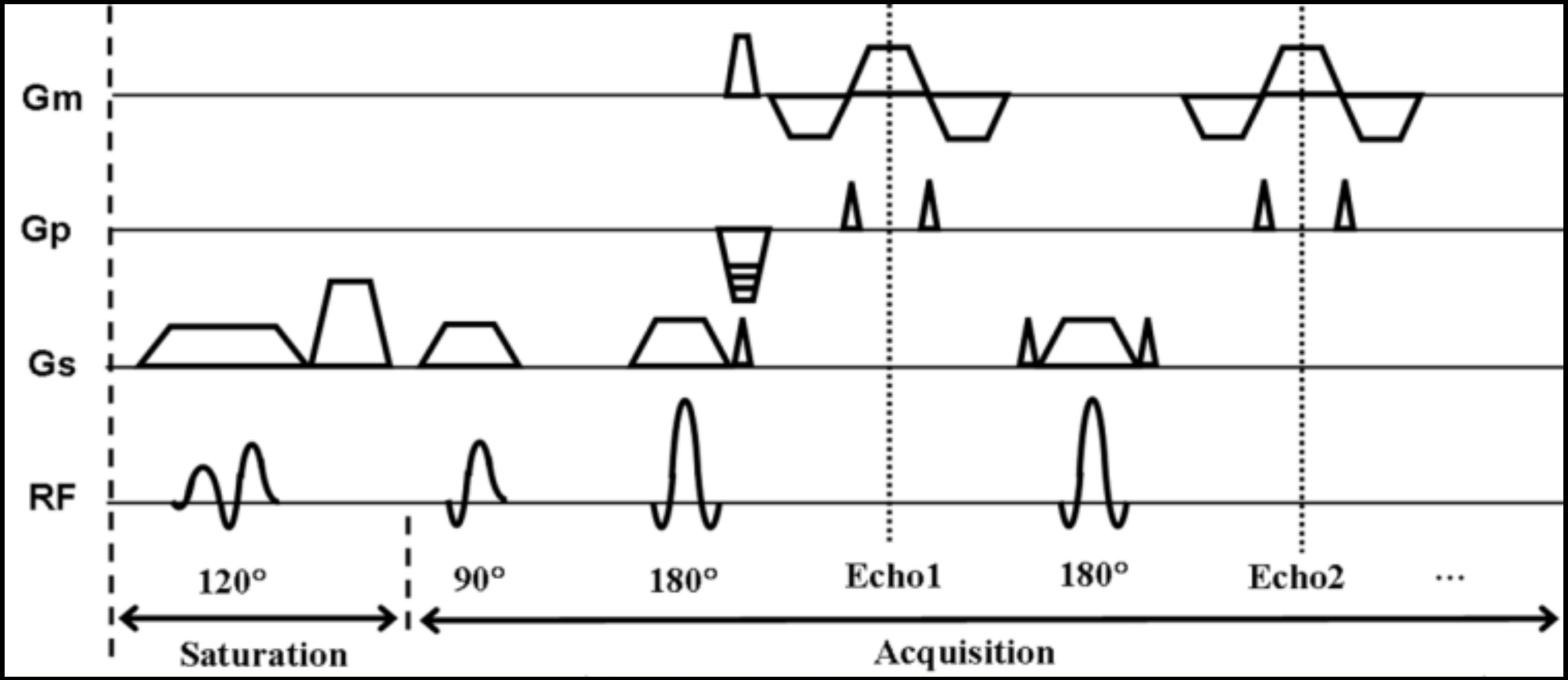
Potential save in scan time is <u>significant</u>





MAGiC … MAGnetic resonance image Compilation

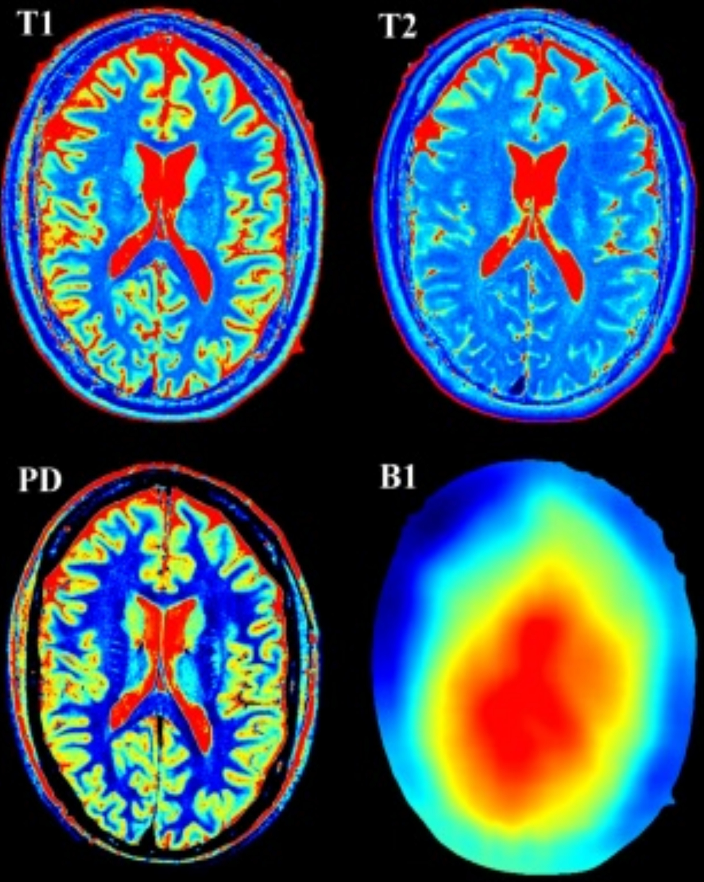
Data is collected using special sequence



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

MAGiC … MAGnetic resonance image Compilation

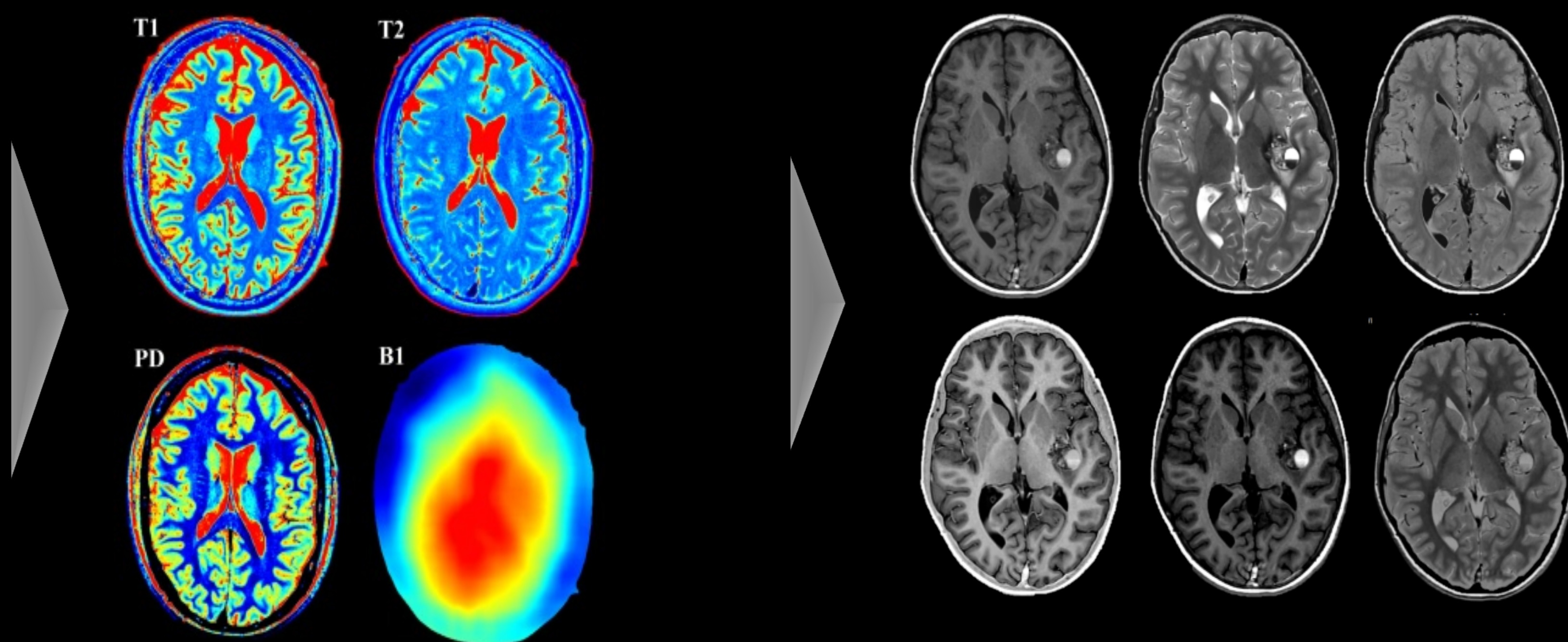
MAGiC Processing



- T1, T2, PD and B1 maps are calculated from measured data

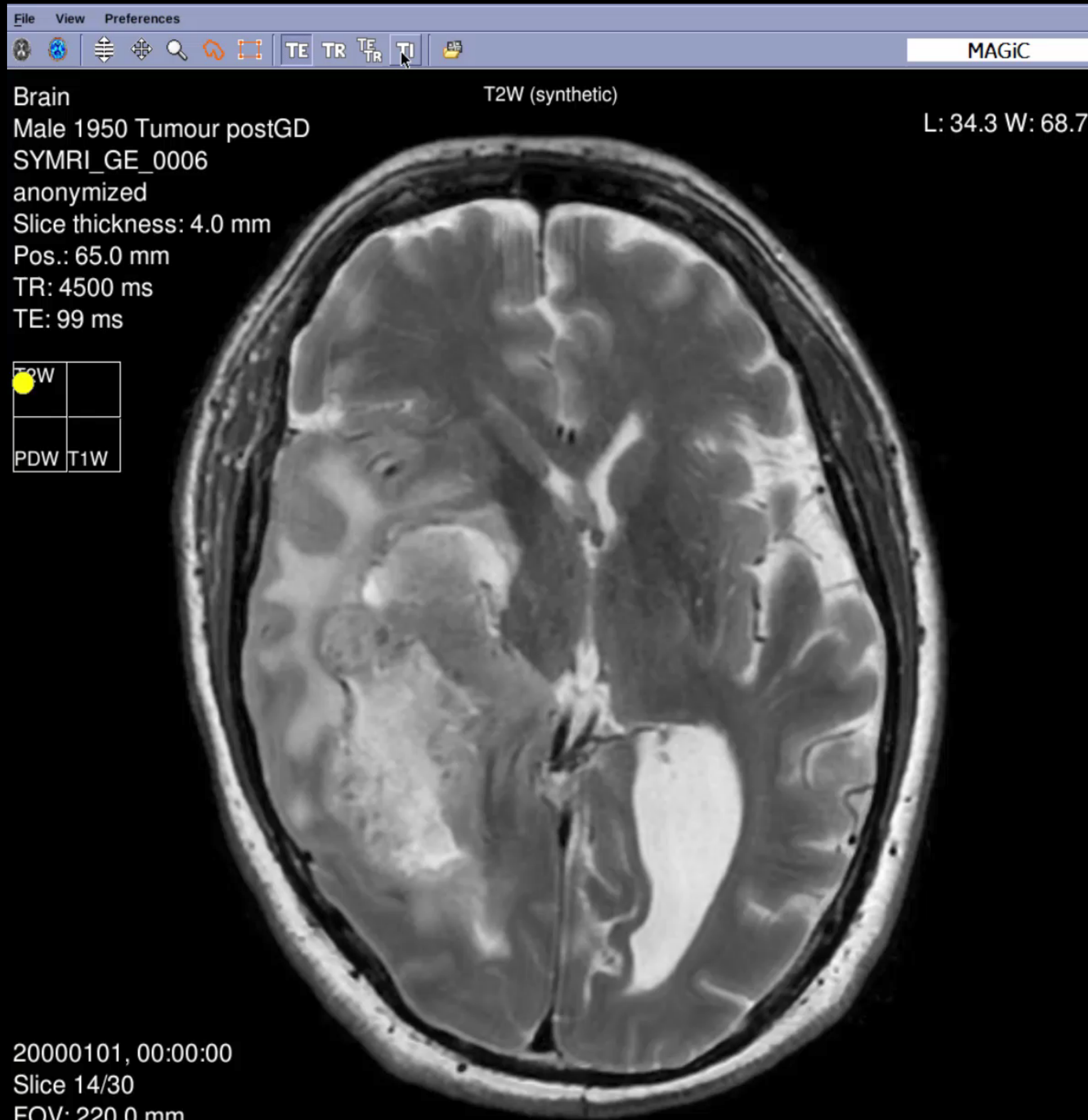
MAGiC … **MAGnetic** resonance **i**mage **C**ompilation

MAGiC Processing



- Using T1, T2, PD and B1 maps you can calculate FSE, IR-FSE, PSIR images using TR/TE/IR parameters that you want.

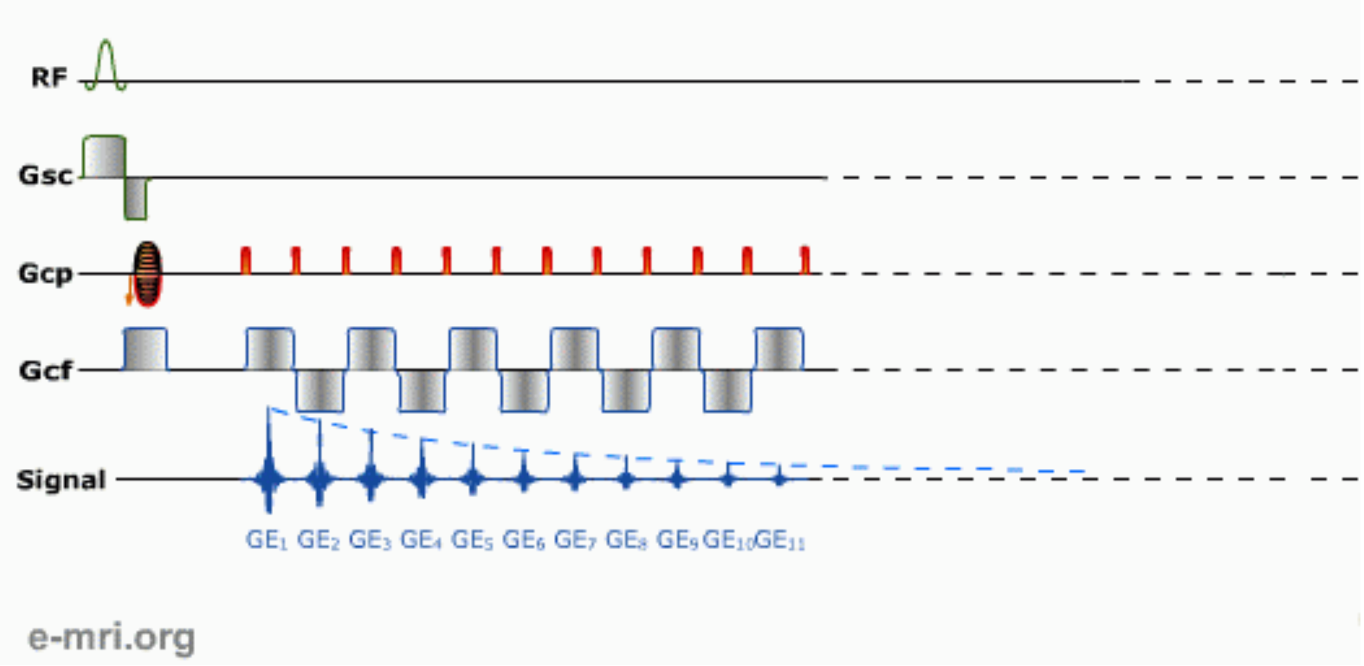
And you can adjust it whenever needed…


File
View
Preferences
TE
TR
MAGiC
Brain
Male 1950 Tumour postGD
SYMRI_GE_0006
anonymized
Slice thickness: 4.0 mm
Pos.: 65.0 mm
TR: 4500 ms
TE: 99 ms
T2W (synthetic)
L: 34.3 W: 68.7
T2W
PDW
T1W
20000101, 00:00:00
Slice 14/30
FOV: 220.0 mm

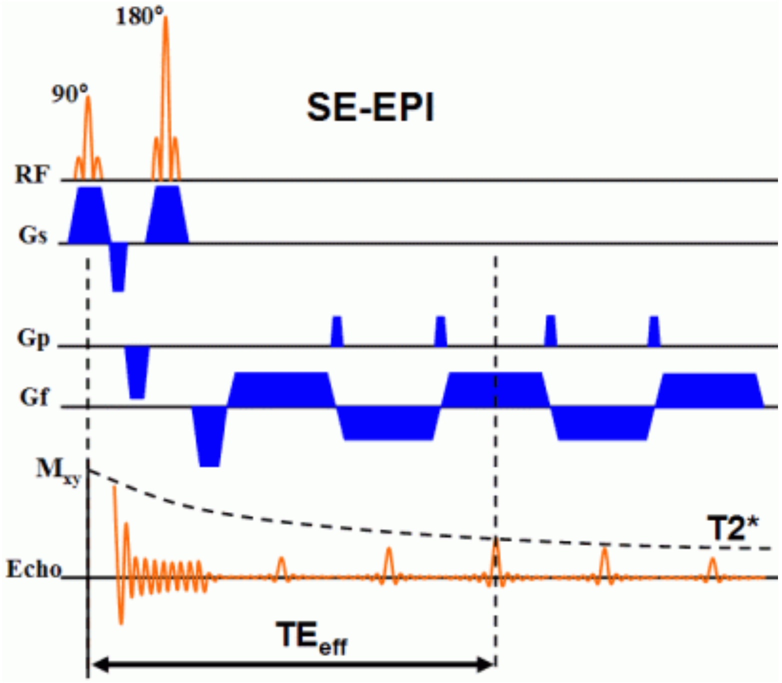
EPI - Echo Planar Imaging

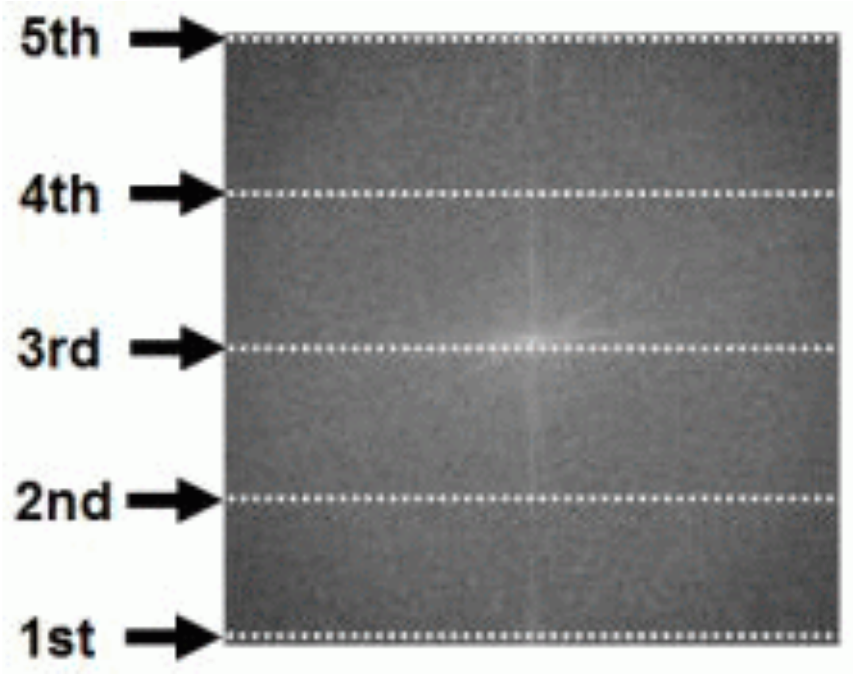
Extremely fast imaging is possible using EPI (Echo Planar Imaging) technique (up to 20 images/second).

This requires very fast gradients, which can cause neurostimulus to patients.

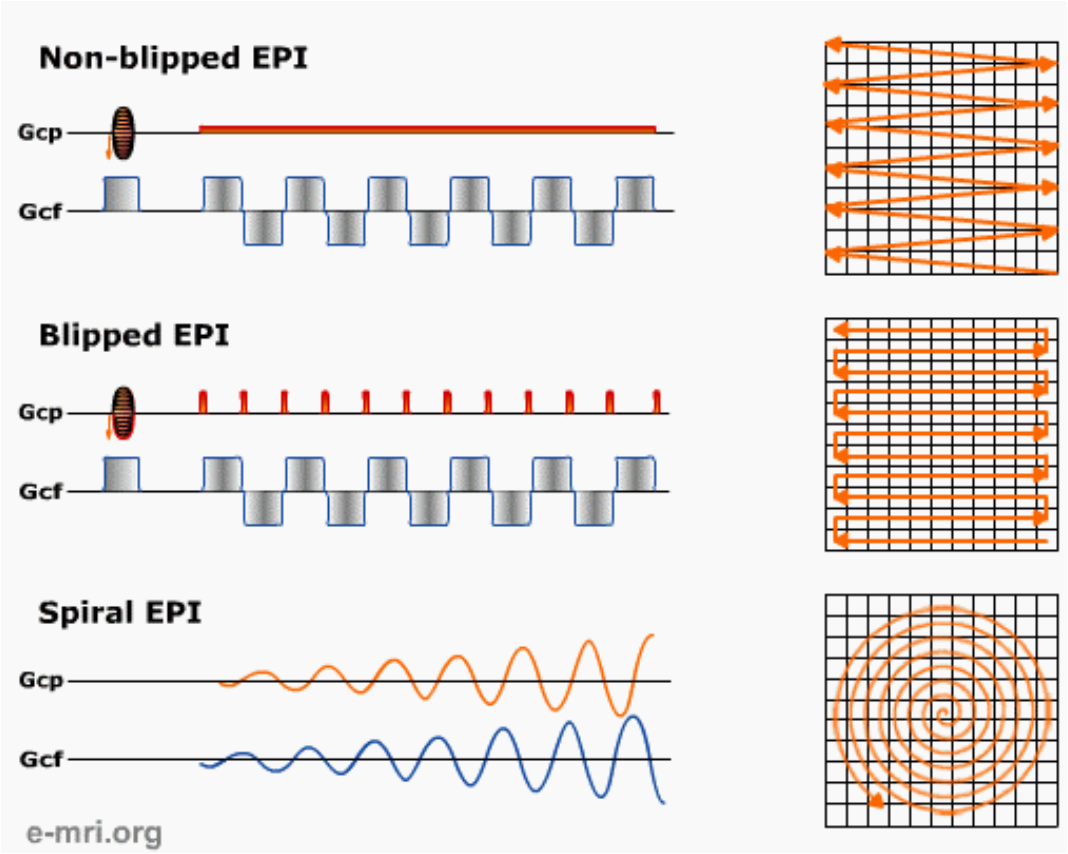


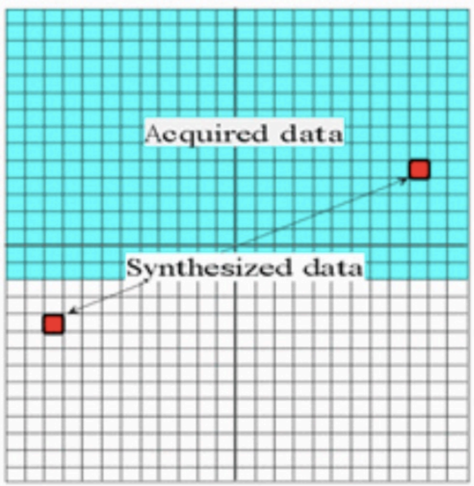
Spin-Echo EPI



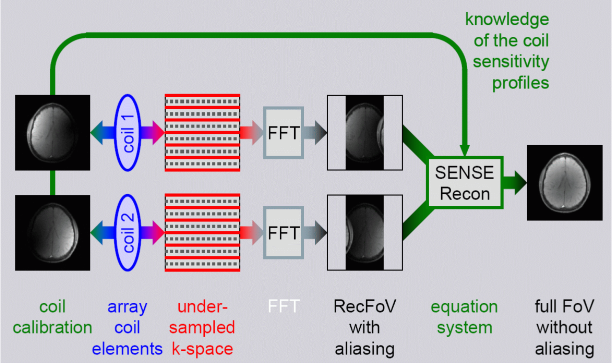


EPI data acquisition options





Phase-conjugate symmetry. About half of *k*-space is sampled by reducing the number of phase-encoding steps. The other half of *k*-space is synthesized/reconstructed.



Brain Perfusion

Cerebral blood flow, or **CBF**, is the blood supply to the brain in a given time. 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

Dynamic Regulation maintains tissue oxygen levels and removes carbon dioxide and other metabolic leftovers

Cerebral Blood Flow (CBF)

- increases sharply due to elevated CO_2 and byproducts of metabolism
- increases due to oxygen depletion
- increases due to functional activity of the neurons

Measurements of cerebral hemodynamics provide insights into the physiological status of the tissue and inform many research and clinical uses

How to measure CBF?

1. PET
2. SPECT
3. CT perfusion
4. MRI using DSC

(Dynamic Susceptibility Contrast MRI with bolus tracking of gadolinium chelate)

5. MRI using ASL

(Blood is the endogenous contrast agent)

How to measure CBF?

Dynamic Susceptibility Contrast MRI

This technique involves the rapid intravenous injection of an MR contrast agent and the serial measurement of the signal loss during the passage of the bolus through the tissue.

In our case:

Gadovist, 0.1ml/kg, **5 ml/s**

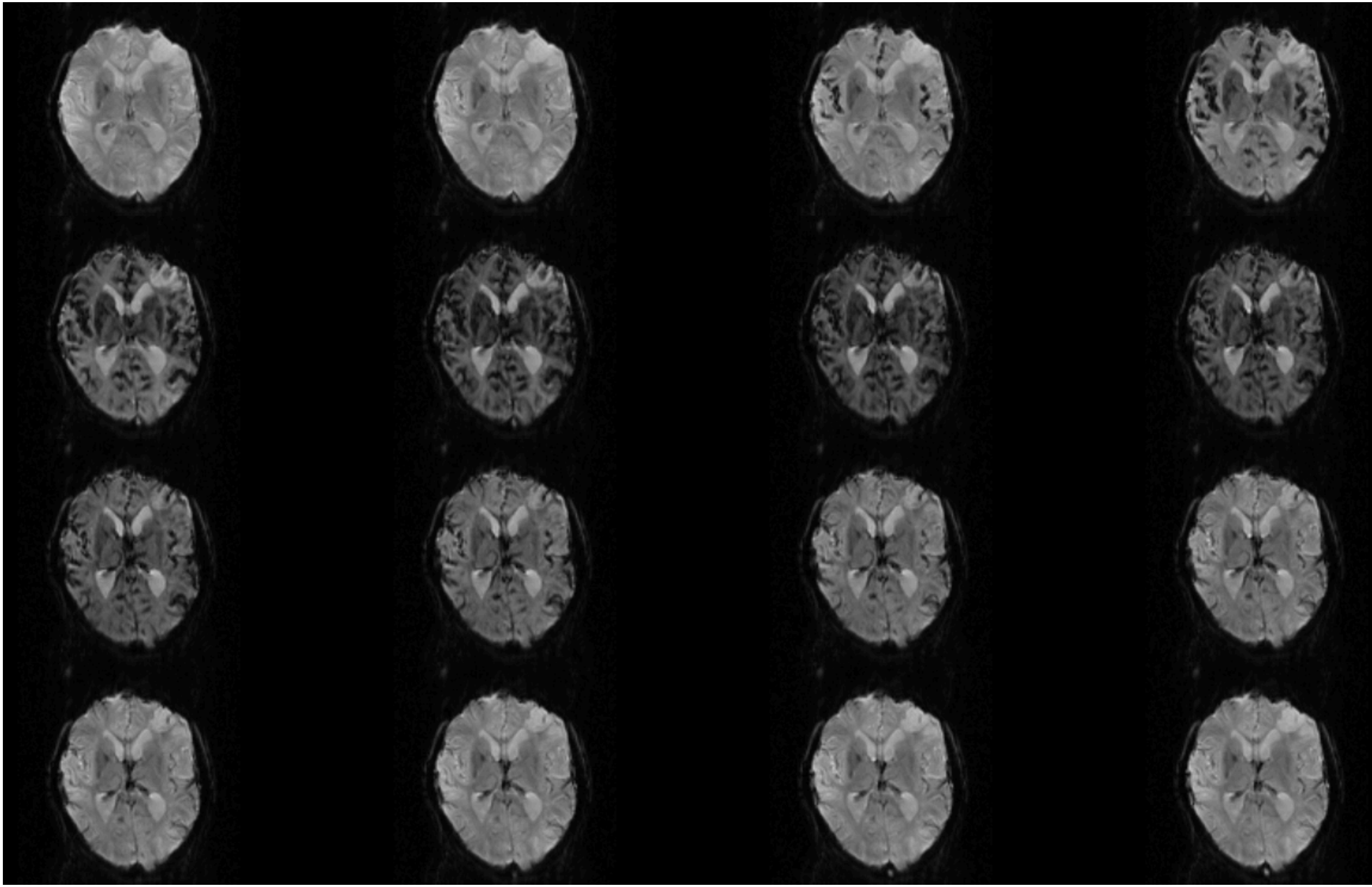
EPI: TR 1500ms, 15 slices (4/1.2 mm), FOV 230, matrix 128

You can calculate the following parameters in the **Perf MR** task card.

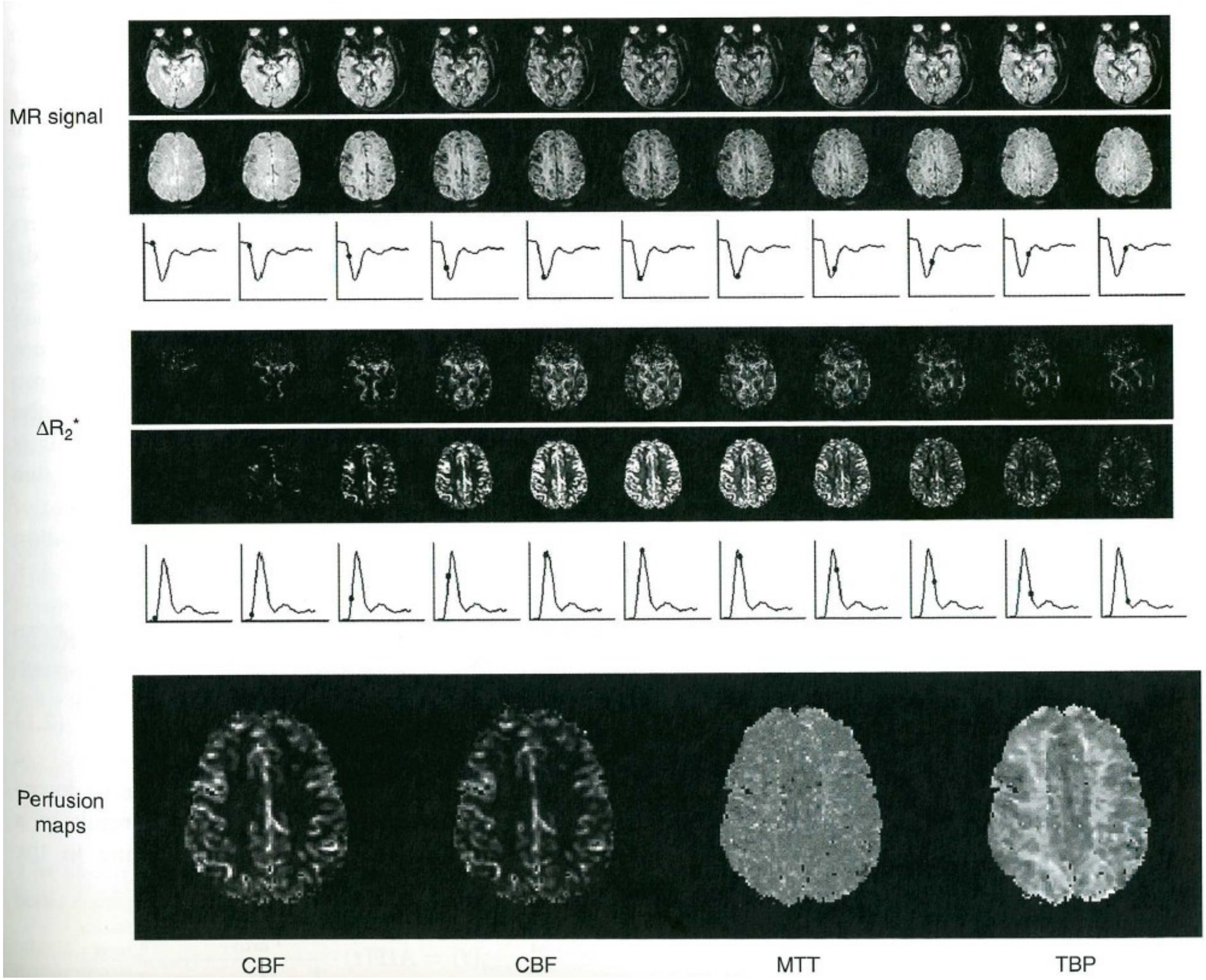
- ❑ Relative cerebral blood volume (relCBV)
- ❑ Relative cerebral blood flow (relCBF)
- ❑ Time to bolus maximum (Time To Peak, TTP)
- ❑ Relative mean transit time (relative mean transit time, relMTT)

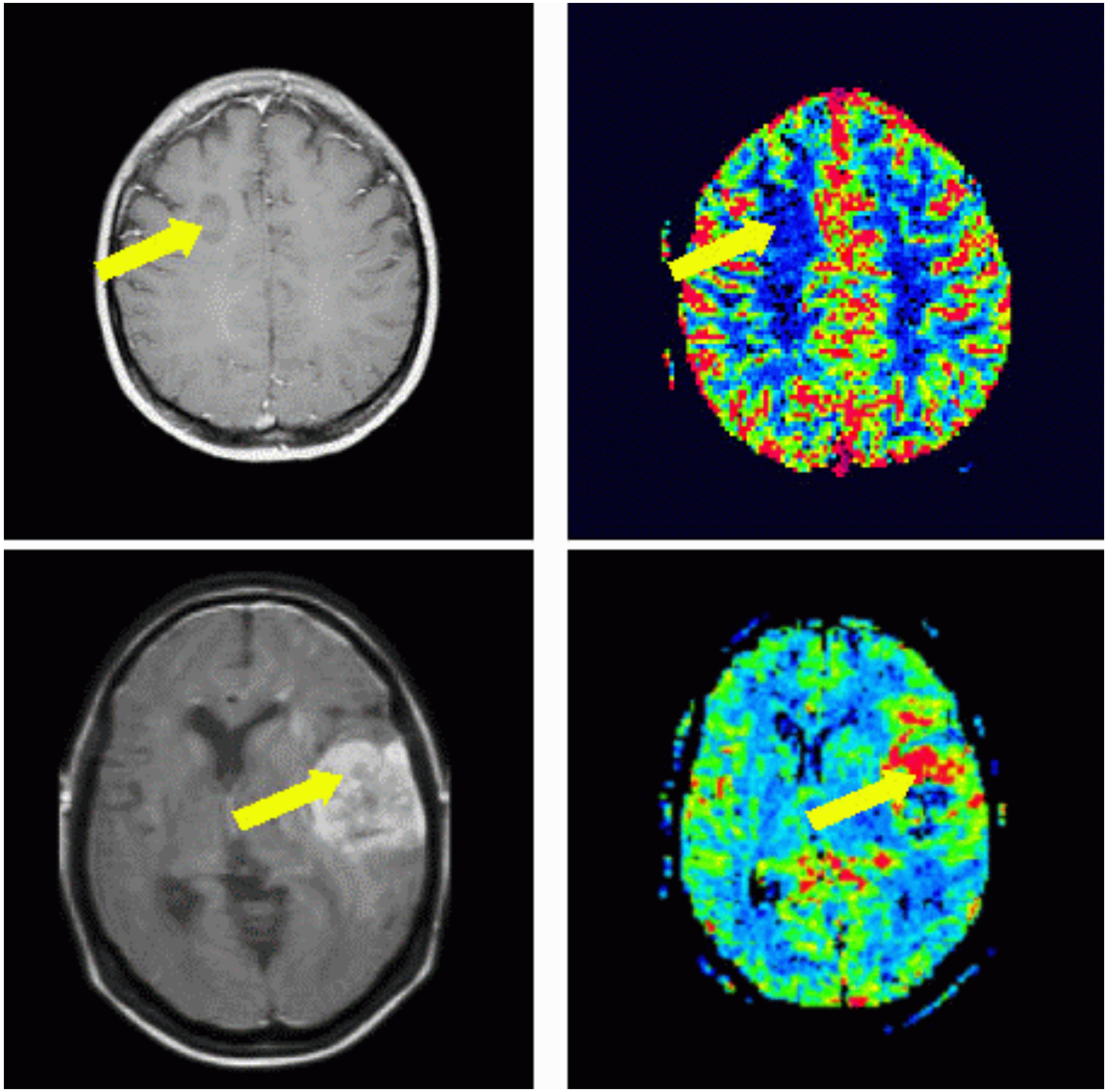
Parameter calculations are performed using well established methods of analysis, primarily based on the technique described by Østergaard et al. (Magn. Reson. Med. 36, 715–725 (1996)).

Performing the scan



6/6/18


MR signal
ΔR_2^*
Perfusion maps
CBF
CBF
MTT
TBP



In the upper two images, it is possible to see that the tumour has a low perfusion, which indicates a slow-growing tumour.

The lower images show very high perfusion within the tumour, which is typical of an aggressive tumour. The brain tumours are indicated with an arrow.

Universiteit Leiden

Research project:

Group of cardiac arrest patients

- 1^{st} scan about 2 days after the cardiac arrest
- 2^{nd} scan around 10 days after the cardiac arrest

T2 TSE ax
3D FLAIR sag
T1 MPRAGE sag
CSI
DTI
ASL
MR Perfusion

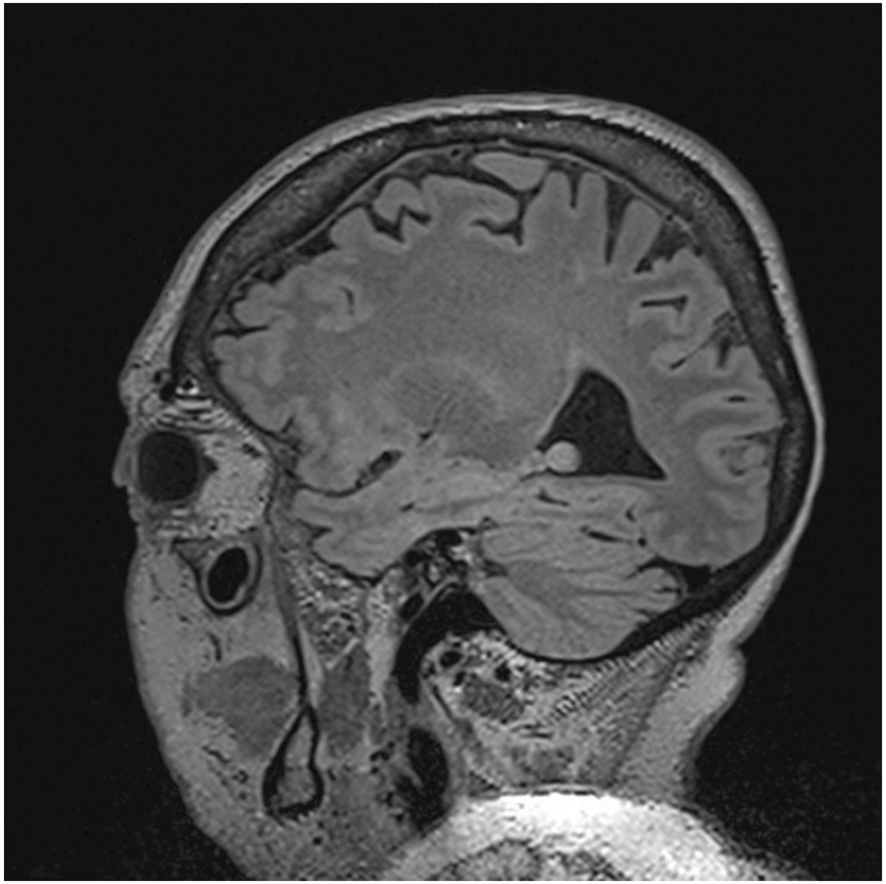
Example case

Sytotoxic edema – Sign of a fresh **ischemia**

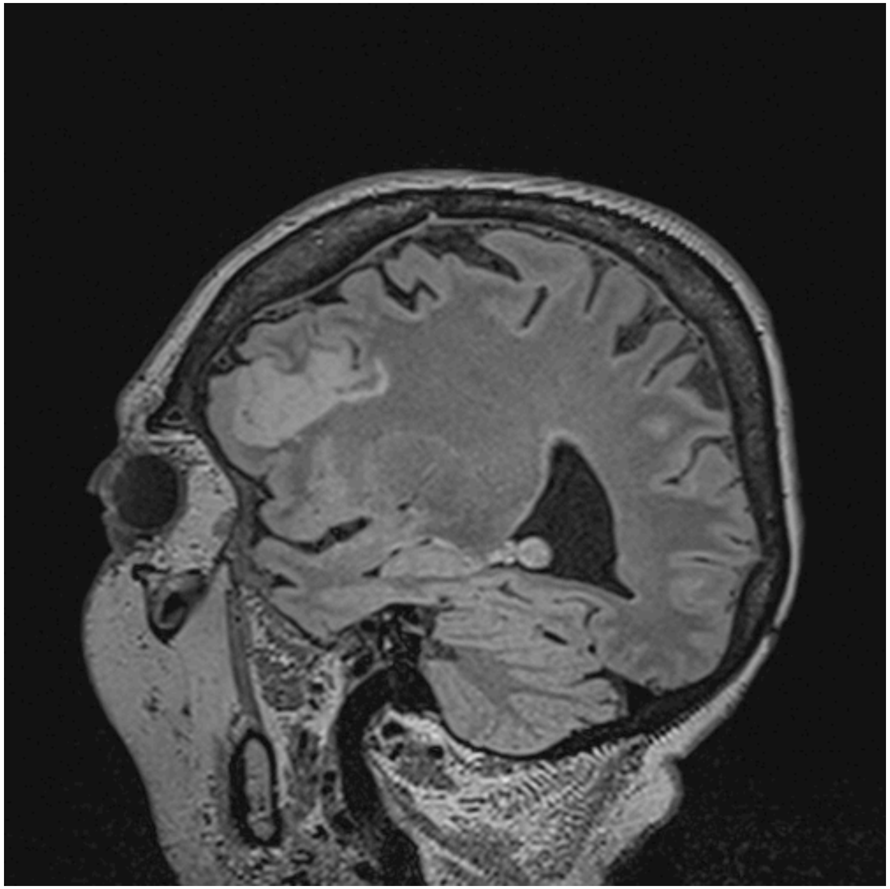
T2 TSE   Day 2 & Day 8

3D FLAIR

Day 2

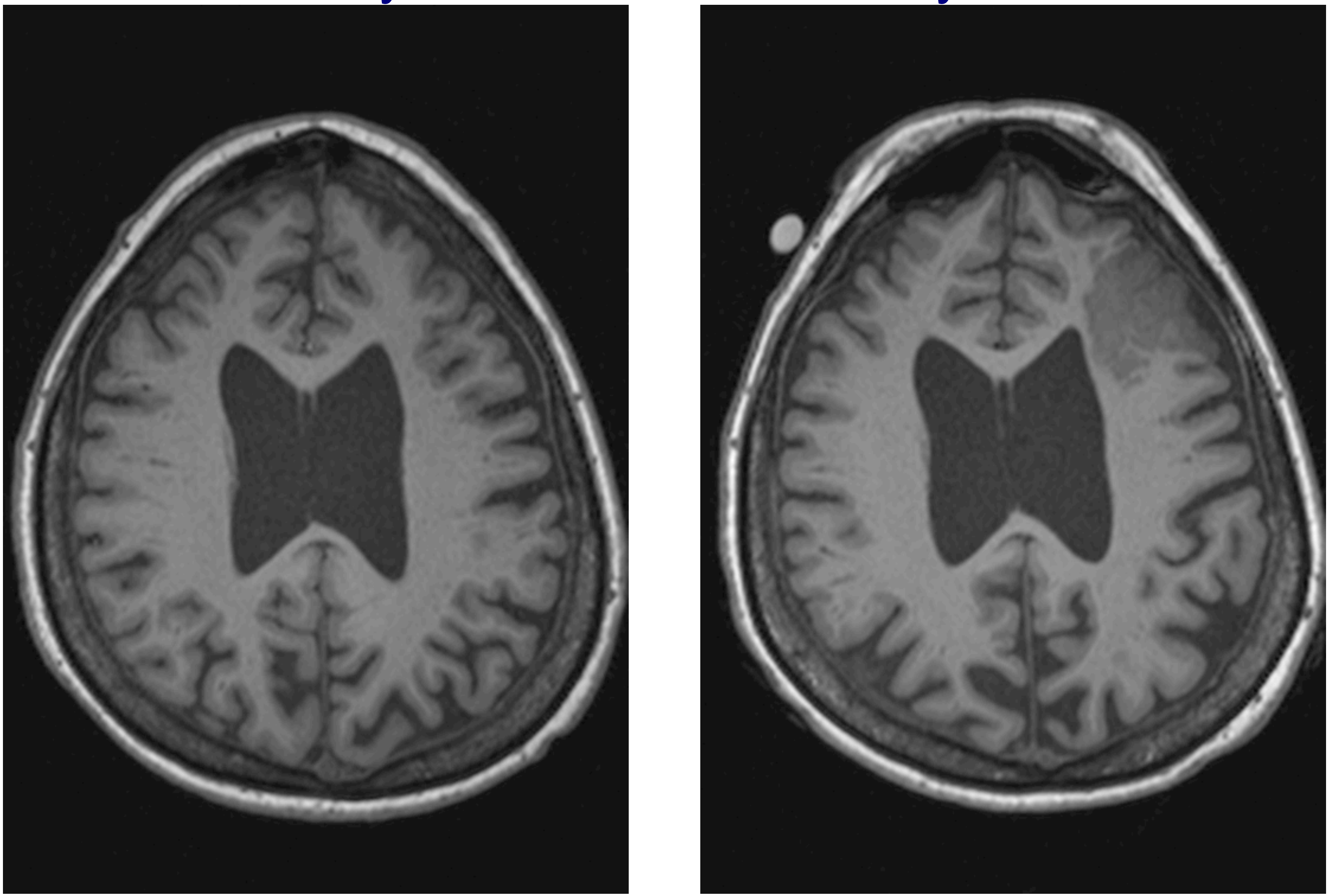


Day 8



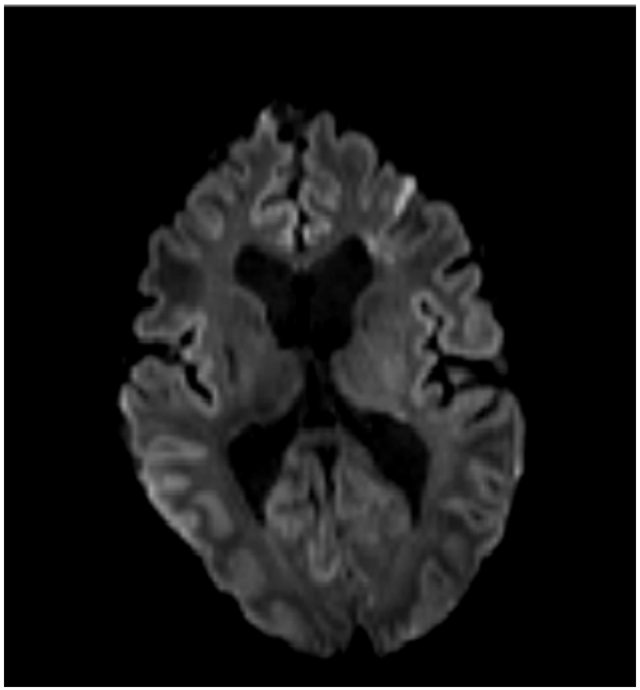
MPRAGE

Day 2 Day 8

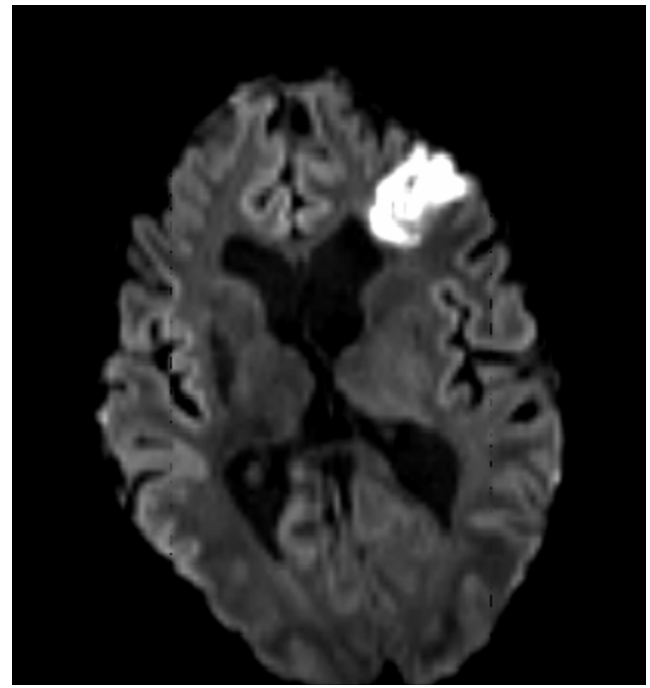


DWI TraceW images

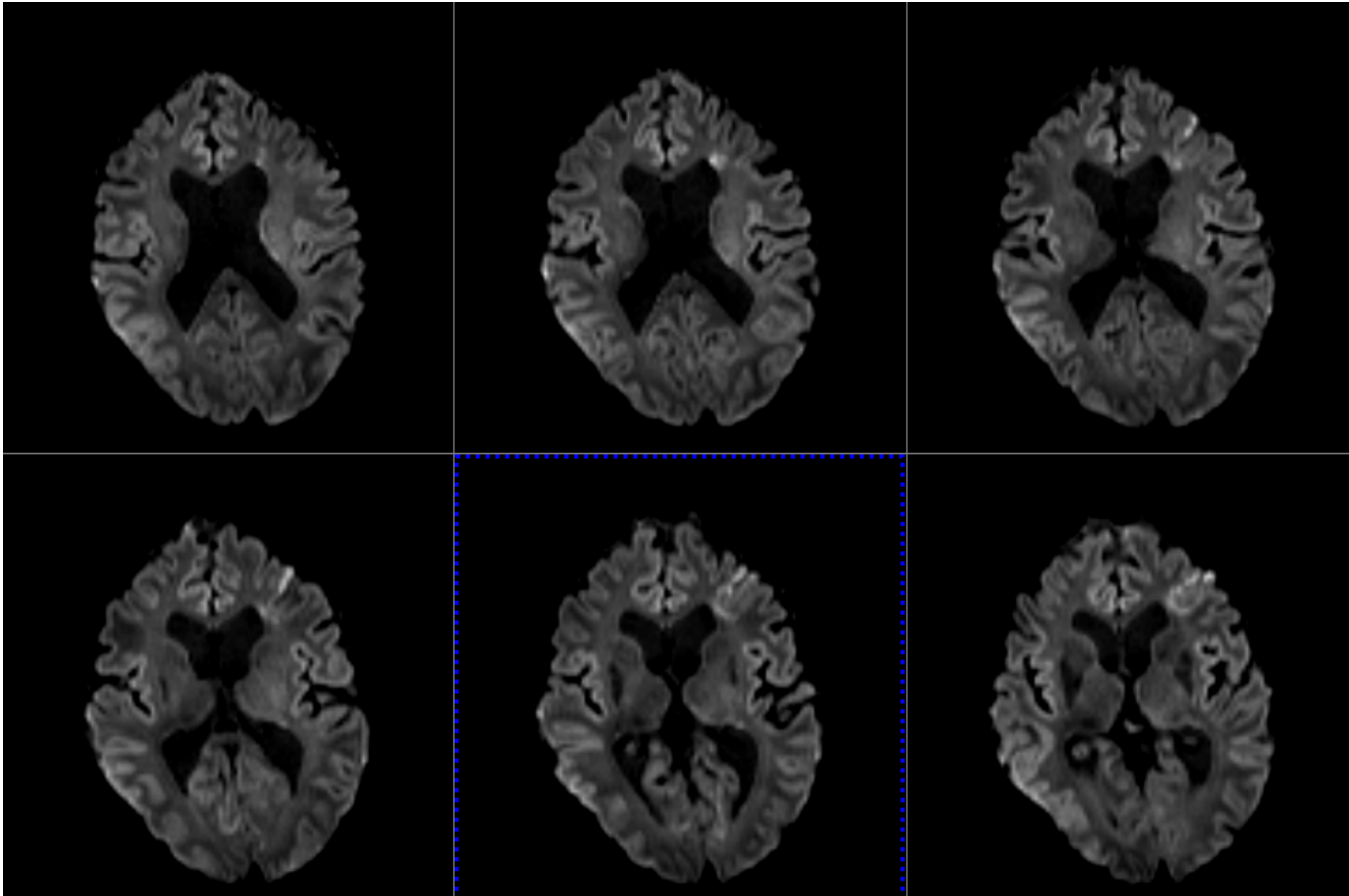
Day 2



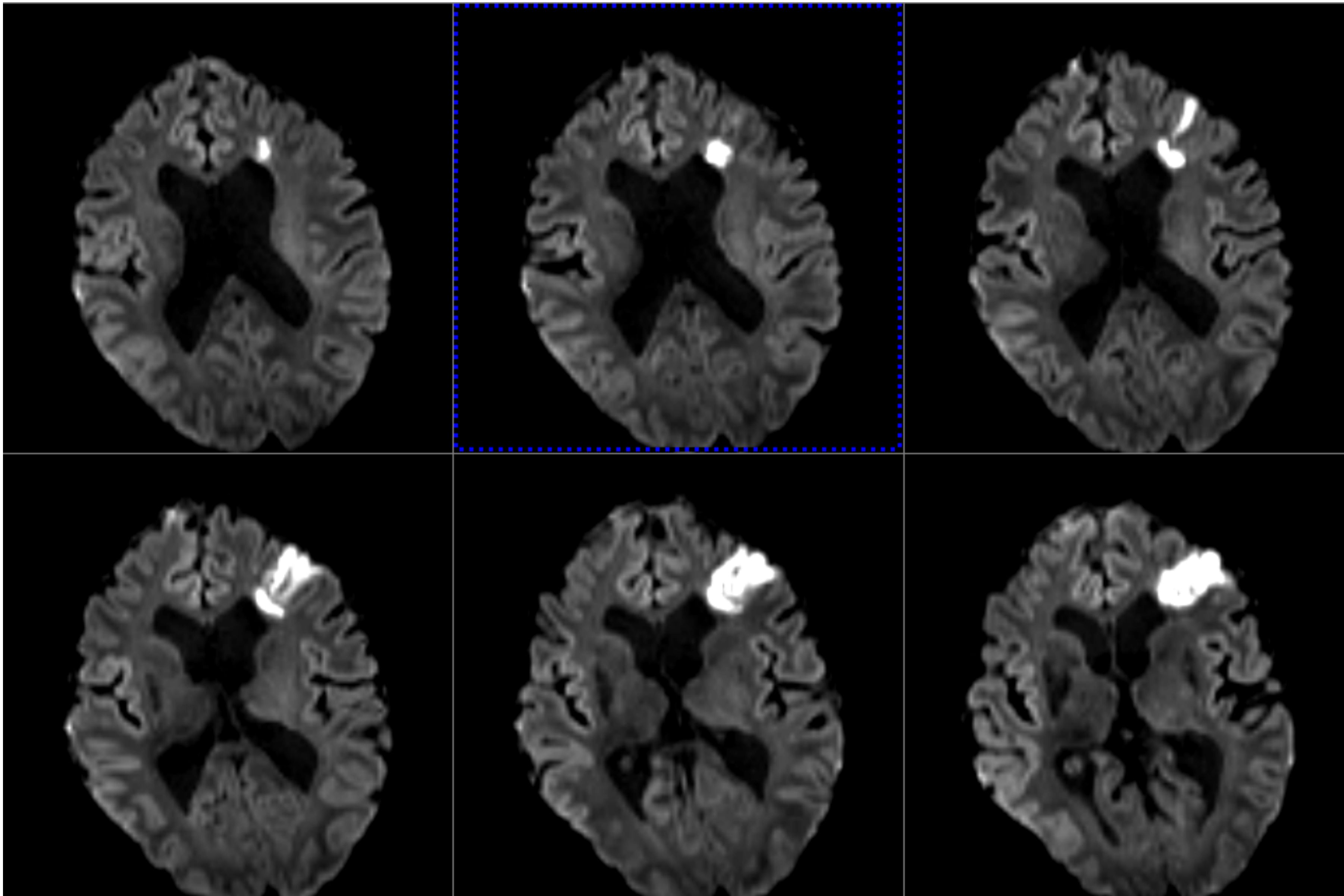
Day 8



TraceW images (Day 2)

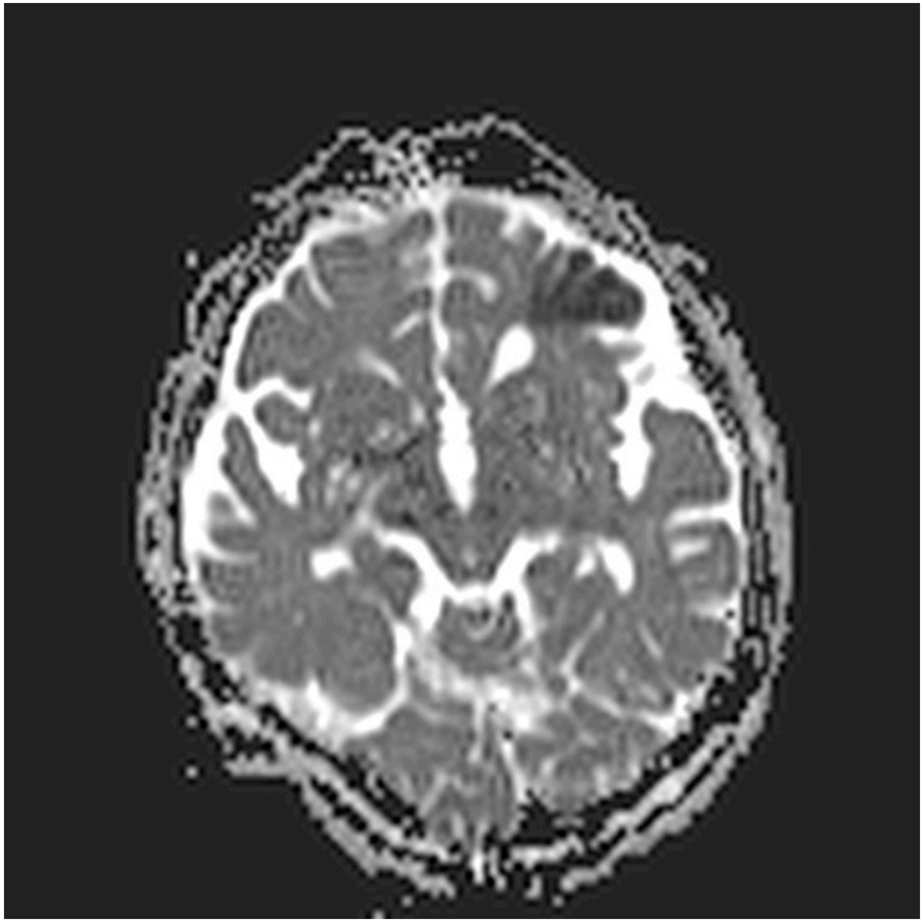


TraceW images (Day 10)

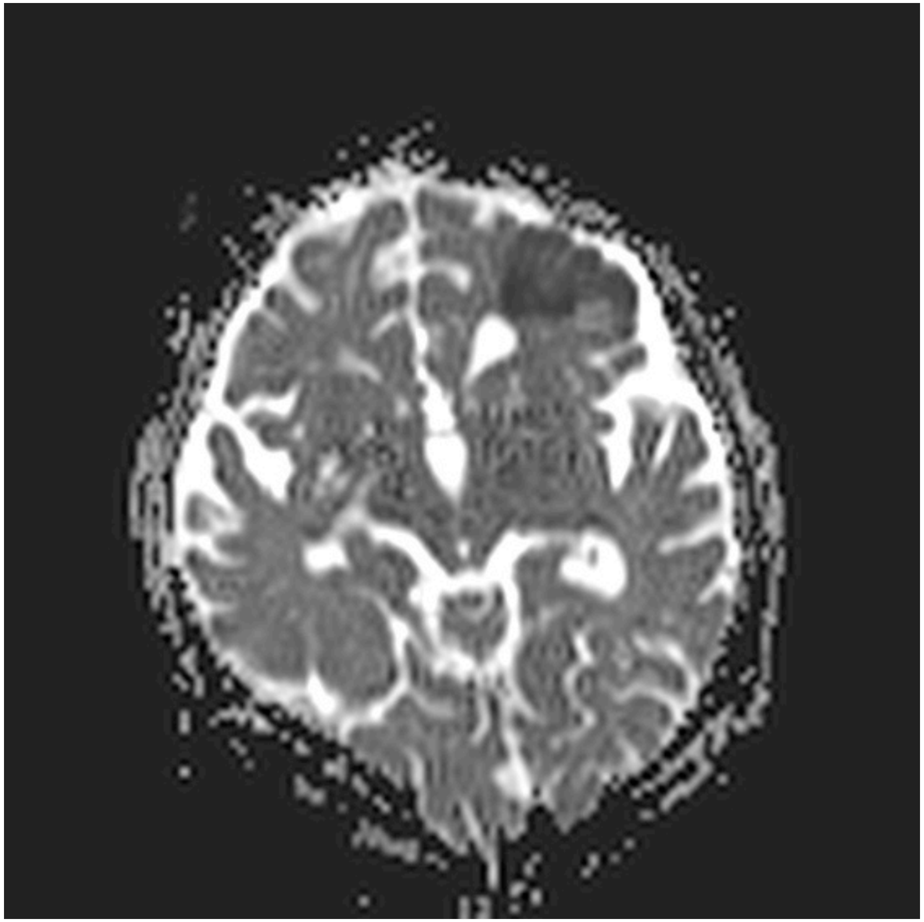


ADC maps

Day 2

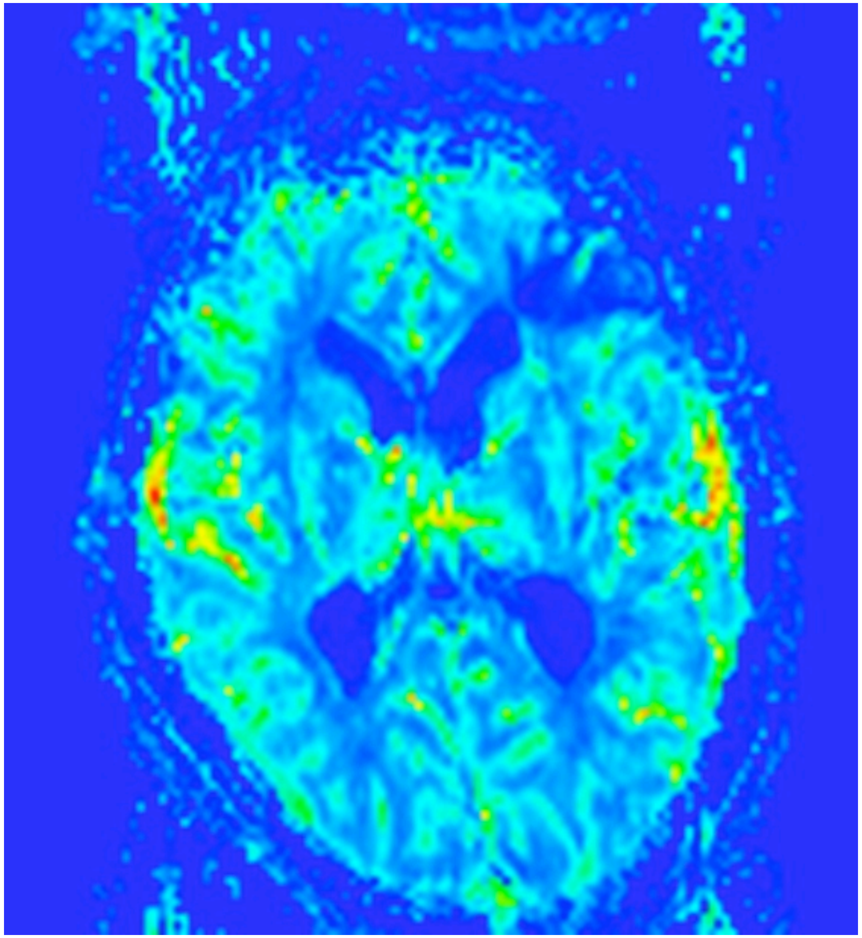


Day 8

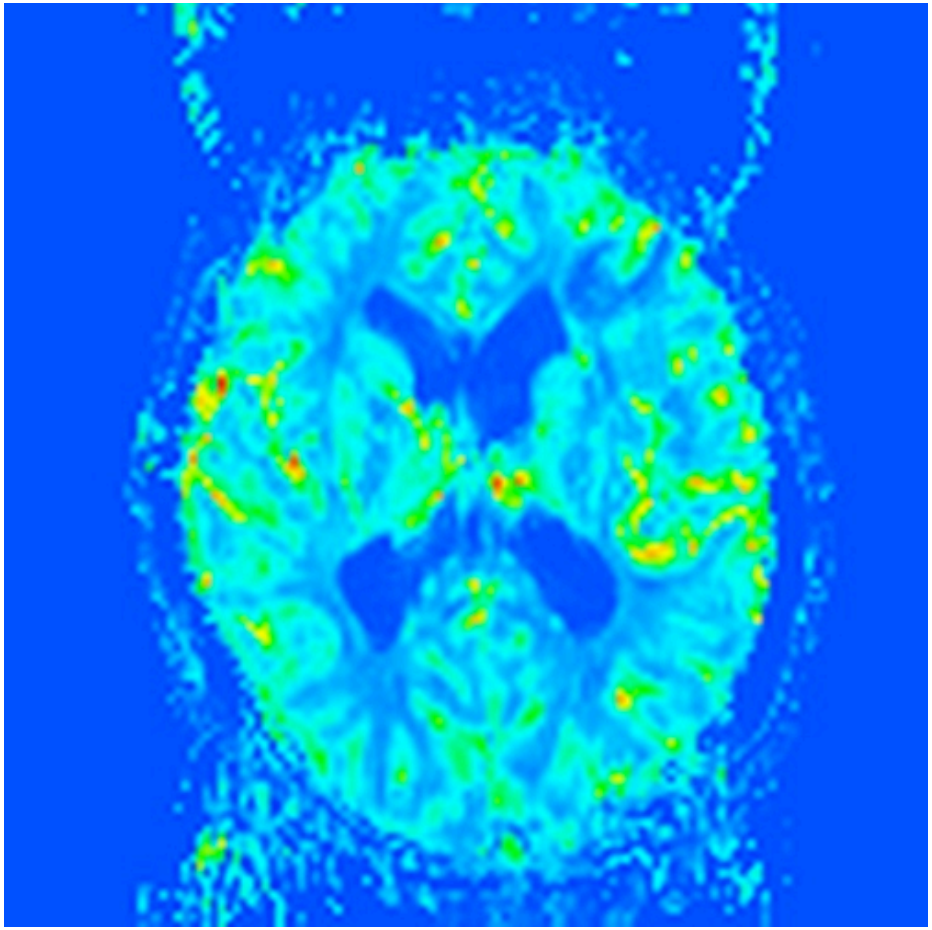


CBF maps

Day 2

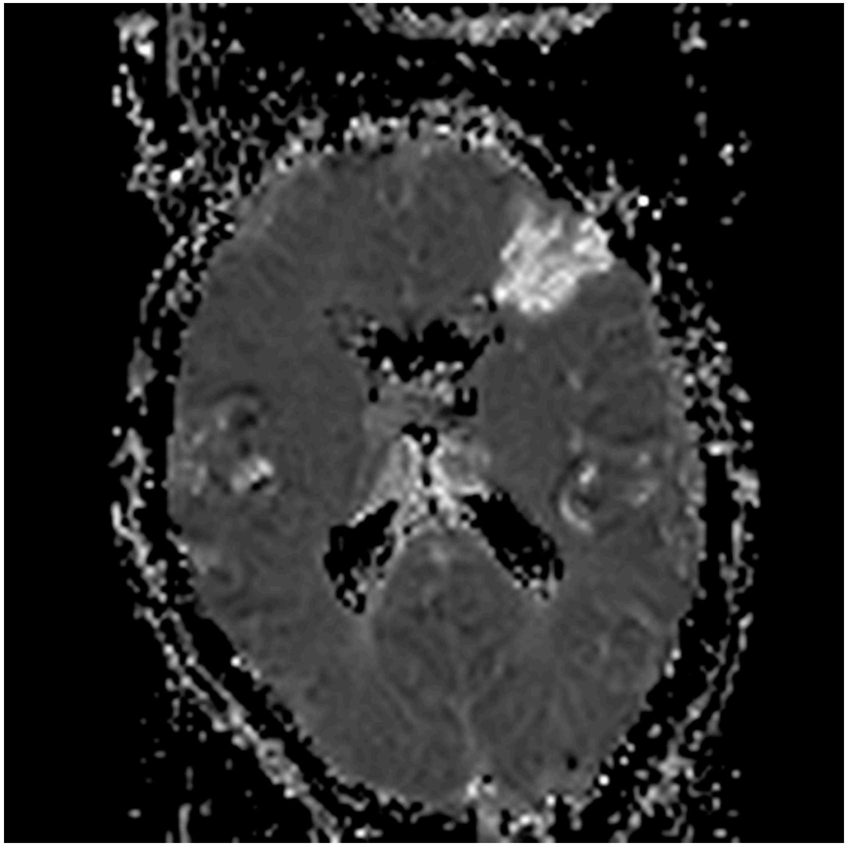


Day 8

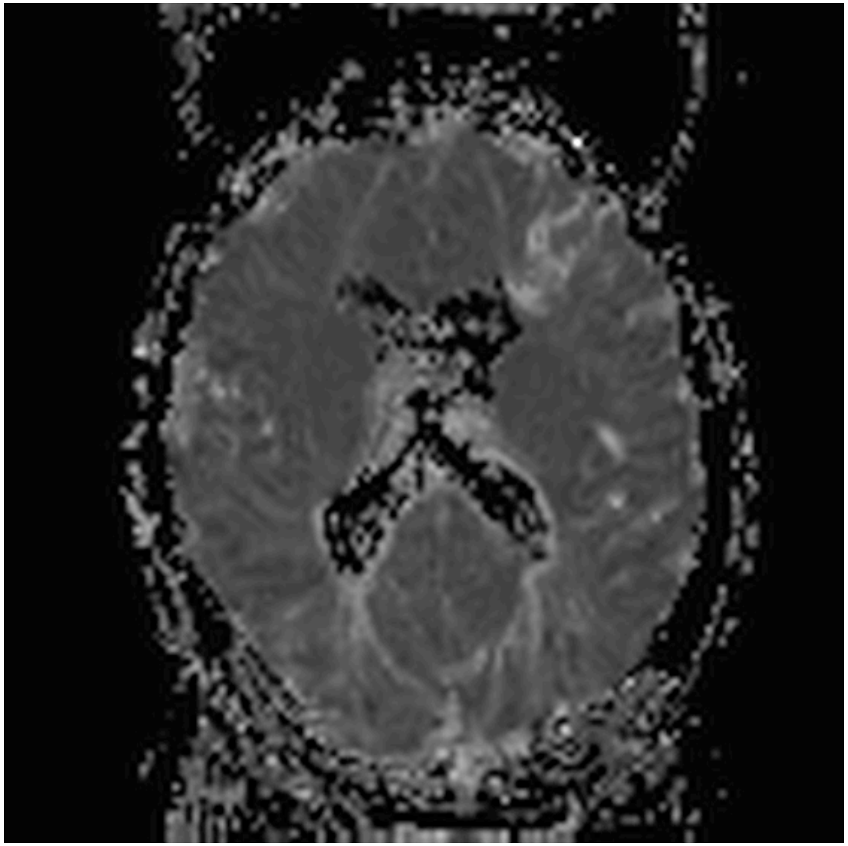


relMTT maps

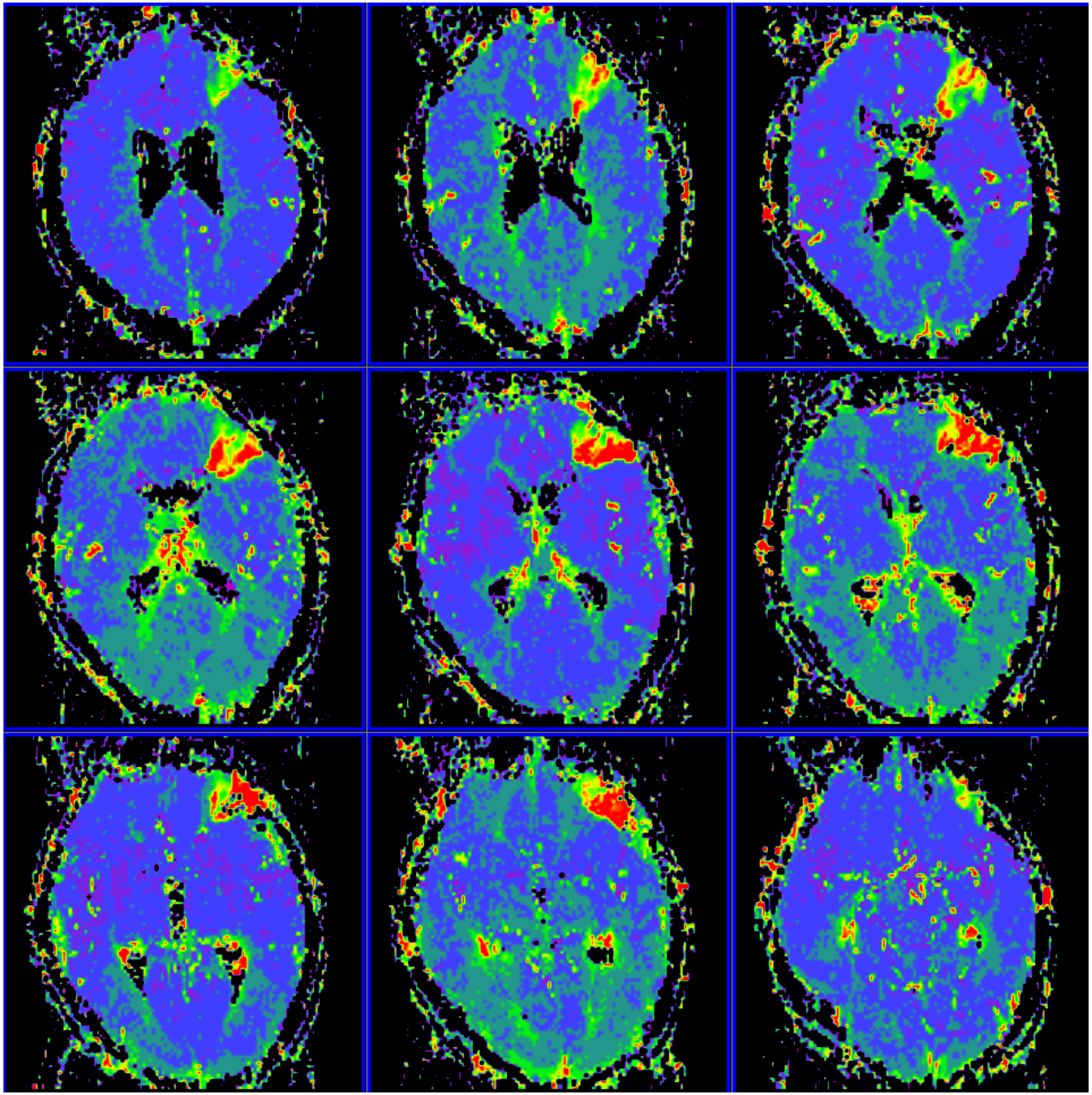
Day 2



Day 8



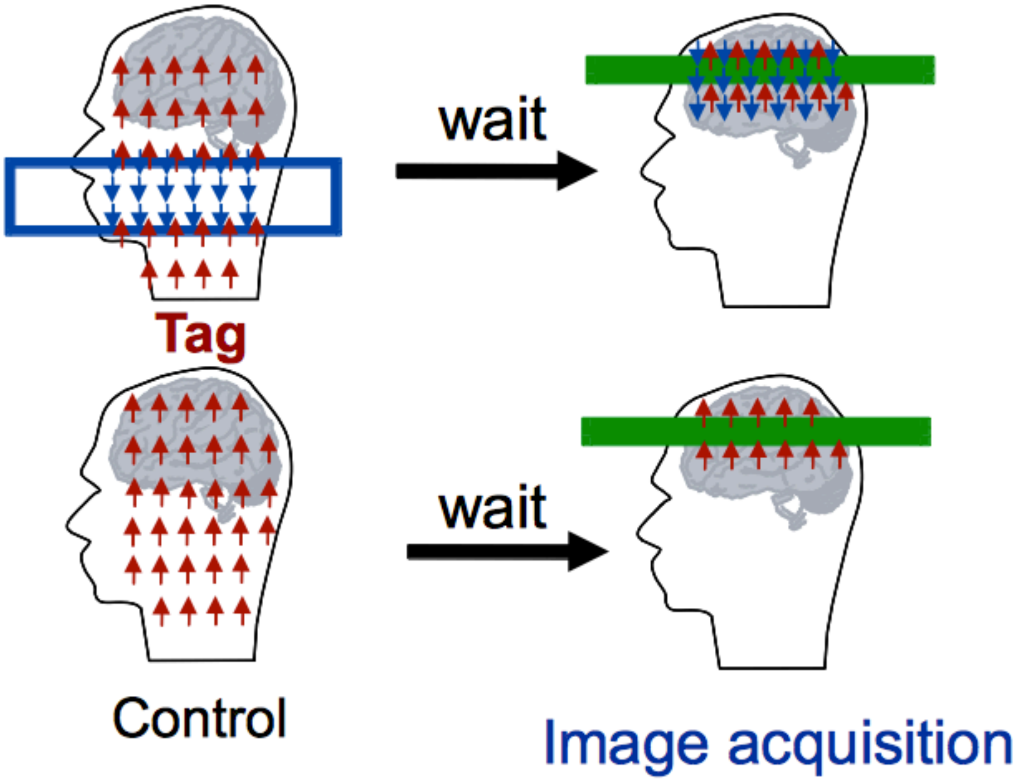
Time to Peak map (day 2)



ASL is a technique for labeling the blood bolus: using an inversion pulse, the arterial blood water is magnetically labeled below the region to be examined.

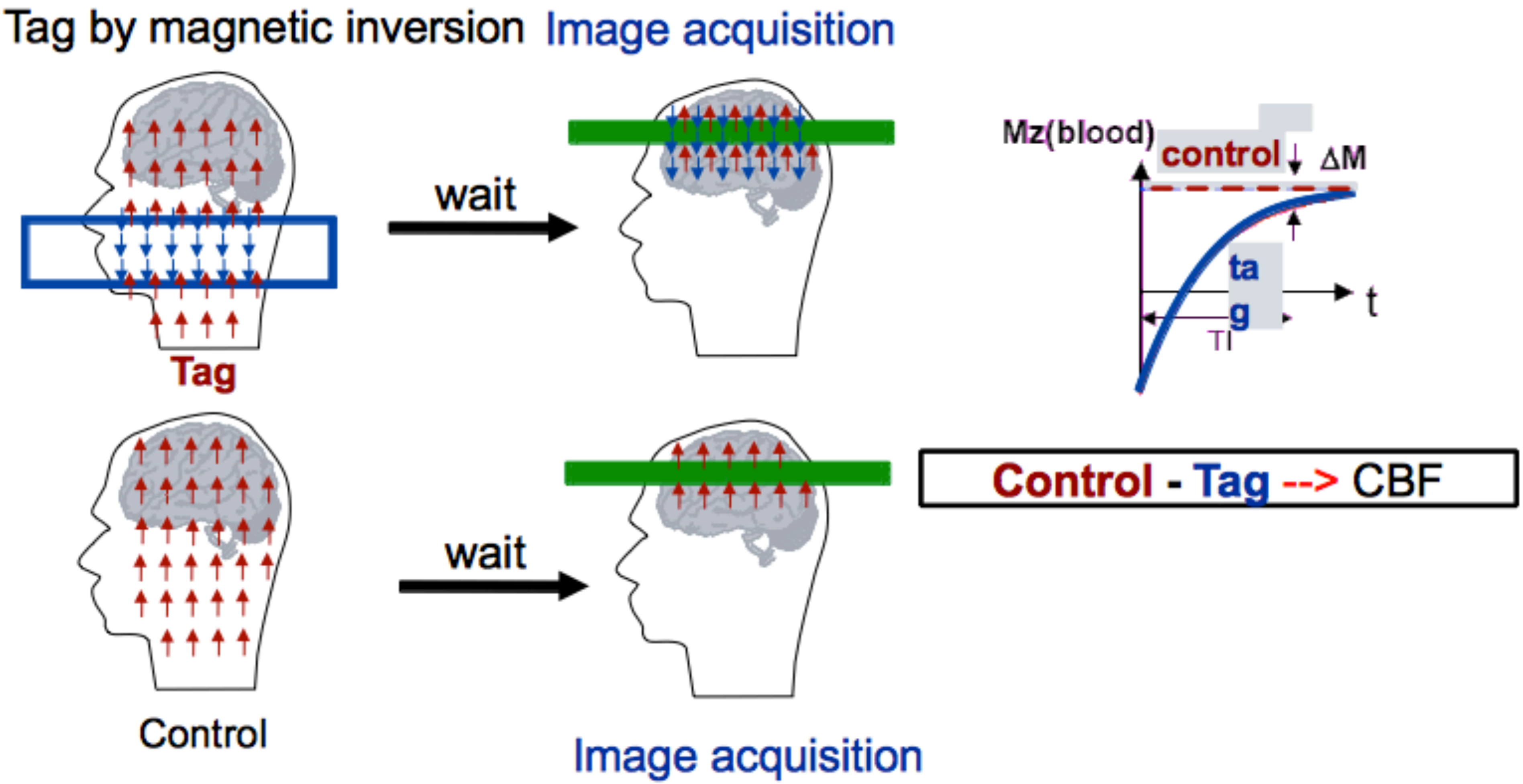
Arterial spin labelling can actually be accomplished using a variety if approaches and in nearly any organ. (ASL studies have successfully been carried out in kidney, lung, retina, heart and skeletal muscle)

However, most ASL has been carried out in the brain because arterial supply is extremely well defined and perfusion to brain tissue is high.



After a certain transit time, the labeled blood has flown into the region of interest where it distributed itself. There the labeled blood spins reduce the tissue magnetization present. If an image is acquired (the tag image), the MR signal is slightly reduced.

Subsequently, a control image without blood labeling is measured. The tag images and control images are measured alternately until the planned series is acquired.


Tag by magnetic inversion
Image acquisition
wait
Tag
Mz(blood)
control
ΔM
ta
g
t
TI
Control - Tag --> CBF
wait
Control
Image acquisition

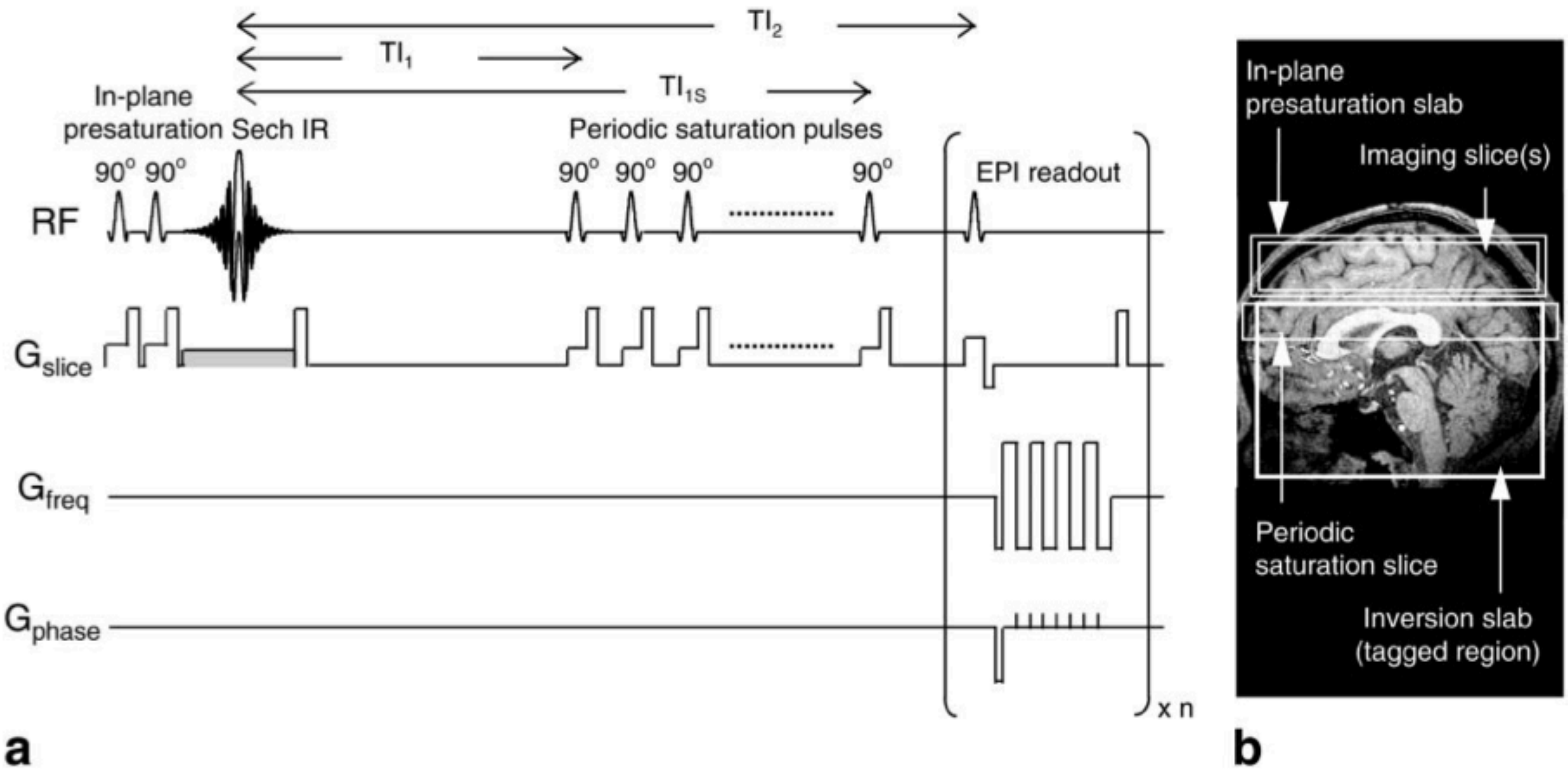
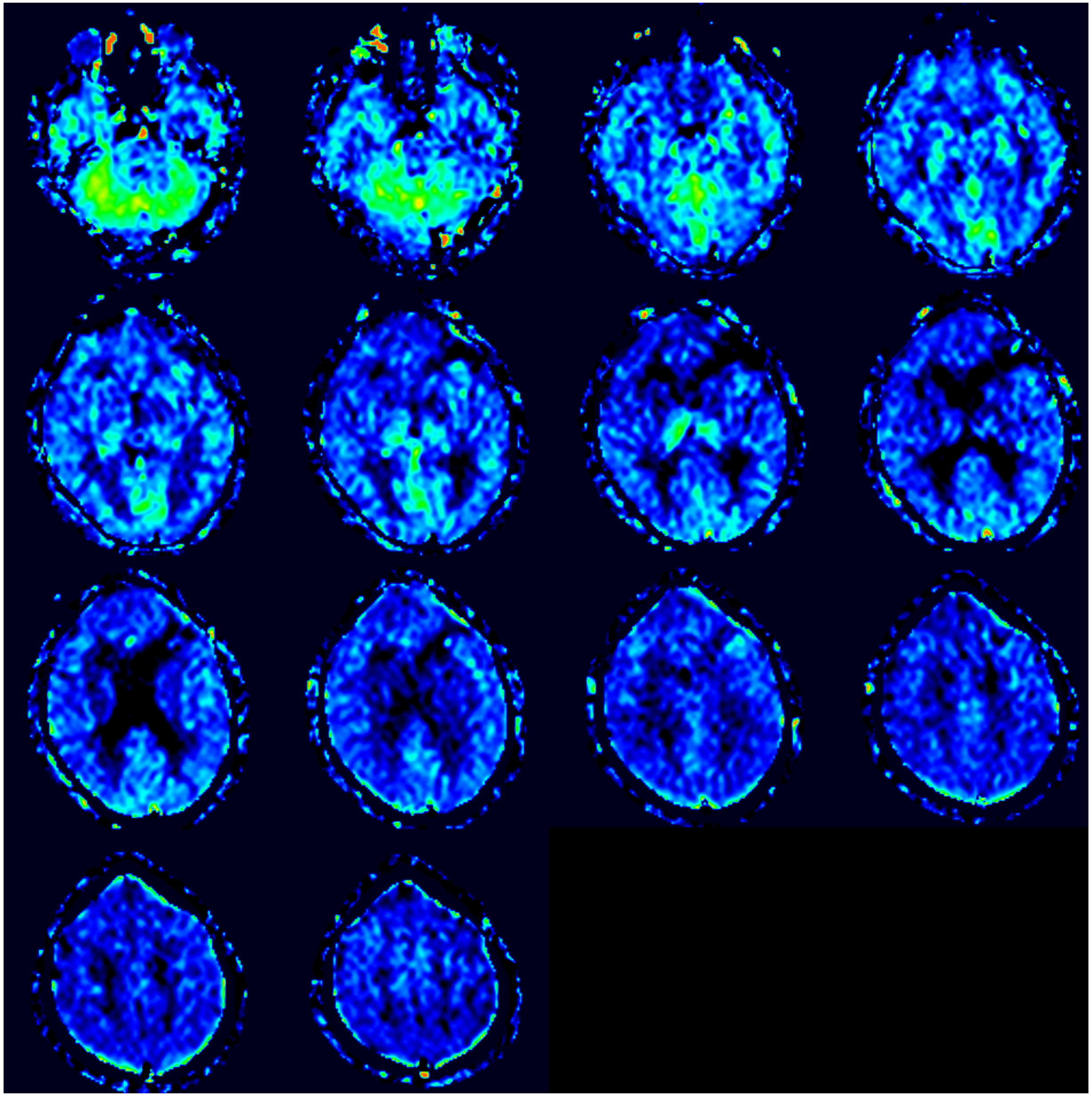
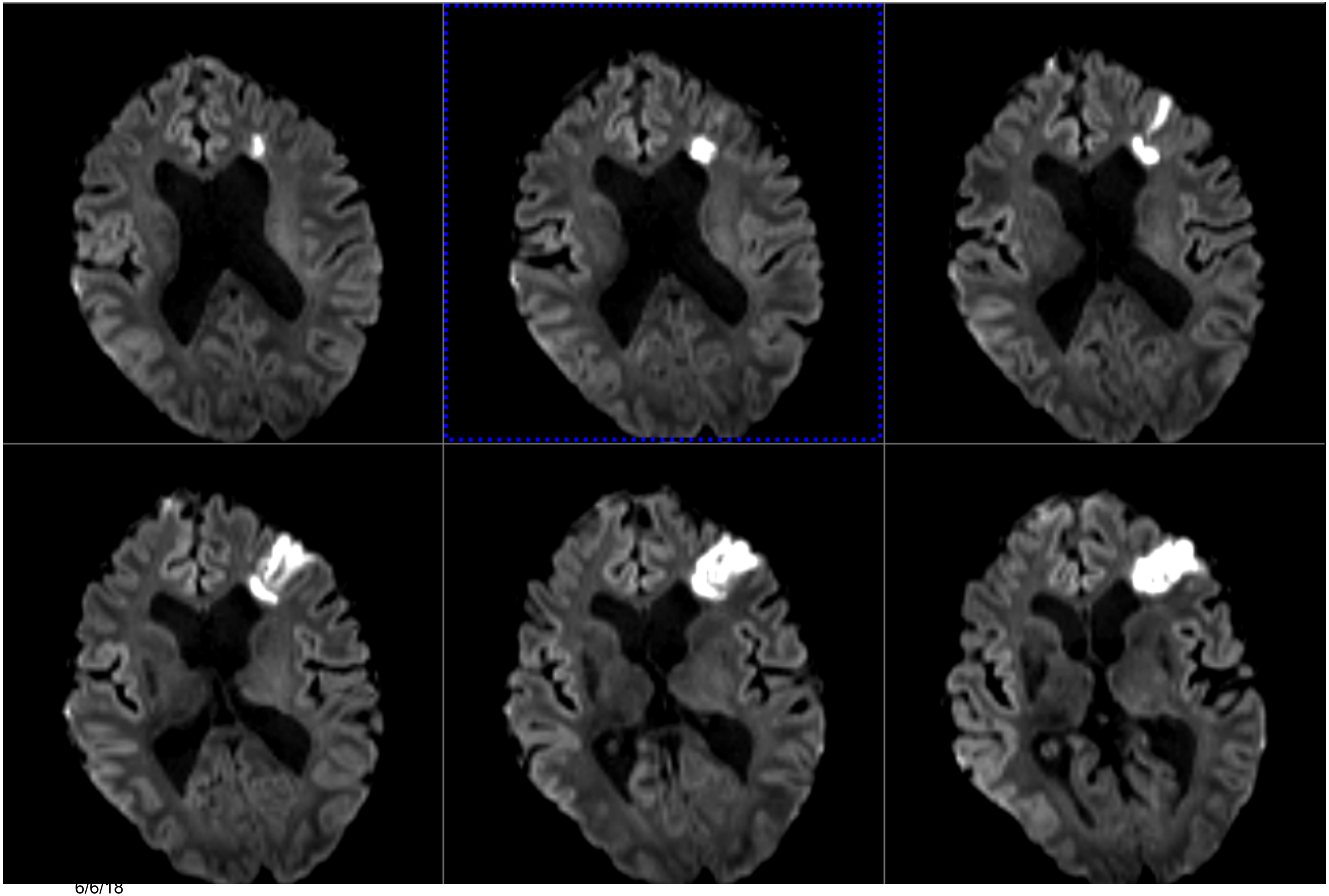


FIG. 1. **a:** Pulse sequence for Q2TIPS. Double in-plane presaturation pulses followed by the sech inversion tagging pulse. The gradient lobe in gray is alternately applied for tag and control states. Periodic saturation pulses applied from TI_1 to TI_{1S} consist of a train of 90° excitation pulses each followed by a crusher gradient. Single or multislice EPI acquisition is applied at TI_2. **b:** Locations of the in-plane presaturation slab, imaging slice(s), periodic saturation slice, and inversion slab used in the PICORE tagging scheme.

ASL Day 2



TraceW images (Day 10)



The latest ASL sequence, developed by GE Healthcare, 3D ASL, is a for both 1.5T and 3.0T and uses an SNR-efficient labeling technique, namely, pulsed continuous arterial spin labeling (pCASL), which allows it to be compatible with body coil excitation.

In addition, it uses background suppression and a 3D FSE acquisition to provide robustness to motion and susceptibility artifacts. The result is whole-brain perfusion coverage with improved SNR (Figure 1)

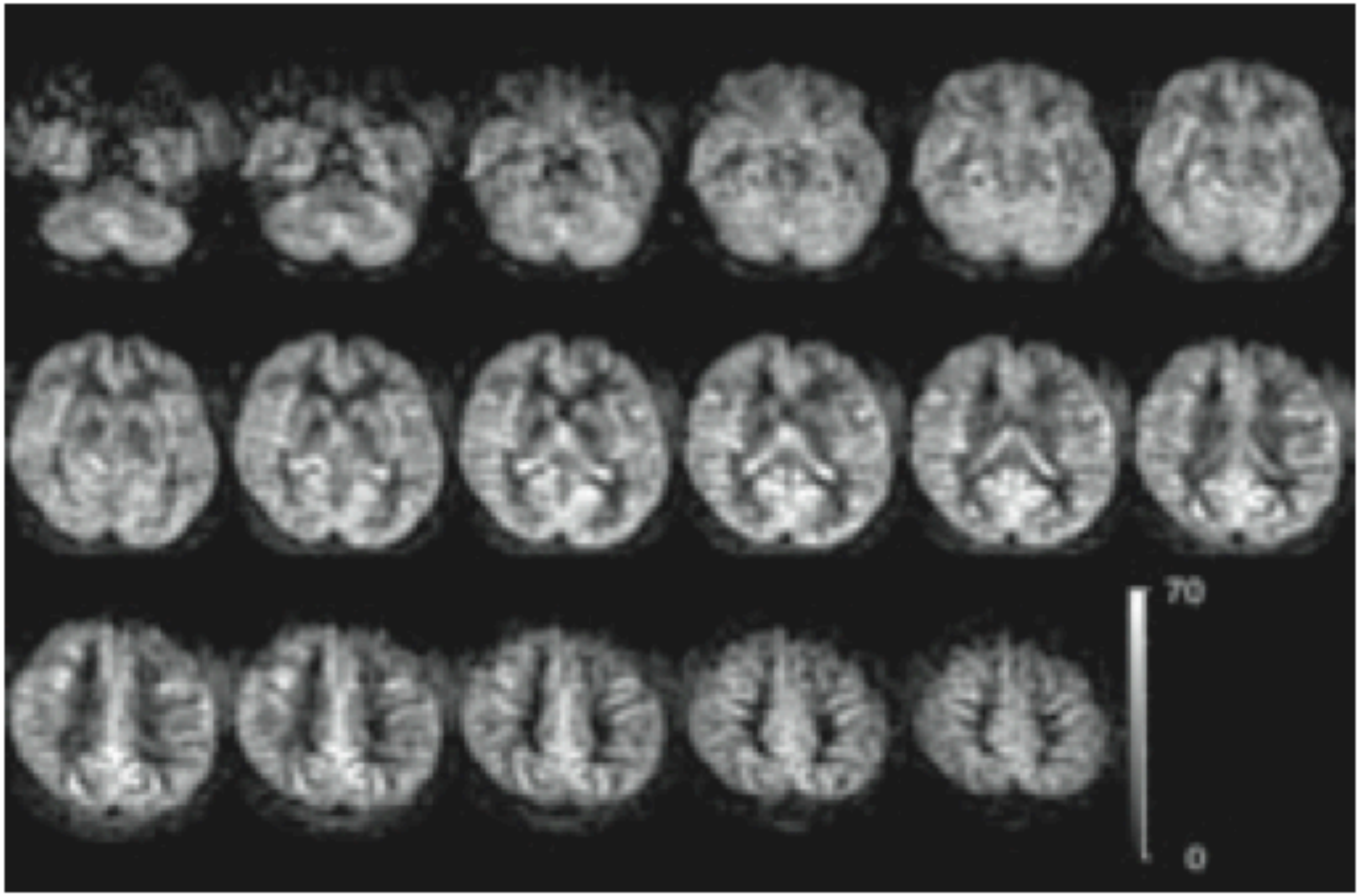


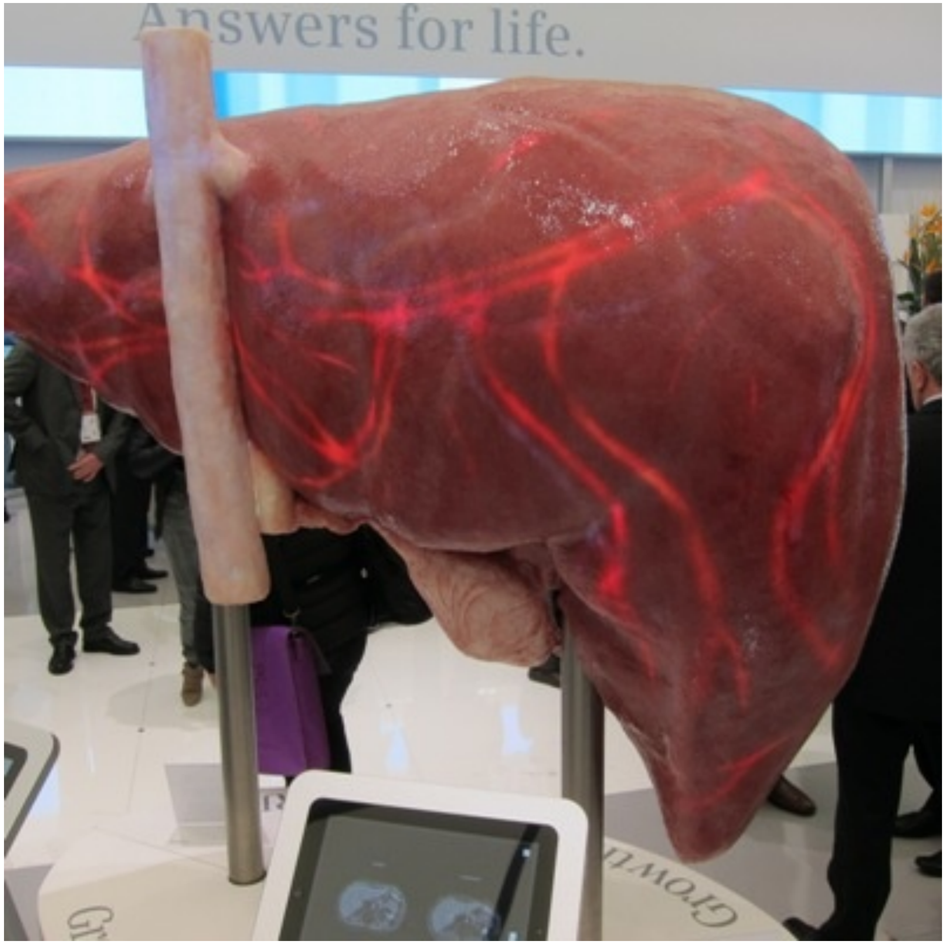
Figure 1. 3D ASL perfusion images of normal brain. 3D ASL prepped 3D FSE acquired with the total acquisition time of 6 minutes and the section thickness of 4.5 mm. Total of 35 sections cover the whole brain region from cerebellum to parietal brain region.

Conclusions

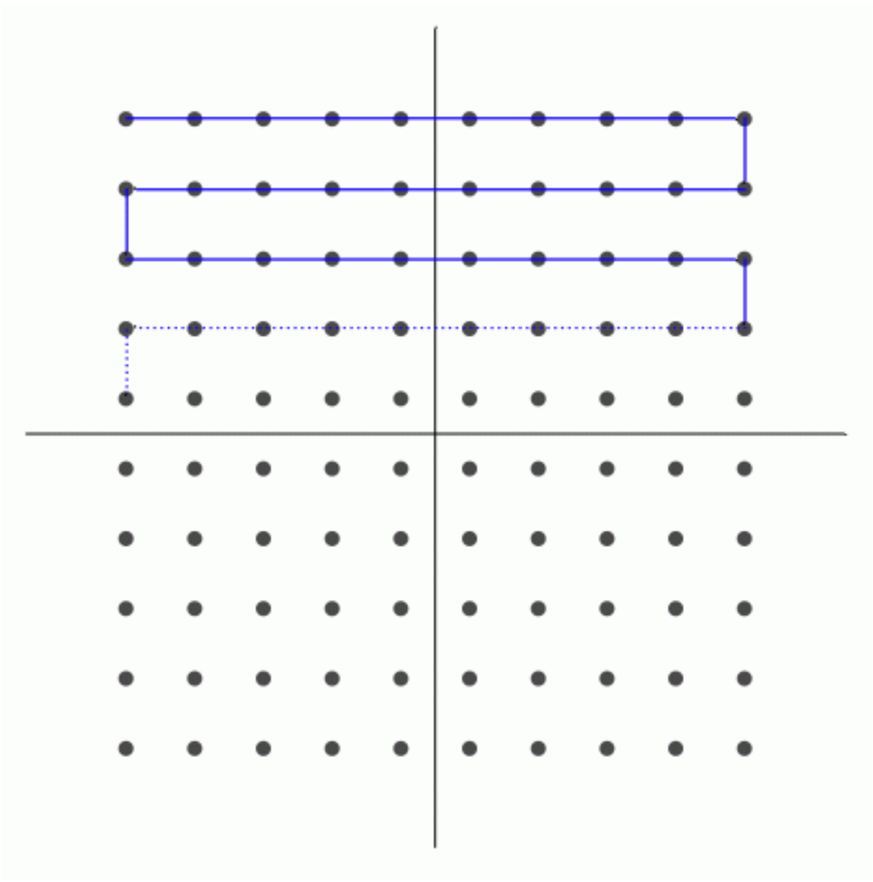
DSC has already proved its value in clinical use.
If you use contrast agent anyway, why not to try DSC as well?
(It is only couple of minutes...)

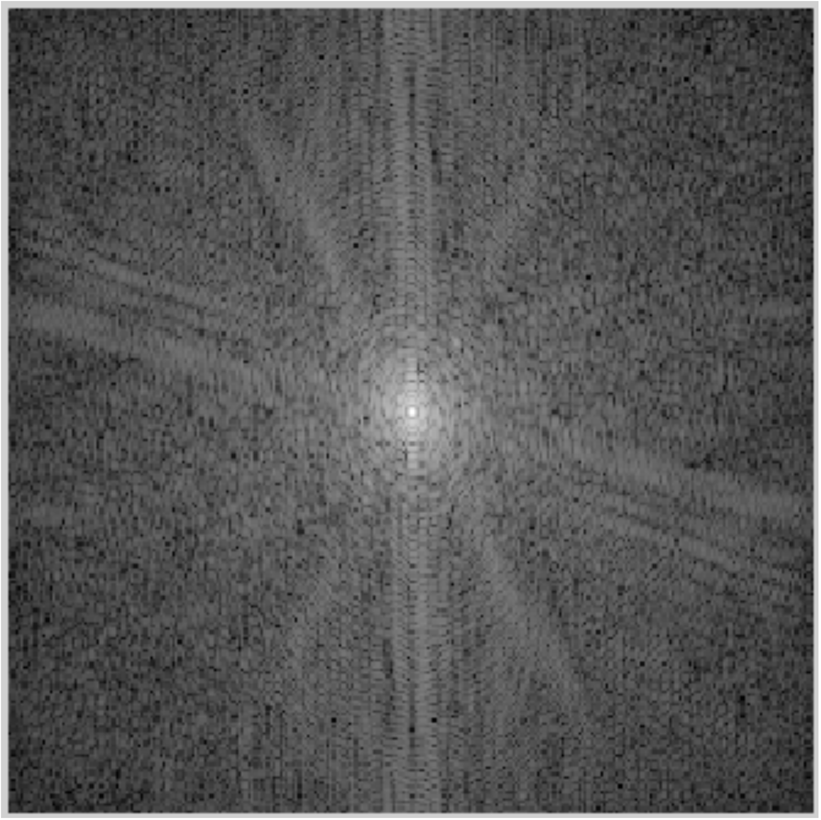
ASL is promising.., but there is no hurry. Method is developing rapidly, so you may get more value for your money after couple of years.

FreezeIt = StarVIBE + TWIST-VIBE

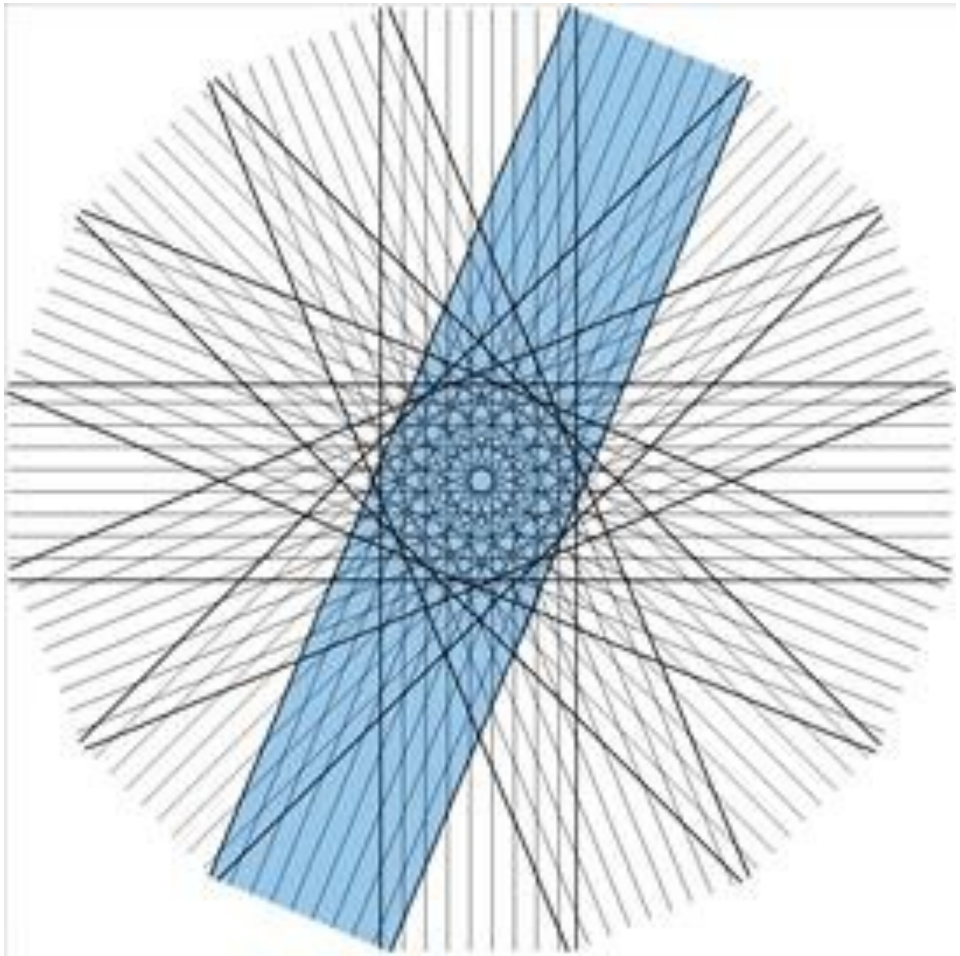


K-avaruus

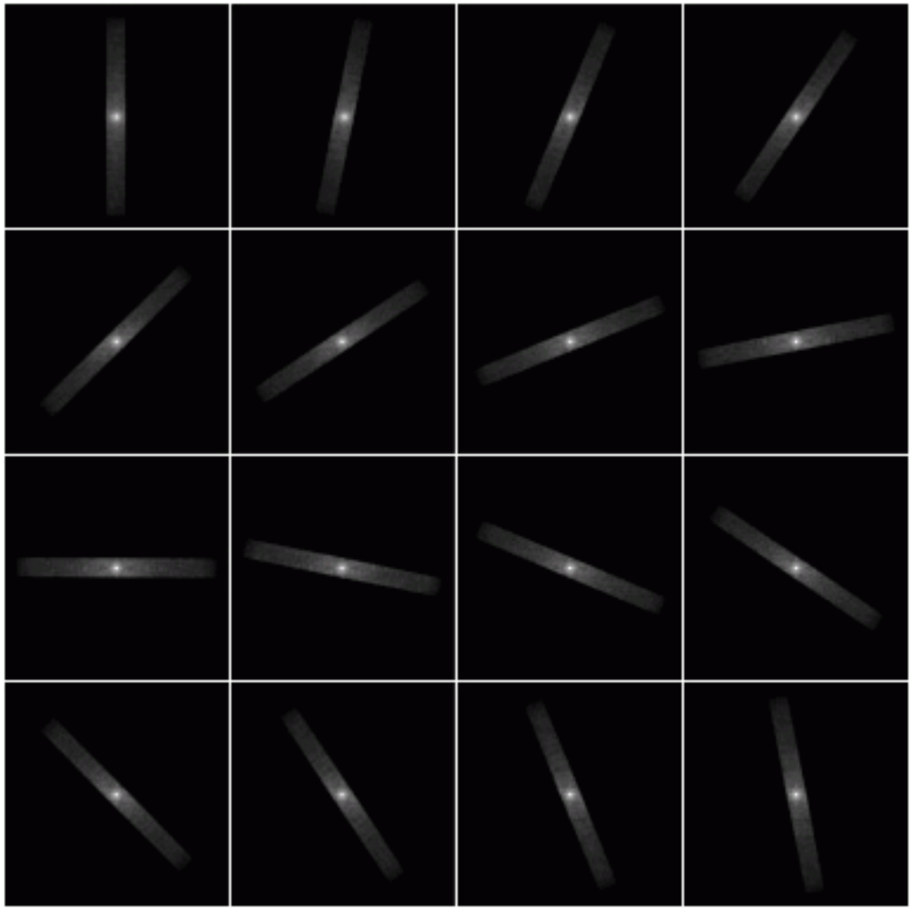


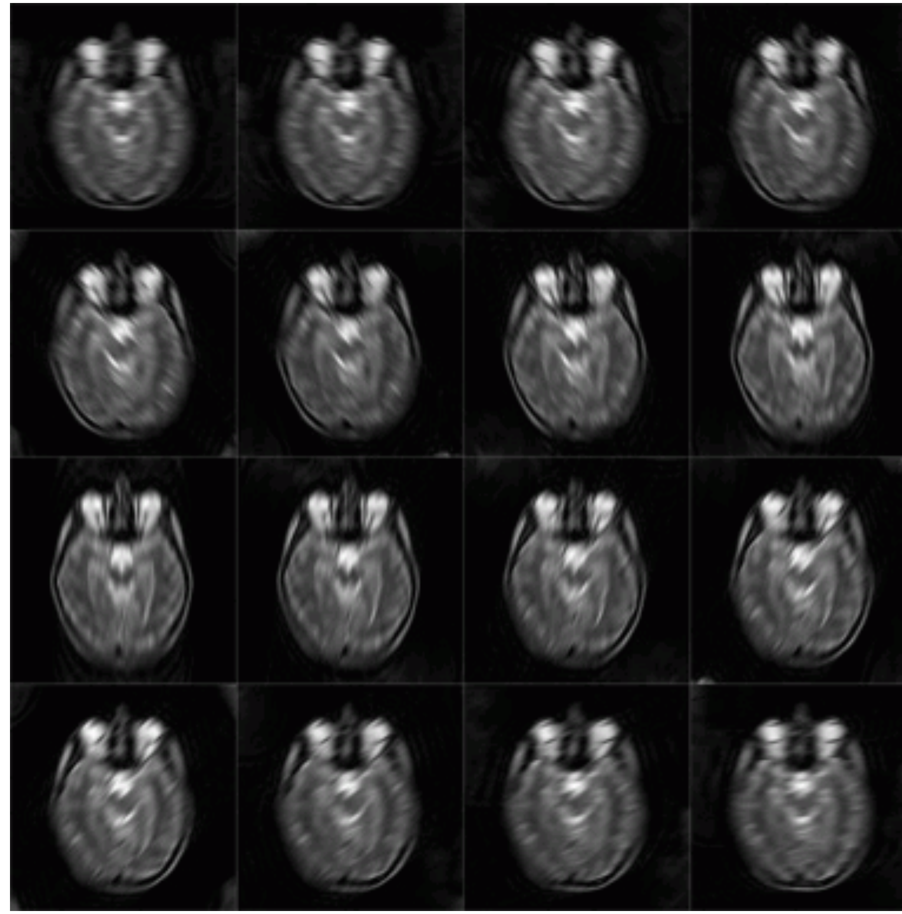


”Propellerissa” data kerätäänkin”potkurin lapa” kerrallaan

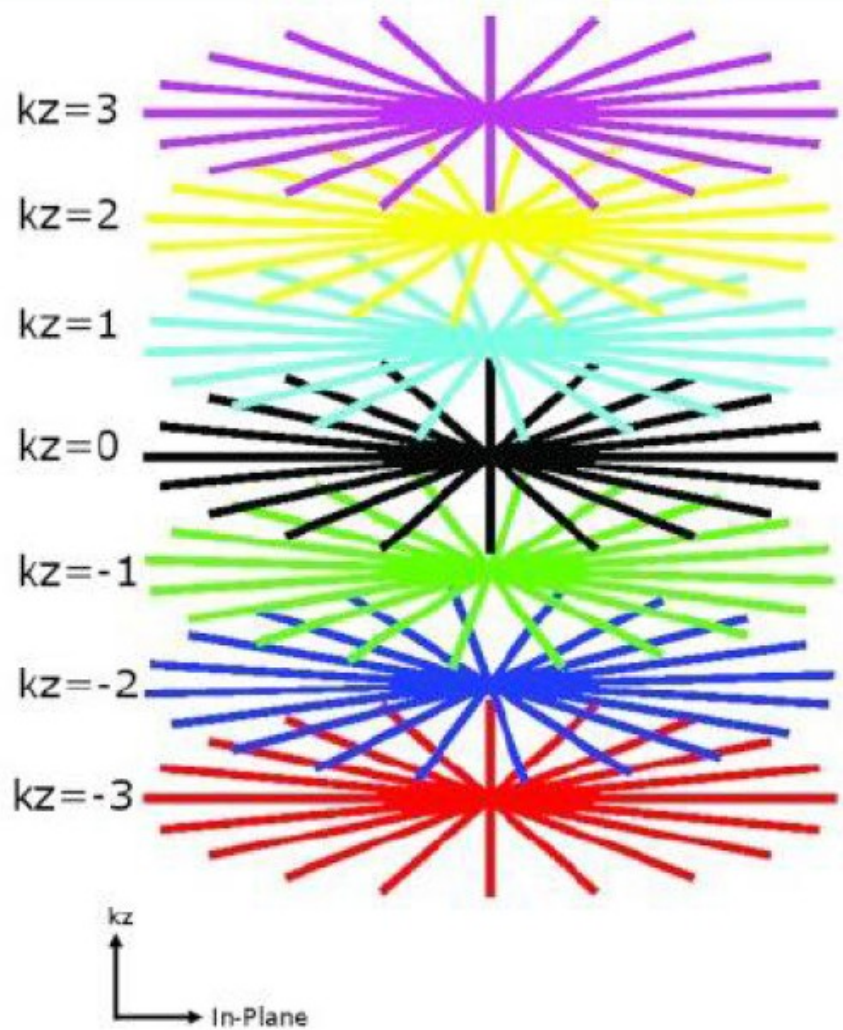


PROPELLER / JET /
BLADE / MULTIVANE



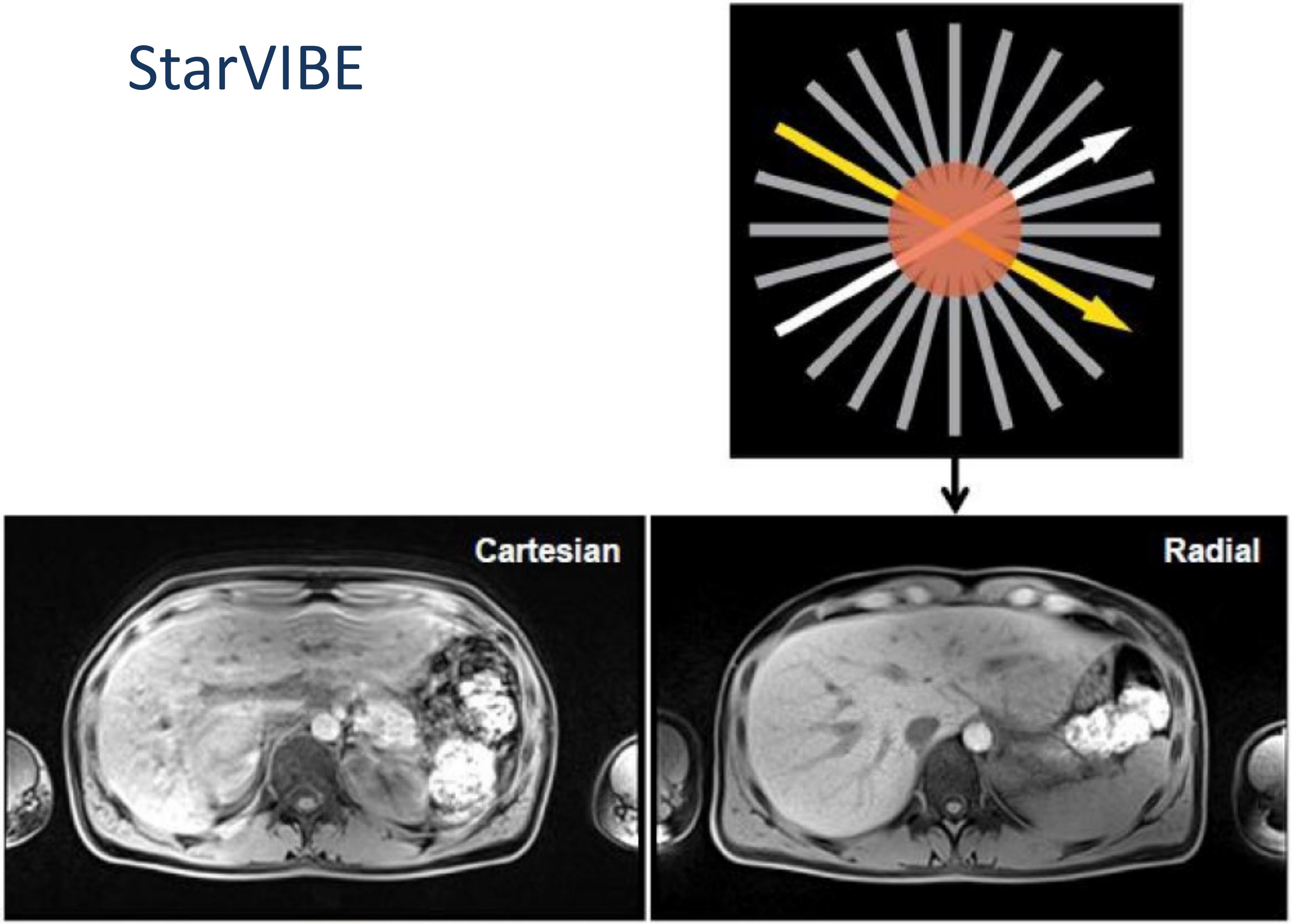


StarVIBE - ”Radiaalinen datan keräys”

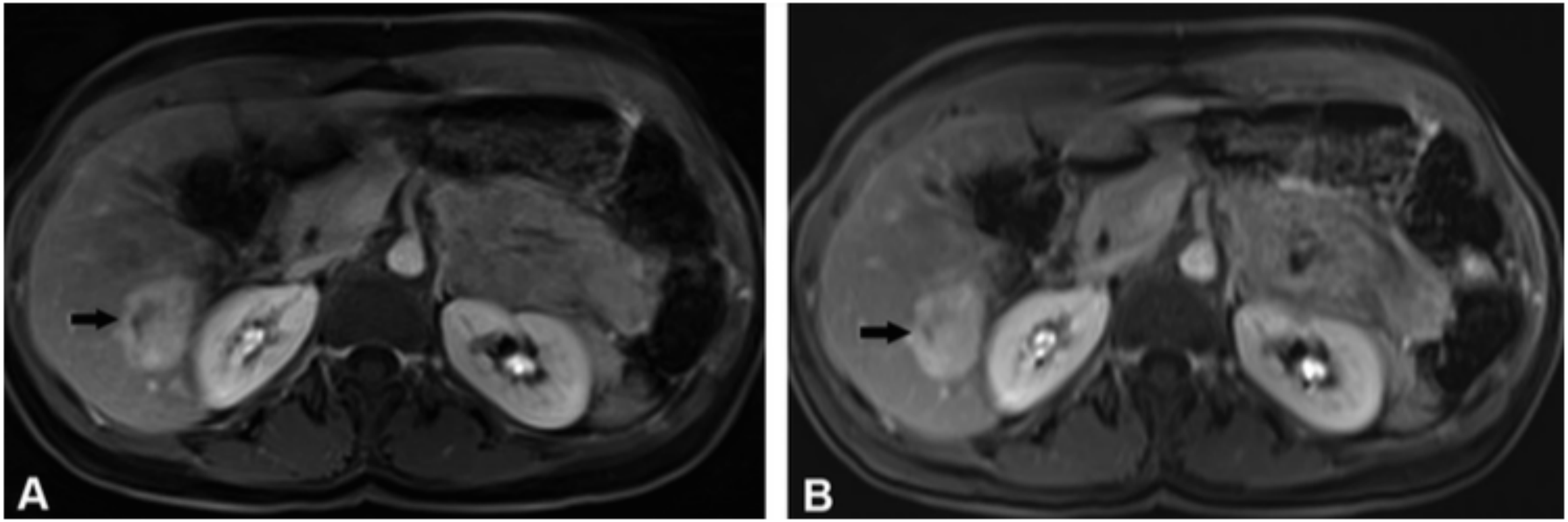


Stack of stars trajectory

StarVIBE

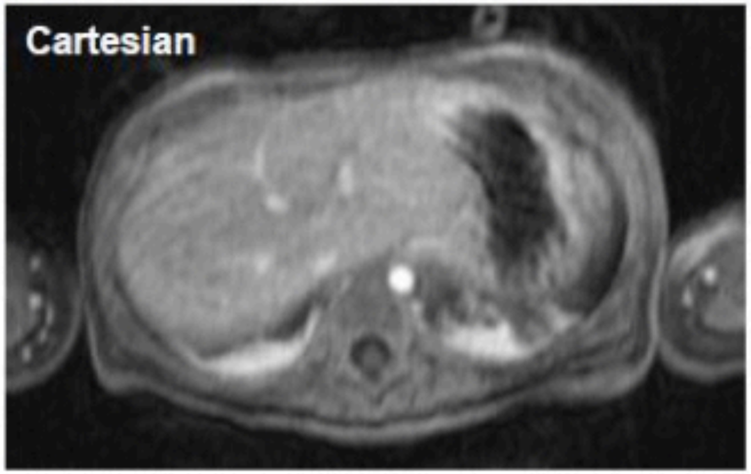


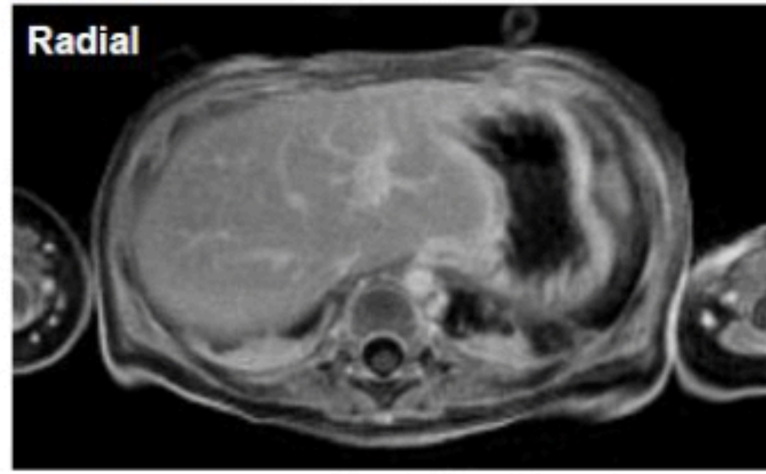
StarVIBE



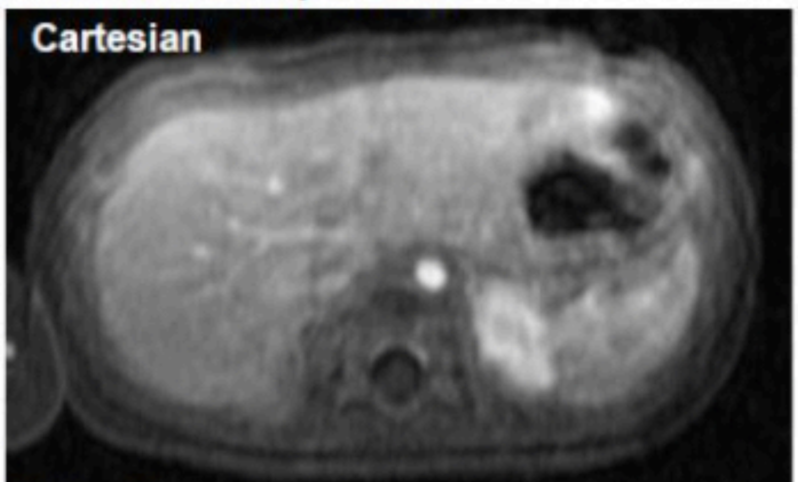
BH VIBE　　StarVIBE

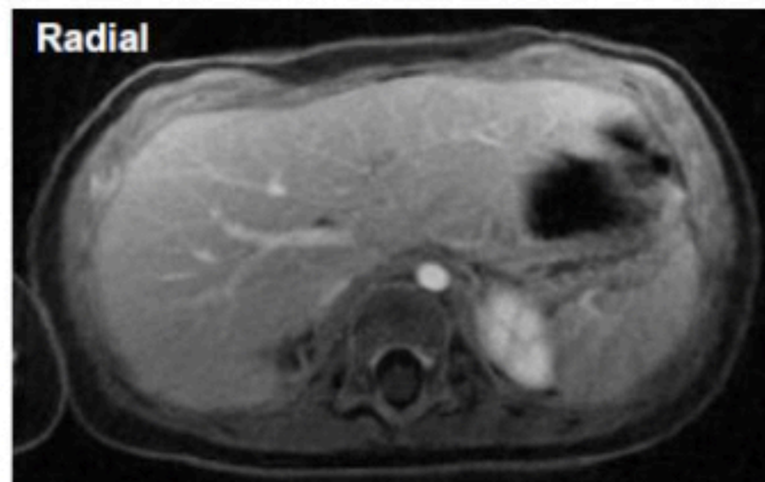
Case of 6-month-old patient at 1.5 Tesla:





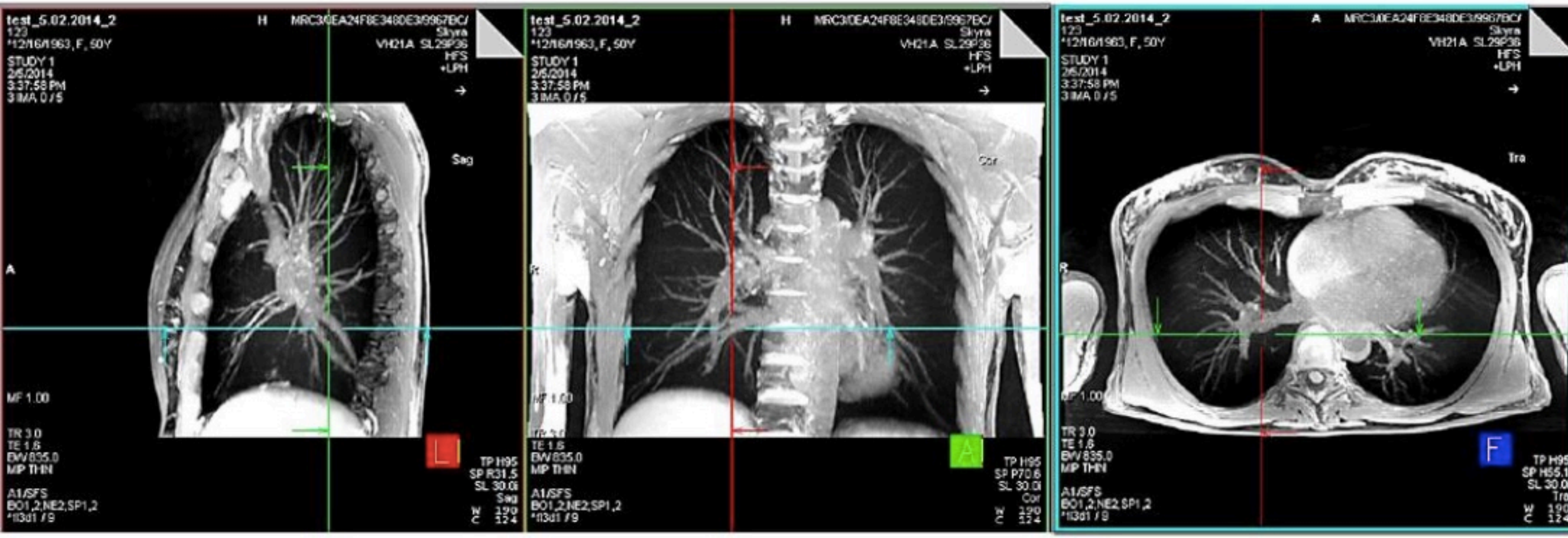
Case of 9-month-old patient:





SIEMENS

StarVIBE Thorax applications



Star-VIBE, isotropic 1x1x1mm in free breathing (thinMIP's)

DIfferential Subsampling with Cartesian Ordering

(DISCO)

Dynamic Contrast Enhanced MRI

with extremely good temporal and spatial resolution

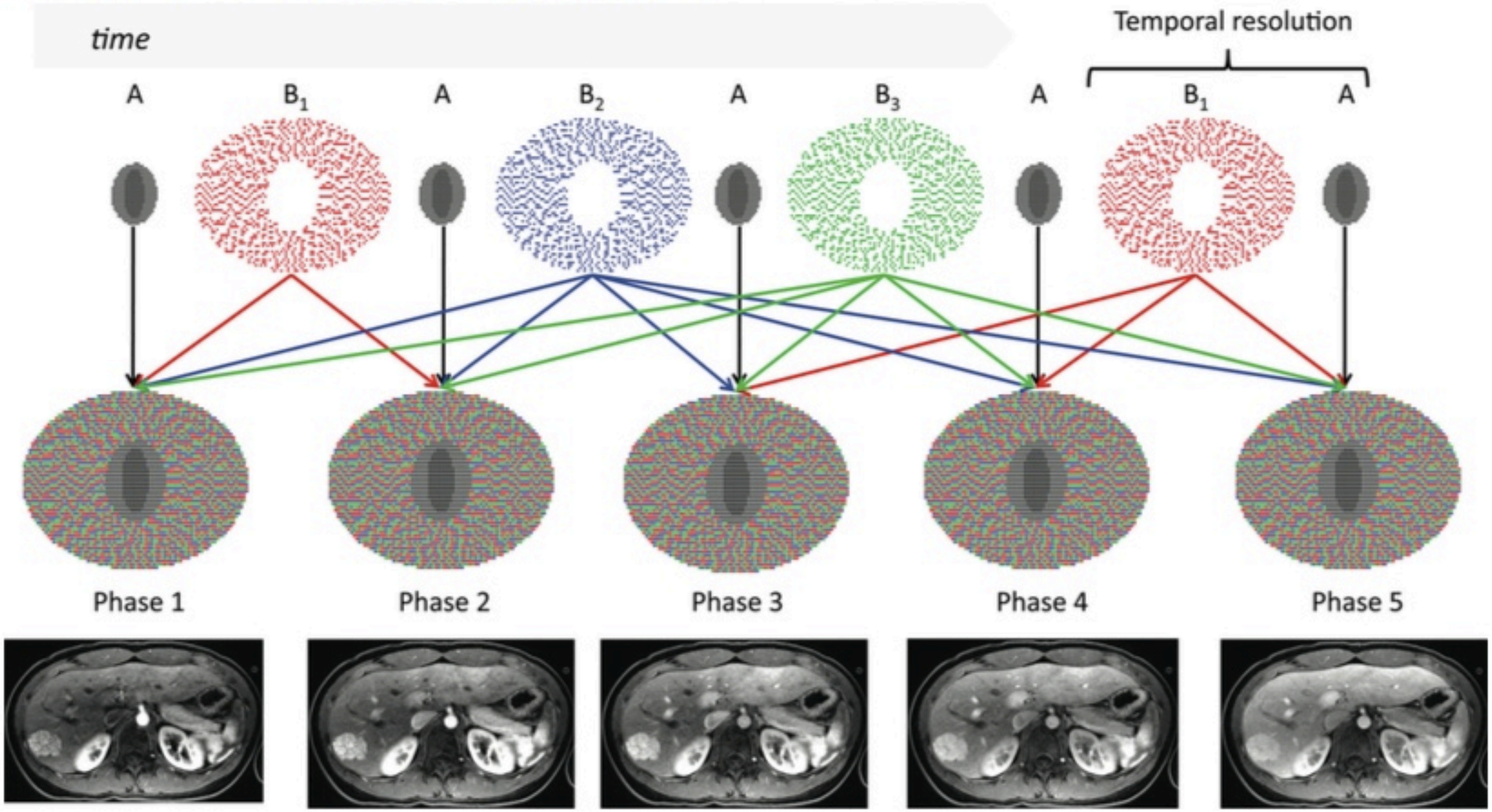
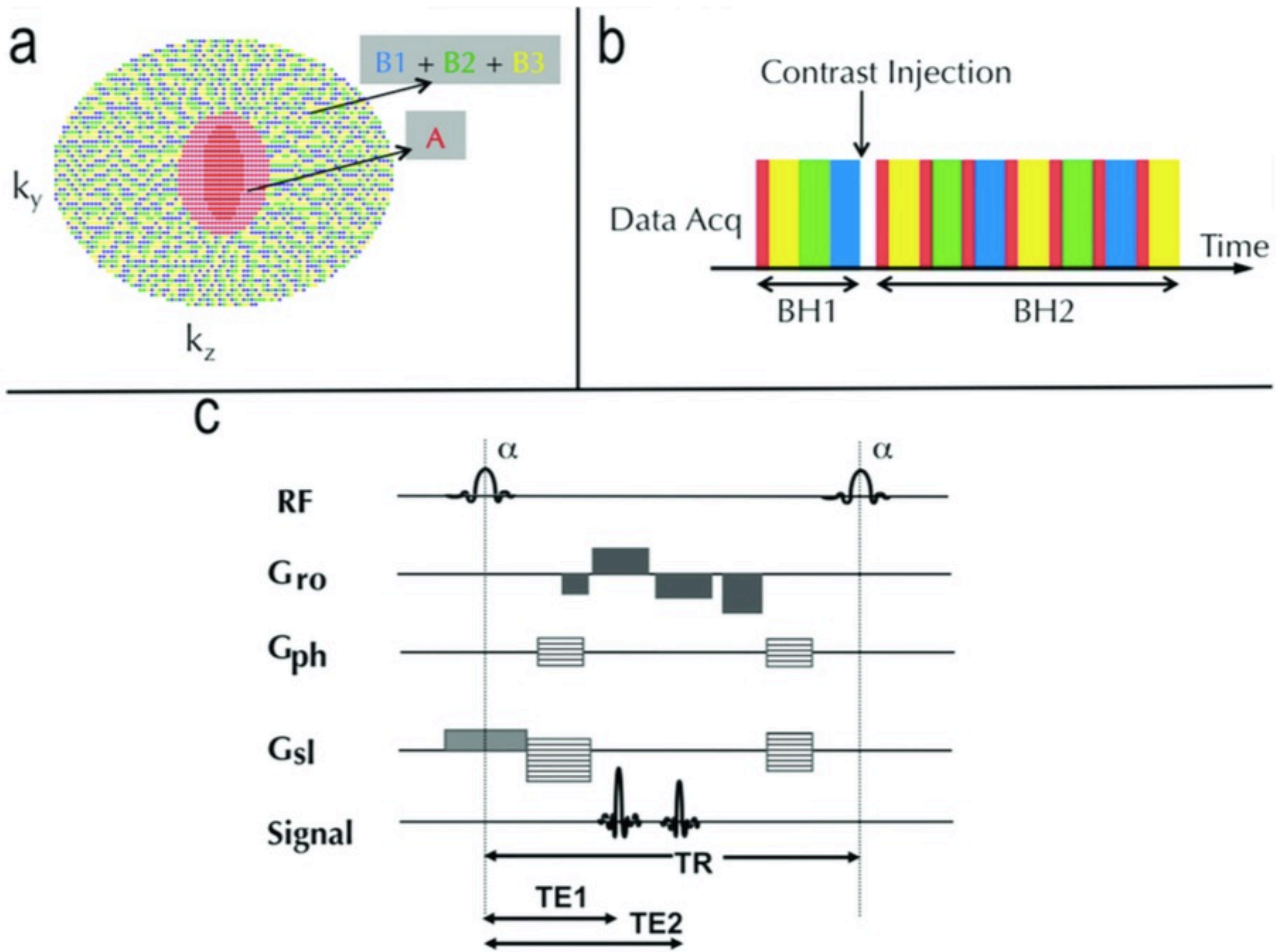
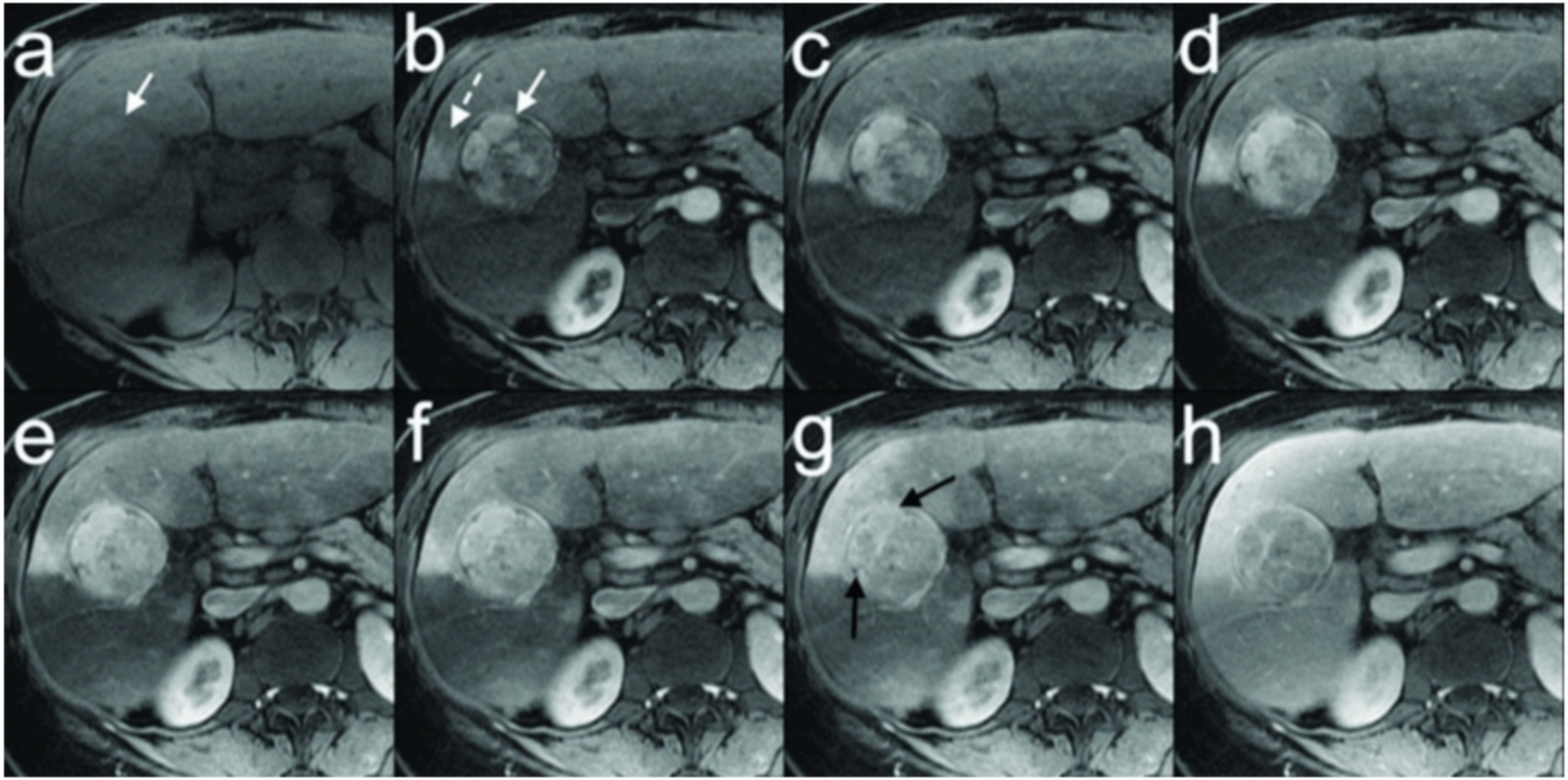


Figure 1. Graphical representation of the high STR multiphase acquisition (DISCO) *k*-space sampling strategy during the arterial breathhold. The periphery of *k*-space is subdivided into three equally distributed pseudo-random selections (labeled B_1, B_2, and B_3). These are sequentially ordered with interspersed acquisitions of the center of *k*-space (labeled A). Each phase is reconstructed from a single center of a *k*-space (A) combined with the nearest peripheral *k*-space neighbors. This results in a temporal resolution of $A + B_n$.

Hope et al, JMRI 38 (2013)


a
B1 + B2 + B3
A
ky
kz
b
Contrast Injection
Data Acq
Time
BH1
BH2
c
α
α
RF
Gro
Gph
Gsl
Signal
TR
TE1
TE2

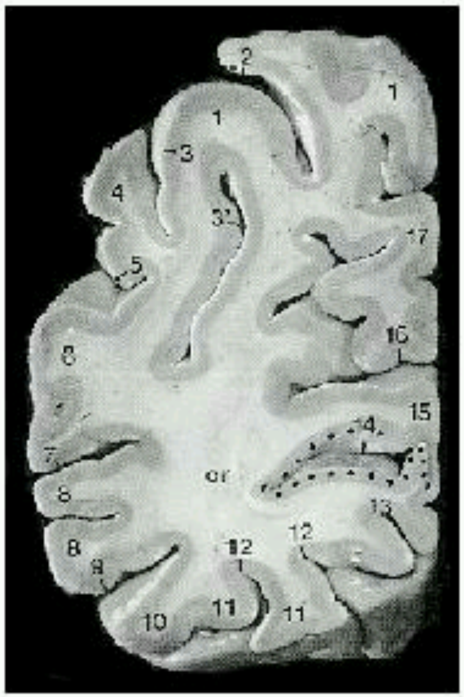


Temporal resolution 4 seconds.

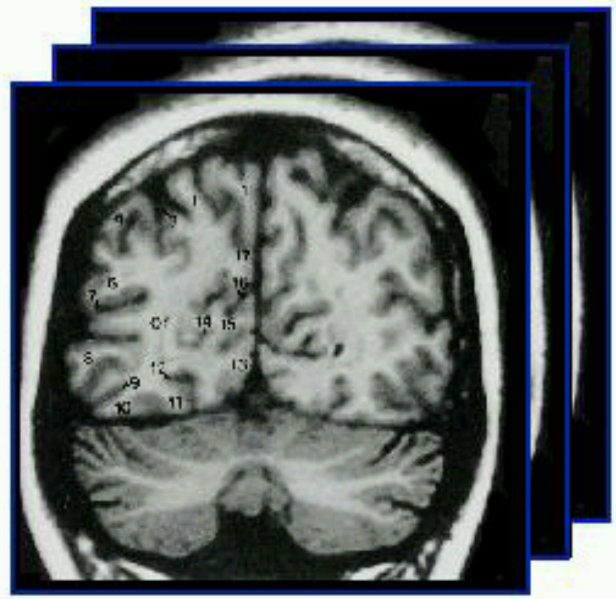
Saranathan et al, JMRI 35 (2012)

Functional MRI ***fMRI***

Structural MRI



Photograph of Cortex



MRI of Cortex

fMRI: BOLD- method

BOLD = **B**lood **O**xygen **D**ependent **L**evel

- oxyhemoglobin HbO_2 is a diamagnetic molecule;
- deoxyhemoglobin Hb is a paramagnetic molecule;

Cerebral activation <u>decreases</u> paramagnetic [Hb]

During cerebral activation regional cerebral blood flow (CBF) does increase, but the cerebral metabolic rate of oxygen consumption (CMRO2) is not commensurately elevated. CBF and CMRO2 are thus said to be "uncoupled". Paradoxically, more fresh (oxygenated) blood has been supplied to that region of brain than is required for its immediate metabolic needs.

This "overshoot" of oxygenated blood means that the relative concentration of deoxyhemoglobin in activated areas will decrease. The T2/T2* shortening effects of dexoyhemoglobin will be diminished and the BOLD signal in activated areas will therefore increase.

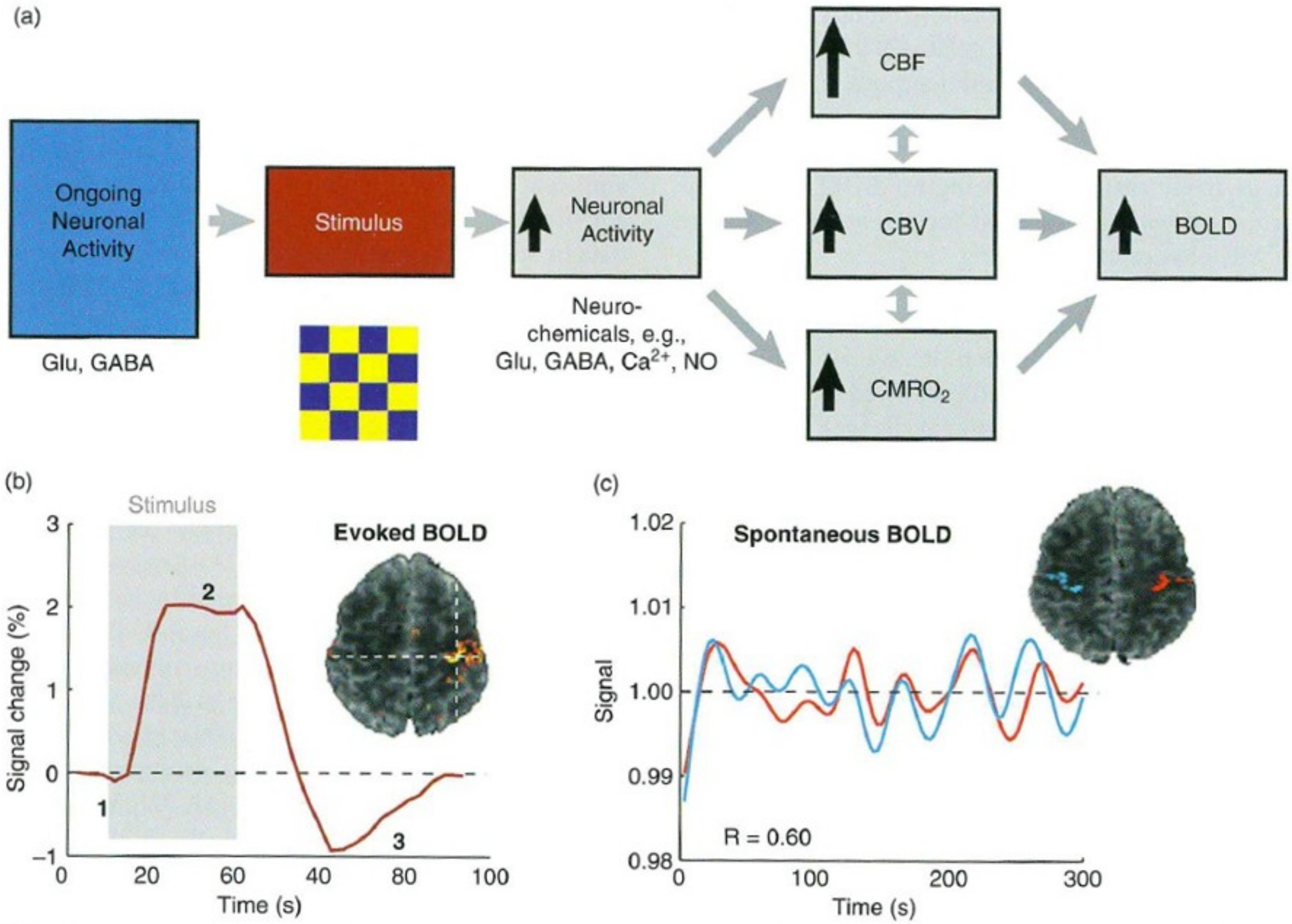


Figure 7.2 Overview of events leading to BOLD signal. (a) Ongoing neuronal activity is primarily influenced by glutamate (Glu) and γ-aminobutyric acid (GABA) signaling. In response to a stimulus, increased neuronal activity and neurochemical changes elicit a large increase in CBF, and a smaller increase in cerebral blood volume (CBV) and cerebral rate of oxygen metabolism ($CMRO_2$). (b) Evoked BOLD fMRI. A stimulus-evoked BOLD activation map (finger tapping) and response showing the (1) initial dip, (2) positive response, and (3) post-stimulus undershoot. (c) Spontaneous BOLD activation. Voxels in the motor cortex showing coherent fluctuations; the coherence of such fluctuations can be used to map regions of functional connectivity in the absence of administered tasks (so-called "resting-state fMRI"). CBF is central to eliciting BOLD responses, and therefore separate measurements of CBF can both complement and in certain applications replace BOLD fMRI. NO, nitric oxide.

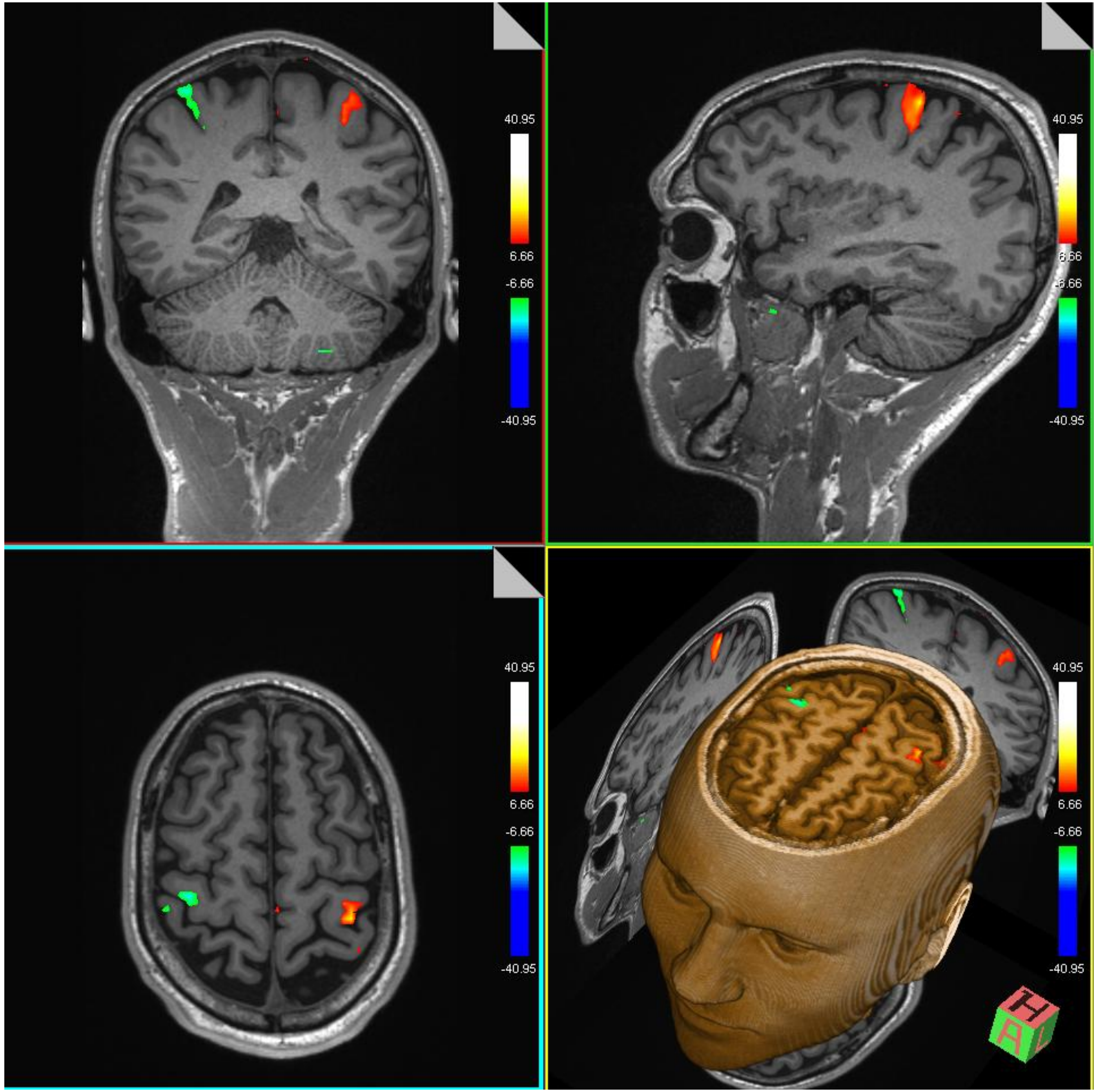
Barker et al. Clinical Perfusion MRI

fMRI experiment

”finger tapping”

Left hand:
Baseline = green

Right hand:
Activation = red



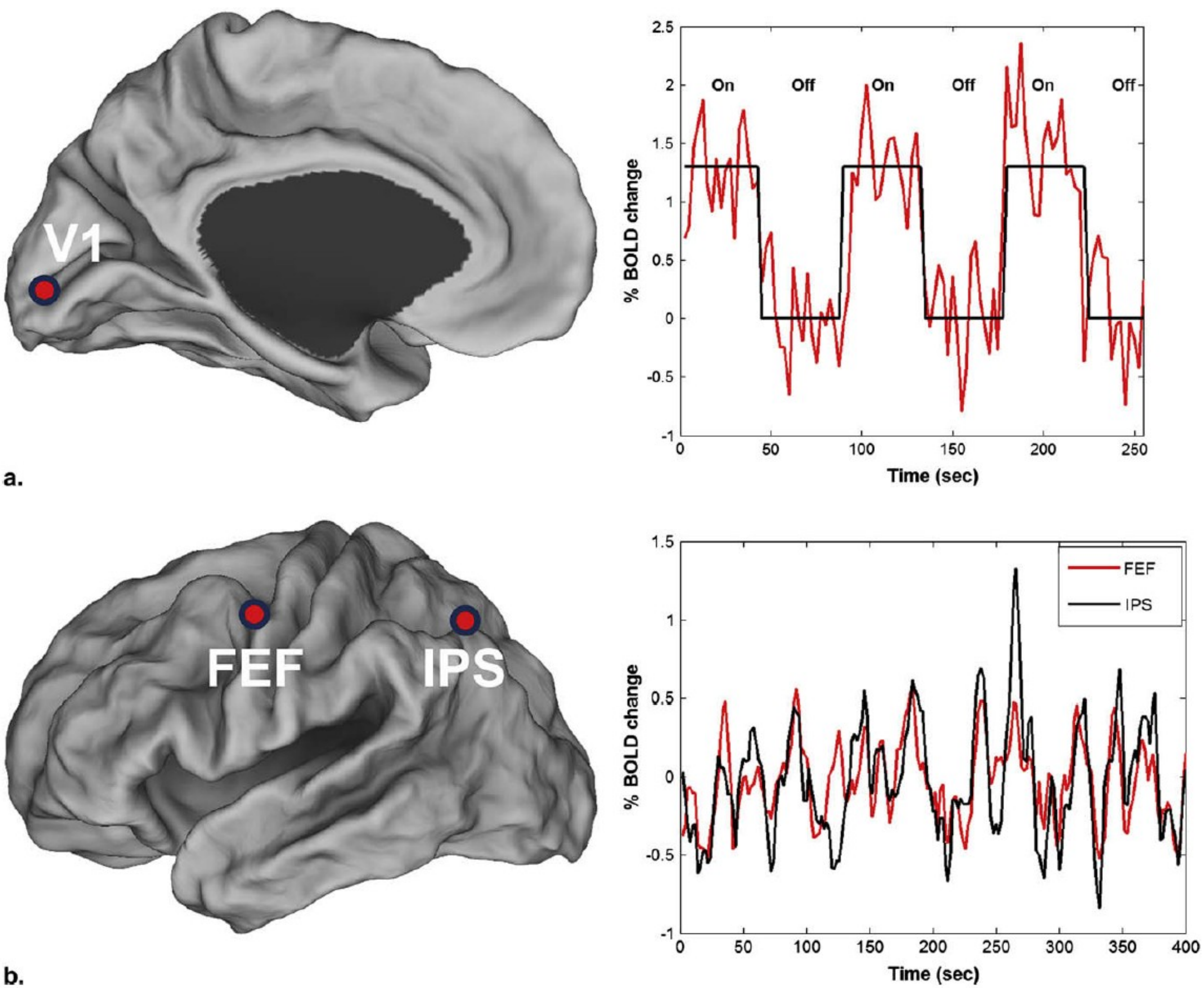


Figure 1. The blood oxygen level–dependent (BOLD) signal during task-based functional magnetic resonance imaging (fMRI) **(a)** and during intrinsic resting-state fMRI **(b)**. **(a)** The subject focused on a flickering checkerboard pattern that was periodically turned on and off. The measurement was made in the V1 region of the visual cortex *(red circle)*. Ongoing spontaneous fluctuations can be seen in this task paradigm. **(b)** Spontaneous fluctuations from two regions of the dorsal attention system. The regions are the intraparietal sulcus (IPS) and the frontal eye fields (FEF) *(red circles)*. The two time curves demonstrate a high degree of correlation (r = 0.60).

Shimony et al.
Acad Radiol 2009

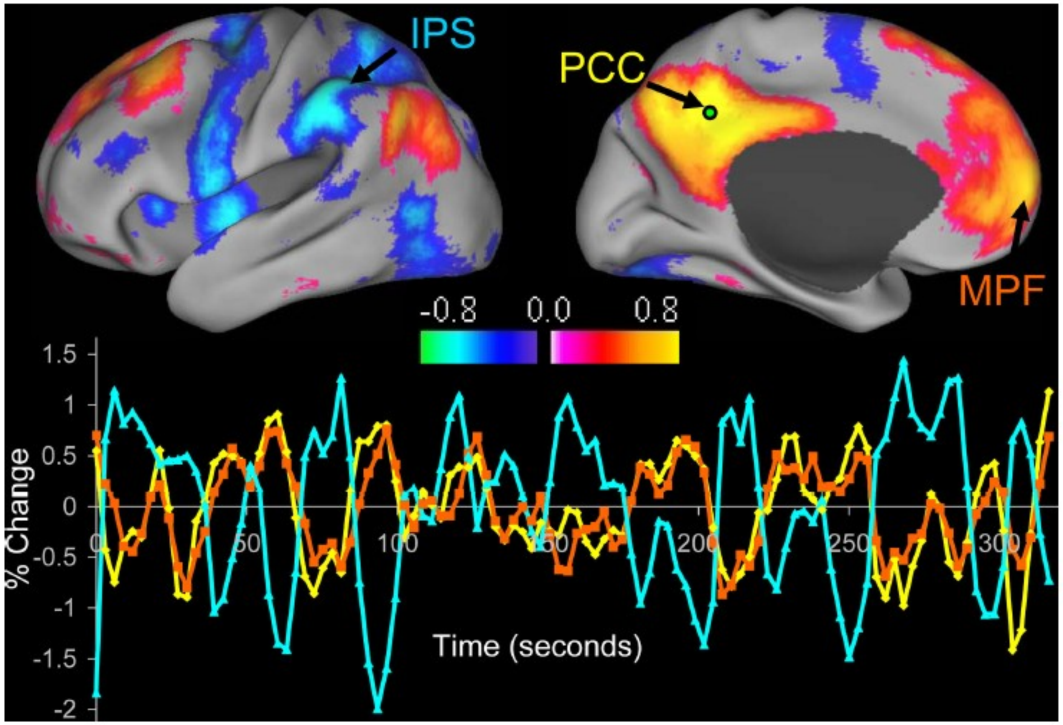


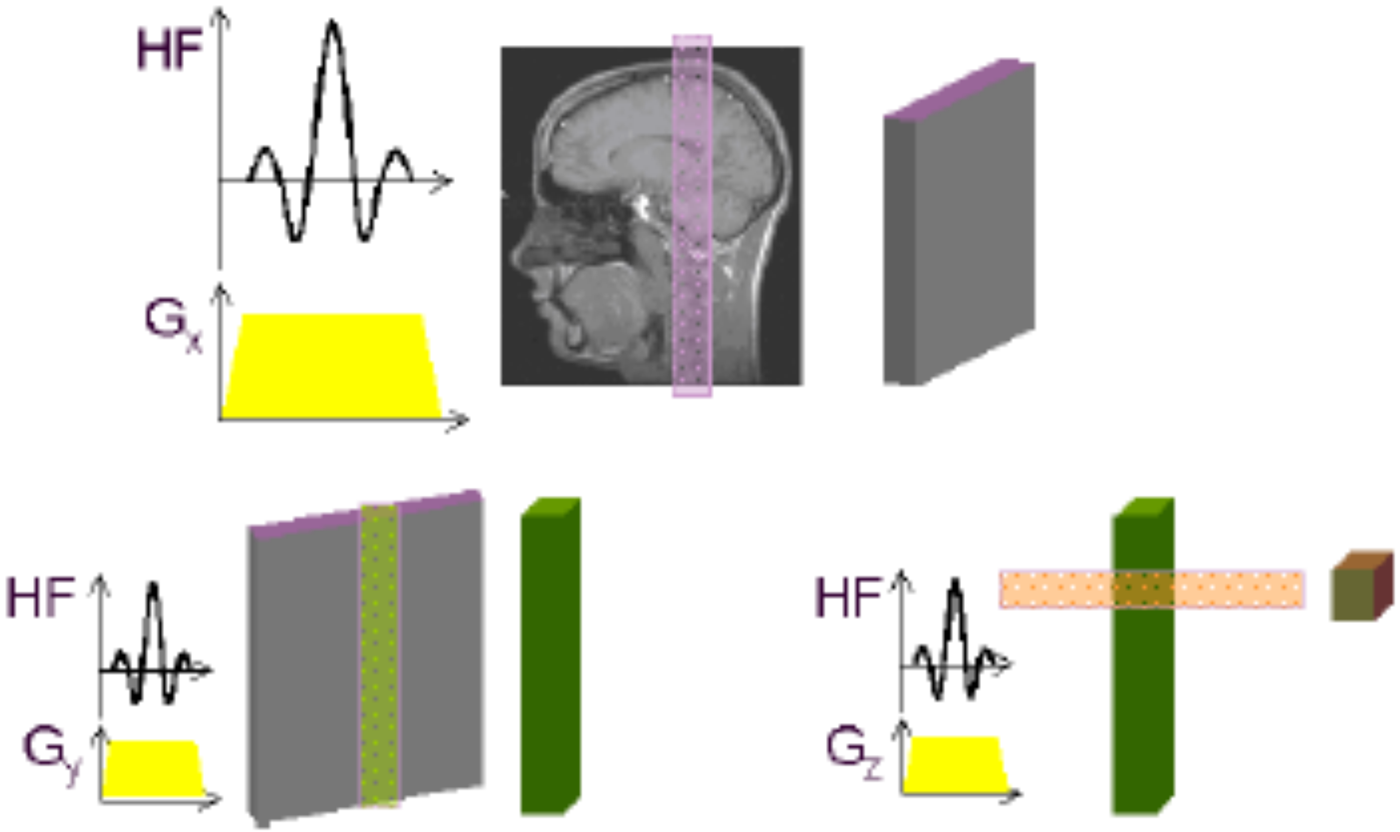
FIGURE 1 | Resting state functional connectivity reveals correlations and anticorrelations with the default mode network. Correlations between a seed region in the posterior cingulate/precuneus (PCC) and all other voxels in the brain for a single subject during resting fixation. Both correlations (positive values) and anticorrelations (negative values) are shown, thresholded at $R = 0.3$. The time course for a single run is shown for the seed region (PCC, yellow), a region positively correlated with this seed region in the medial prefrontal cortex (MPF, orange), and a region negatively correlated with the seed region in the intraparietal sulcus (IPS, blue). Reproduced with permission from (Fox et al., 2005).

Applications

- Display of neurally active regions of the brain due to motor or sensory stimulation and/or cognitive processes
- Analysis of the cerebral organization of functional systems
- Examination of changes in activity due to local brain lesions
- Identification of functionally important areas prior to brain surgery

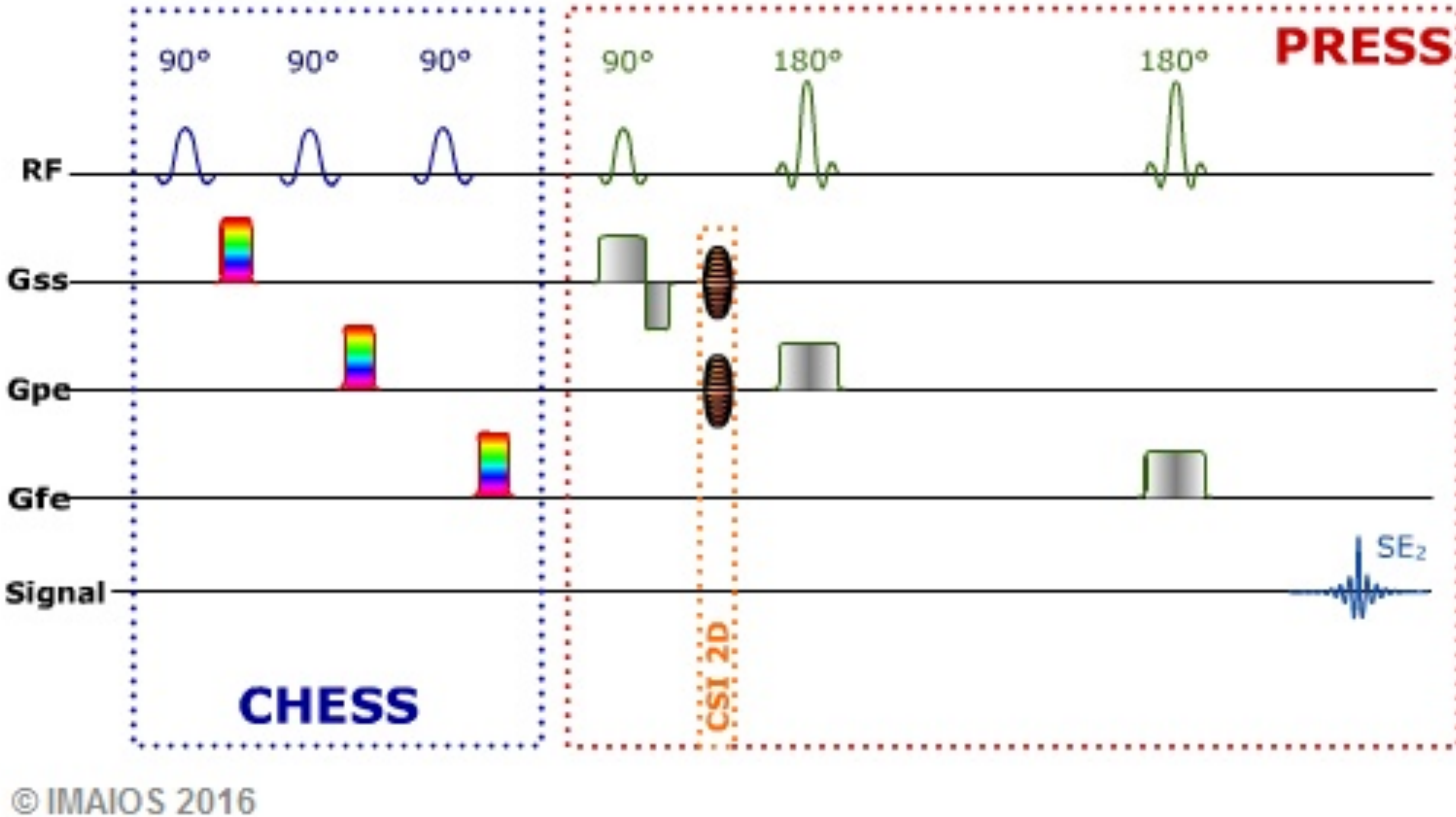
MR spectroscopy

Single voxel spectroscopy



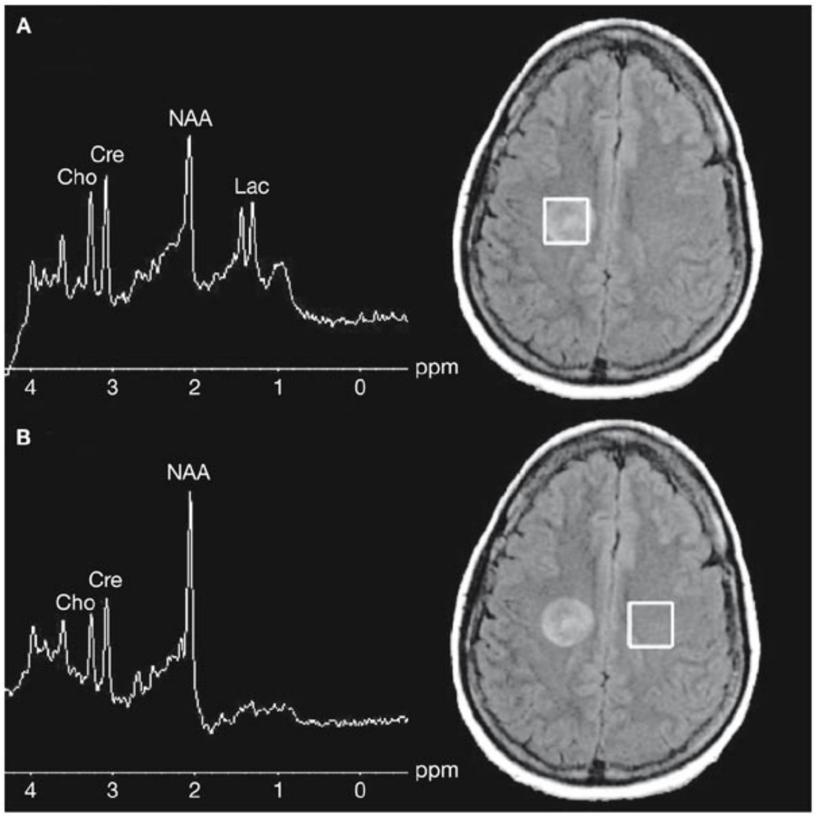
By applying orthogonal ”slice encoding gradients” during excitation, it is possible to measure signal only from the voxel you want.
Signals from other regions outside the desired voxel are eliminated by dephasing crusher gradients and/or phase-cycling of the radiofrequency pulses

Chemical Shift Imaging

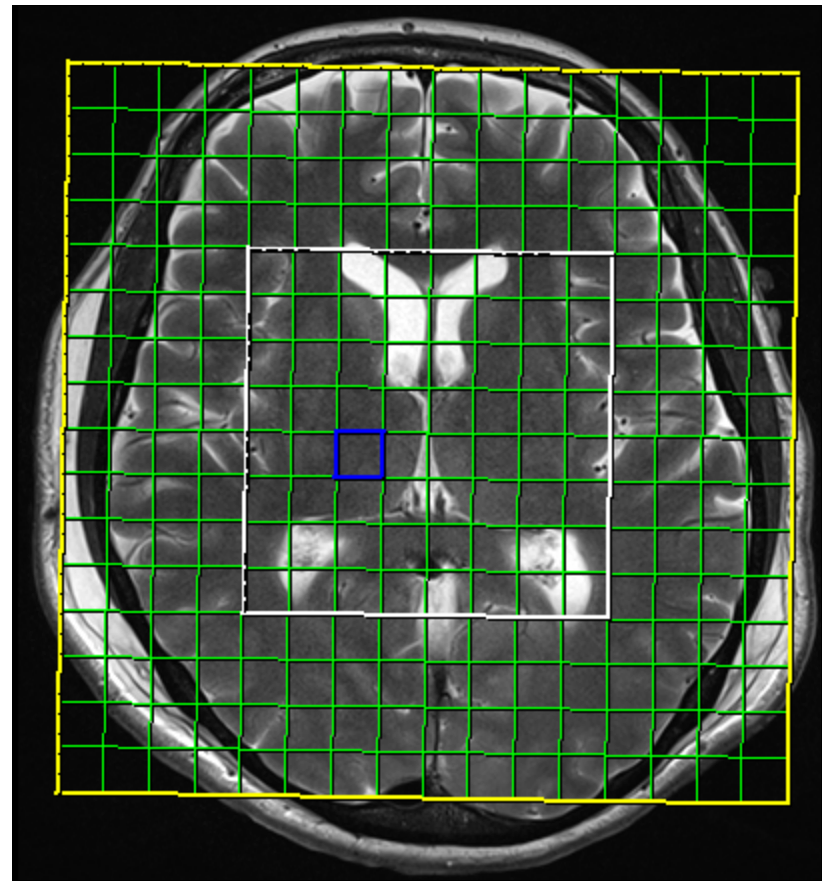


Metabolic imaging (CSI) consists in recording the spectroscopic data for a group of voxels, in slice(s) (2D) or by volume (3D). It is based on a repetition of STEAM or PRESS type sequences to which is added spatial phase encoding. The number and direction of phase encodings depend on the number of dimensions explored (1D, 2D or 3D), adding on to acquisition time.

Only after anatomical imaging, it is possible to determine the position of the voxel or grid (”voxel matrix”), where spectrum is measured…



Single voxel spectroscopy (SVS)



Multiple-voxel spectroscopic imaging (MRSI)
Chemical Shift Imaging (CSI)

Very simplified explanation of phase encoding in CSI

If you want get CSI data with 16x16 voxels, you have to collect 16x16=256 acquisitions. Each time phase encoding gradients are used in little bit different way in order to get spatial (location) information to acquired signal.

If TR time is 3 seconds, total acquisition time will be almost 13 minutes…