INTERNAL MRI COURSE

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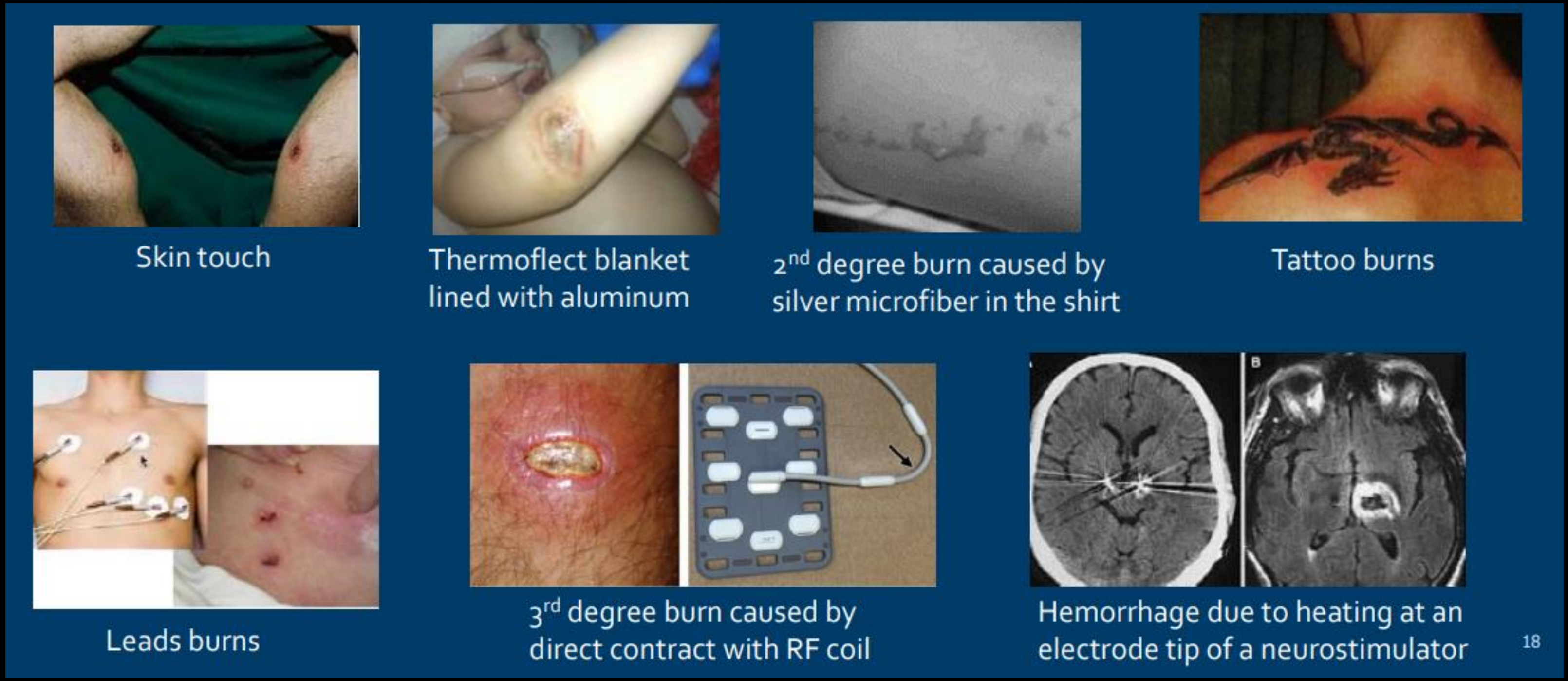
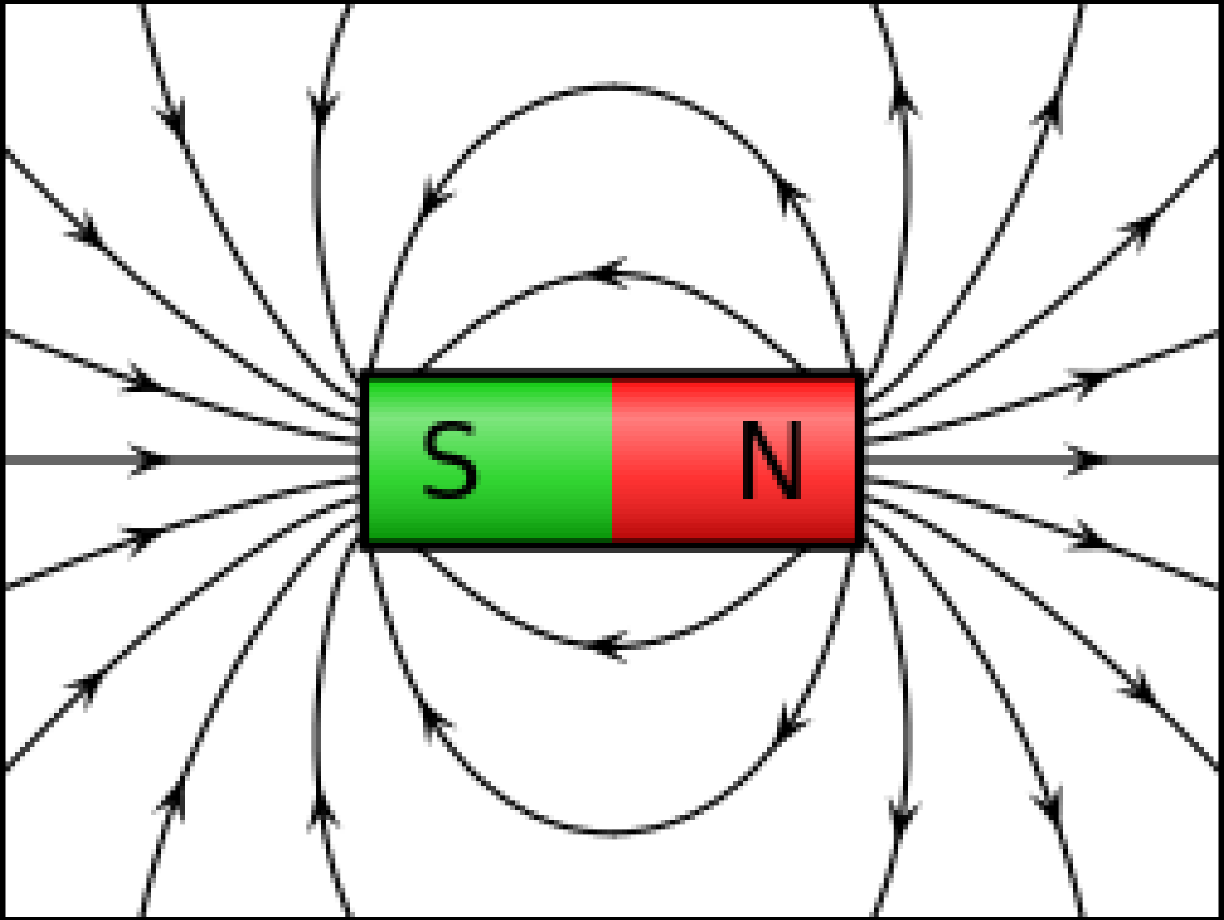
WHY KNOW THE BASICS OF MRI

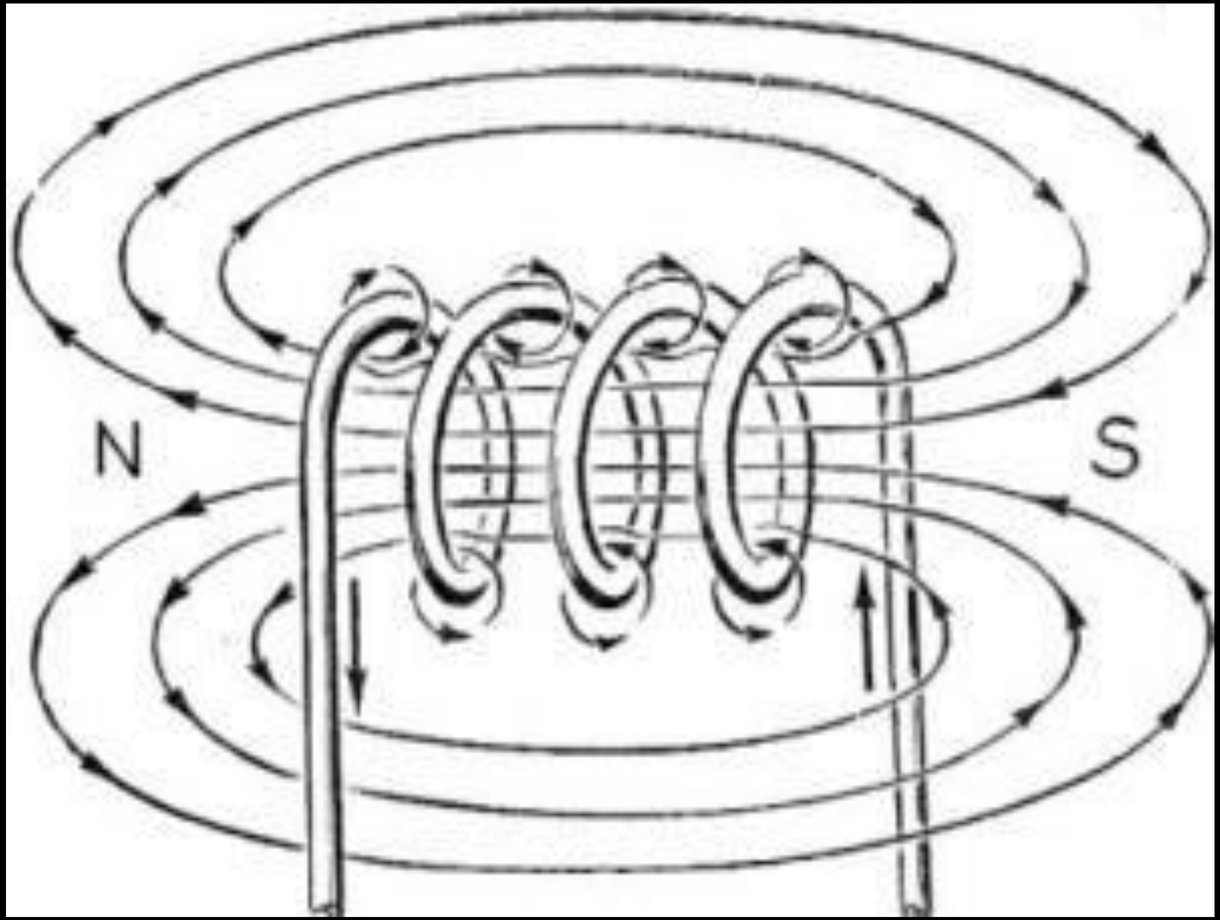


HISTORY OF MRI

- 1921 – Discovery of electron spin (A. Compton).
- 1924 – Discovery of nuclear spin (W. Pauli).
- 1938 – Confirmation of the Magnetic Quantum Phenomenon (NMR) (I.I. Rabi).
- 1945 – Improvement of the Rabi instrument (birth of NMR spectroscopy) (F. Bloch and E. Purcell).
- 1949 – Discovery of chemical shift.
- 1971 – Different tissues have different relaxation periods (R. Damadian).
- 1973 – the beginnings of tomographic MRI (P. Lauterbur).
- 1977 – First full-body MRI (R. Damadian).
- 1987 – birth of MR angiography (blood flow imaging).
- 1992 – Birth of functional MRI (fMRI).
-

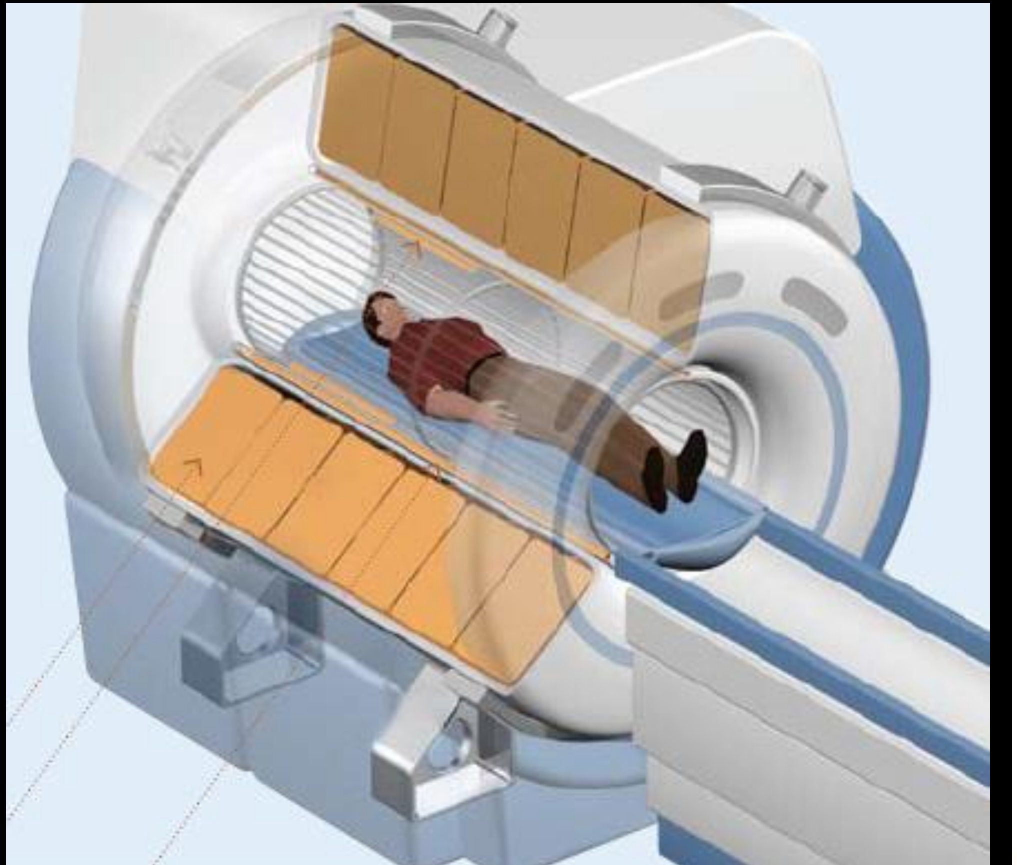
MAGNETIC FIELD

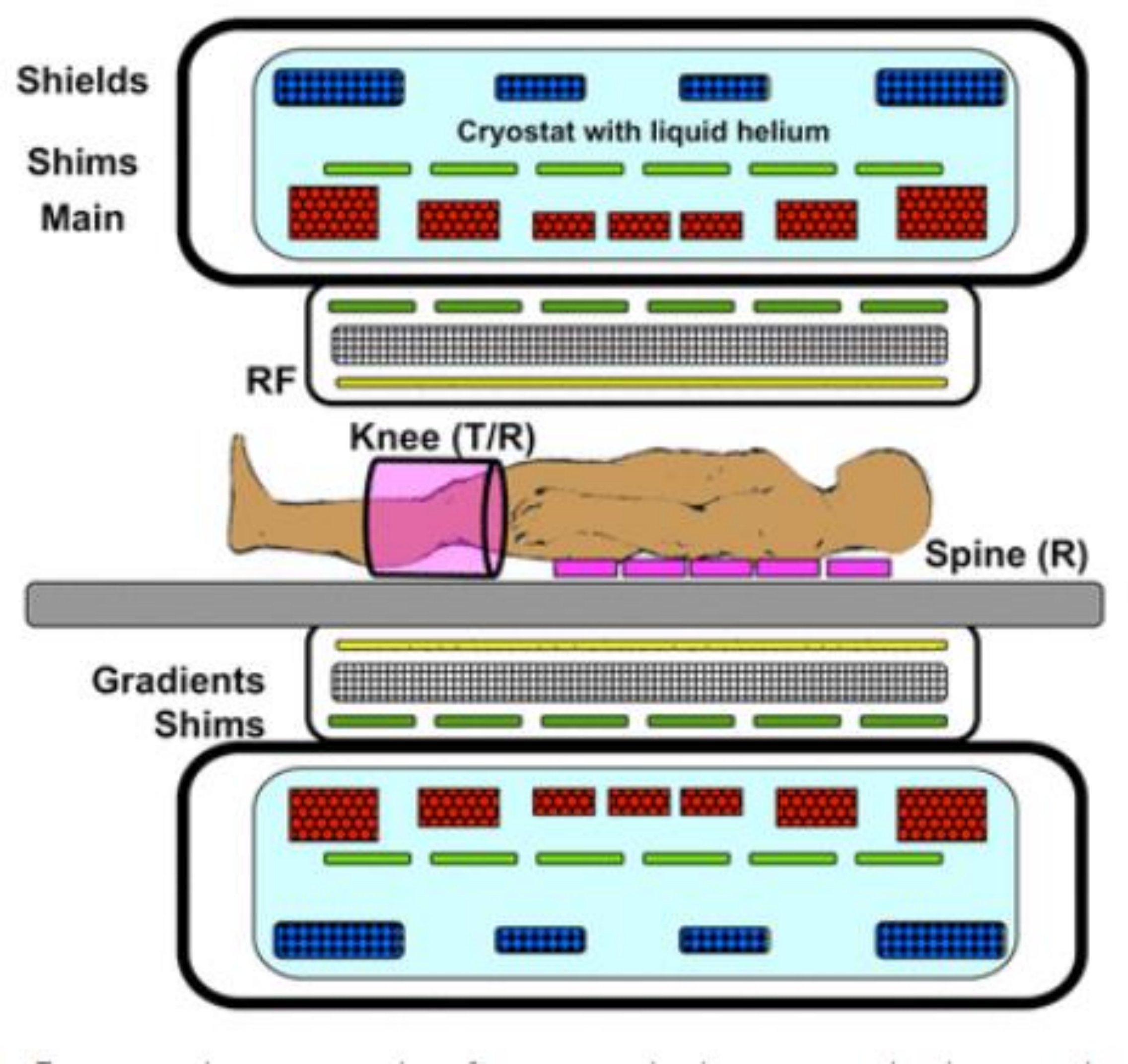




MAGNETIC FIELD

- Homogeneity of mag. Field
- Coils
-





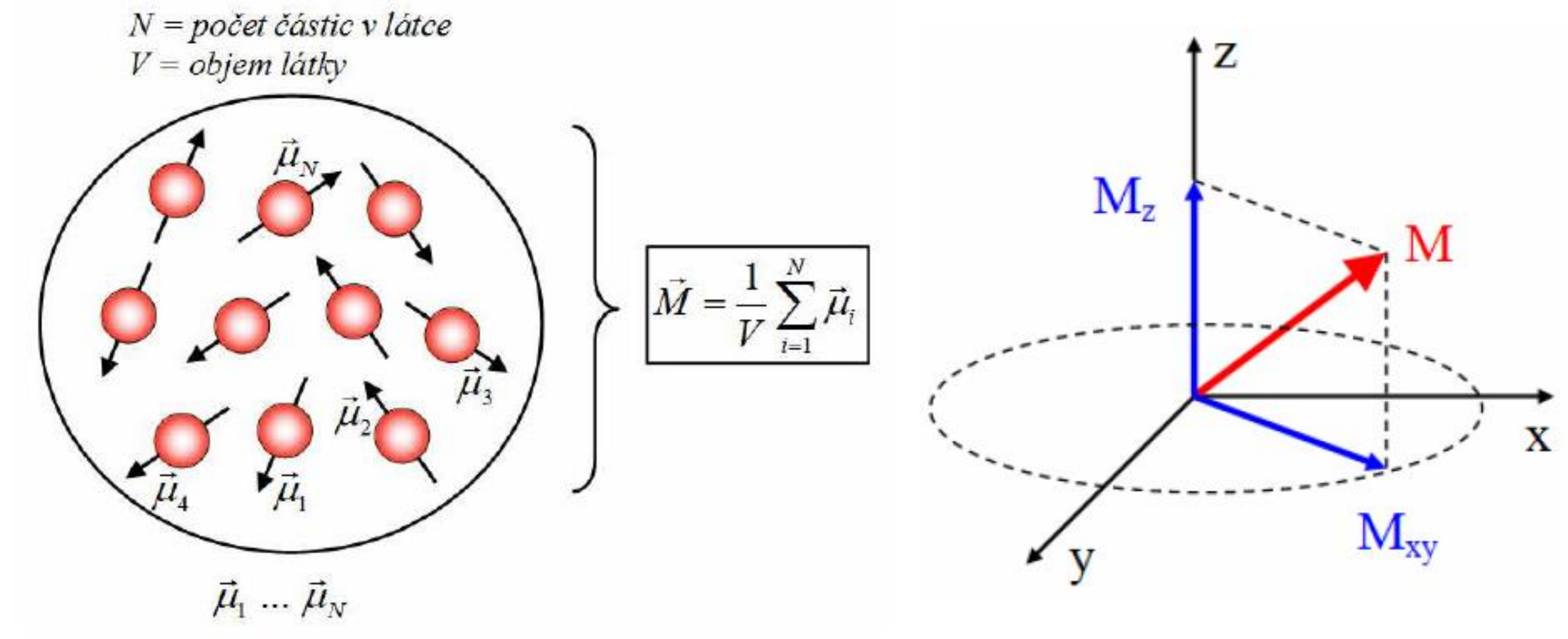
MAGNETIC FIELD

- Magnetic moment (μ)
- It characterizes the source of the magnetic field.
- Vector quantity.
- What does this have to do with MR?
-

MAGNETIC FIELD

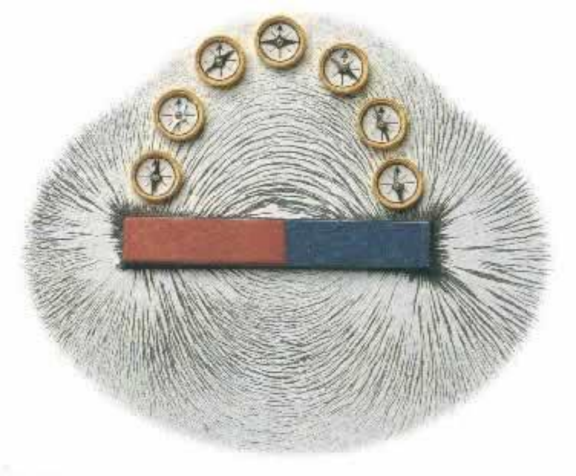
- Electrons "orbit" around the nucleus (analogy with a coil).
- Orbital mag. torque (μL)
- Electrons have an internal angular momentum ("rotation around an axis").
- Spin mag. torque (μS)
- Nucleons have an internal angular momentum ("rotation around an axis").
- Nuclear mag. moment
-

MAGNETIZATION

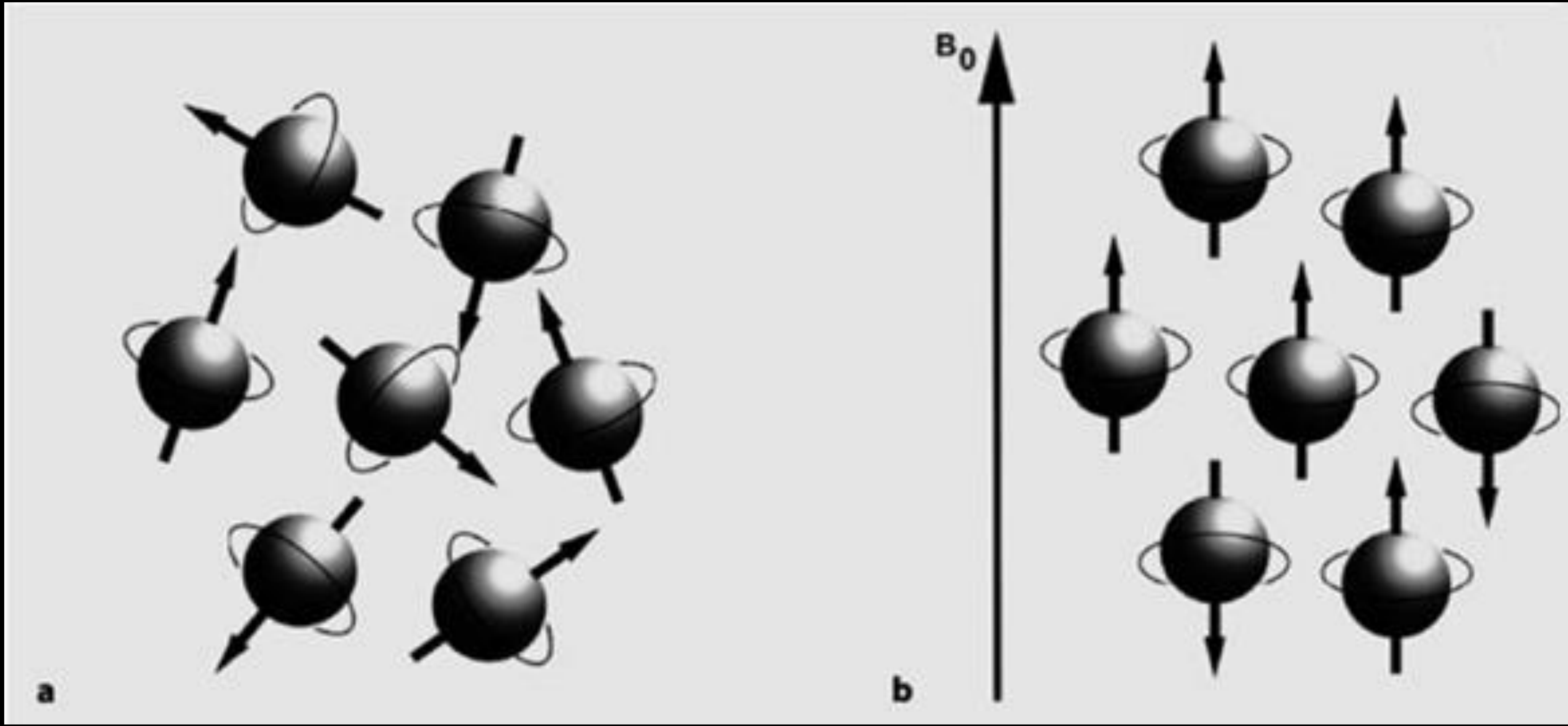


MAGNETIZATION

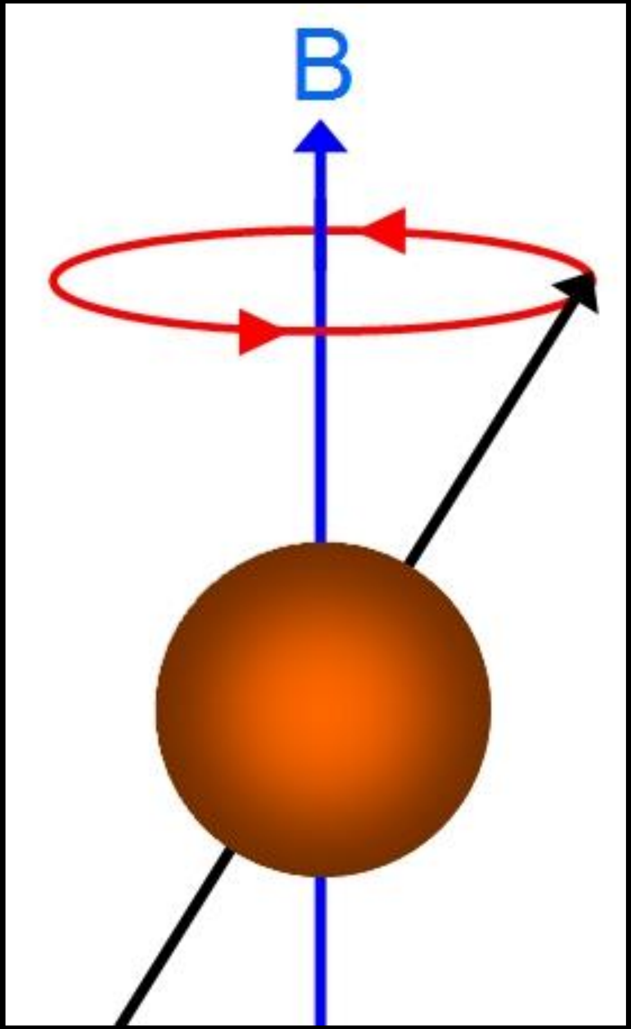
- As a result of the non-zero temperature (T > 0 K), the particles move completely randomly, and also the orientation of the magnetic moments is completely random.
- Therefore, the mean value of the magnetization vector is zero $\langle \vec{M} \rangle = 0$.
- Orientation mag. moments in a strong external static mag. Field.
- Compass needle
-



MAGNETIZATION



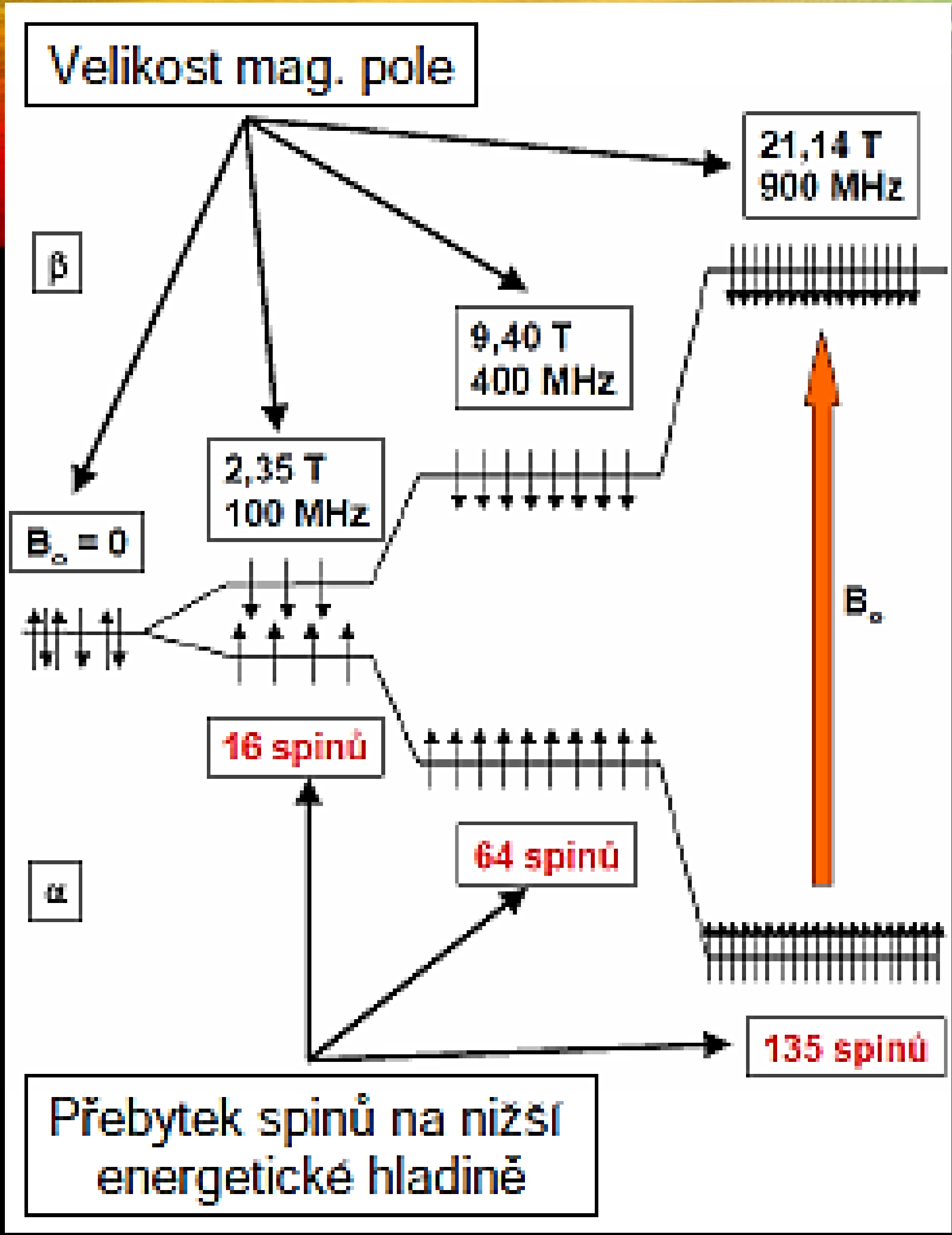
MAGNETIZATION



$$f_L = \frac{\gamma}{2\pi} B_0$$

$$E = hf$$

Atom	Isotop	f_L [MHz] v B=1T
Vodík	^{1}H	42,7
Uhlík	^{13}C	10,7
Dusík	^{14}N	6,1
Fosfor	^{31}P	17,2

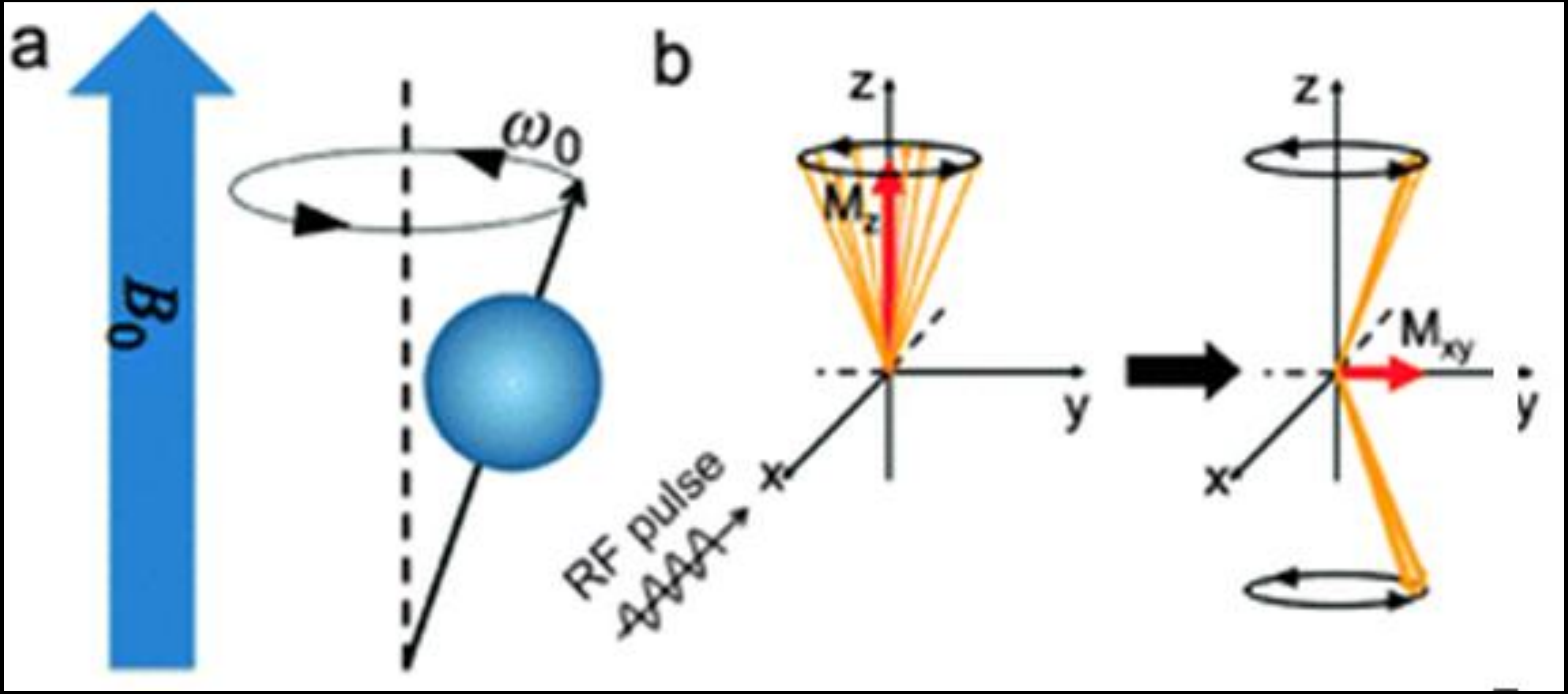


MAGNETIZATION

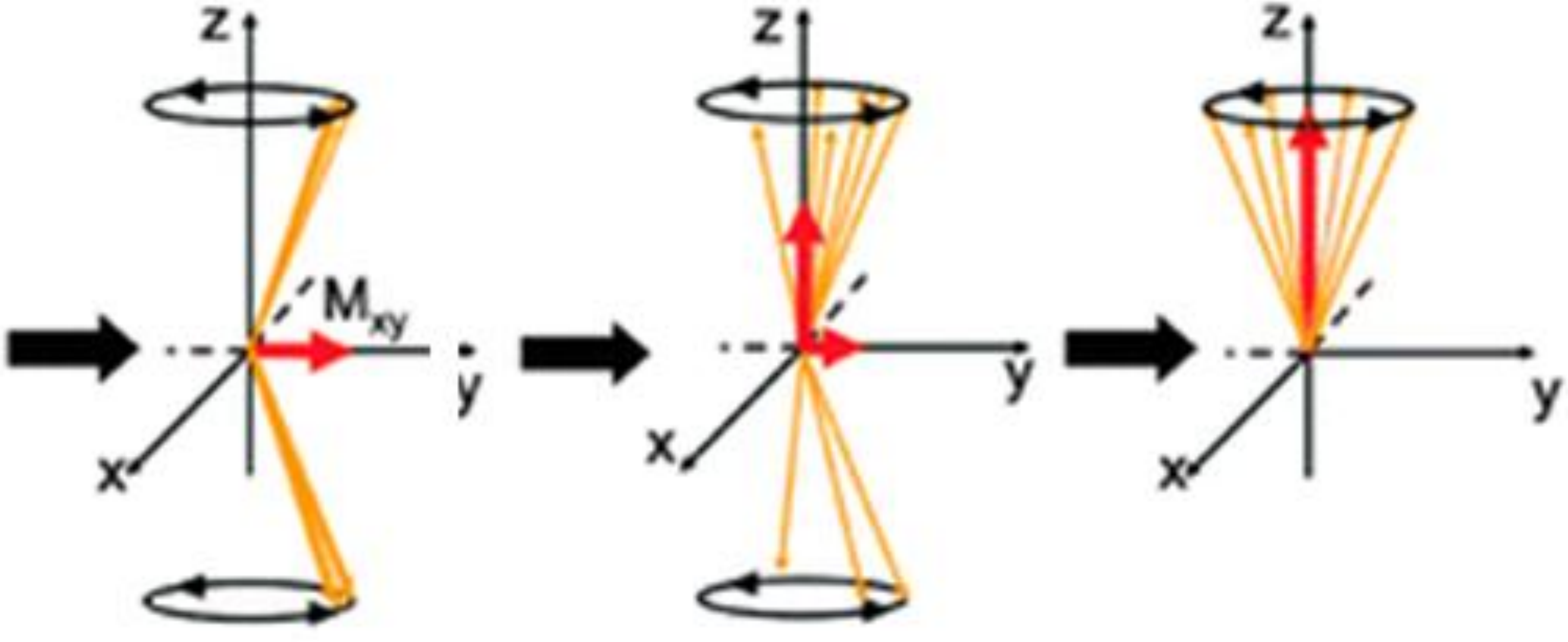
$$\frac{N_\alpha}{N_\beta} = e^{\left(\frac{\Delta E}{k_B T}\right)}$$

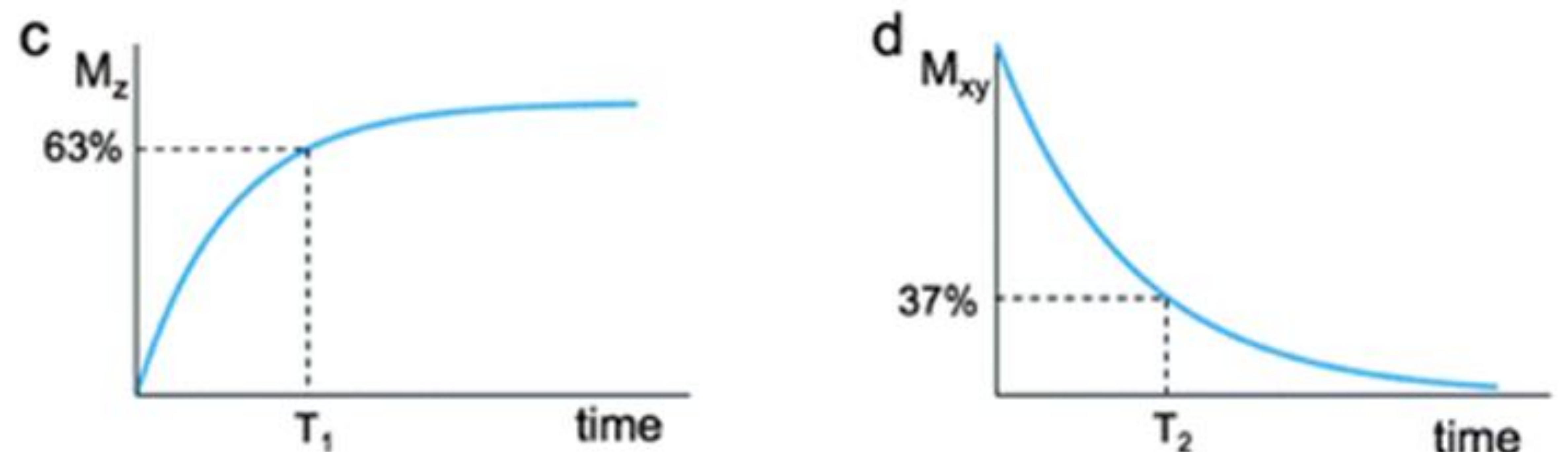
$$\Delta E = \gamma \hbar B_0$$

RELAXATION



RELAXATION

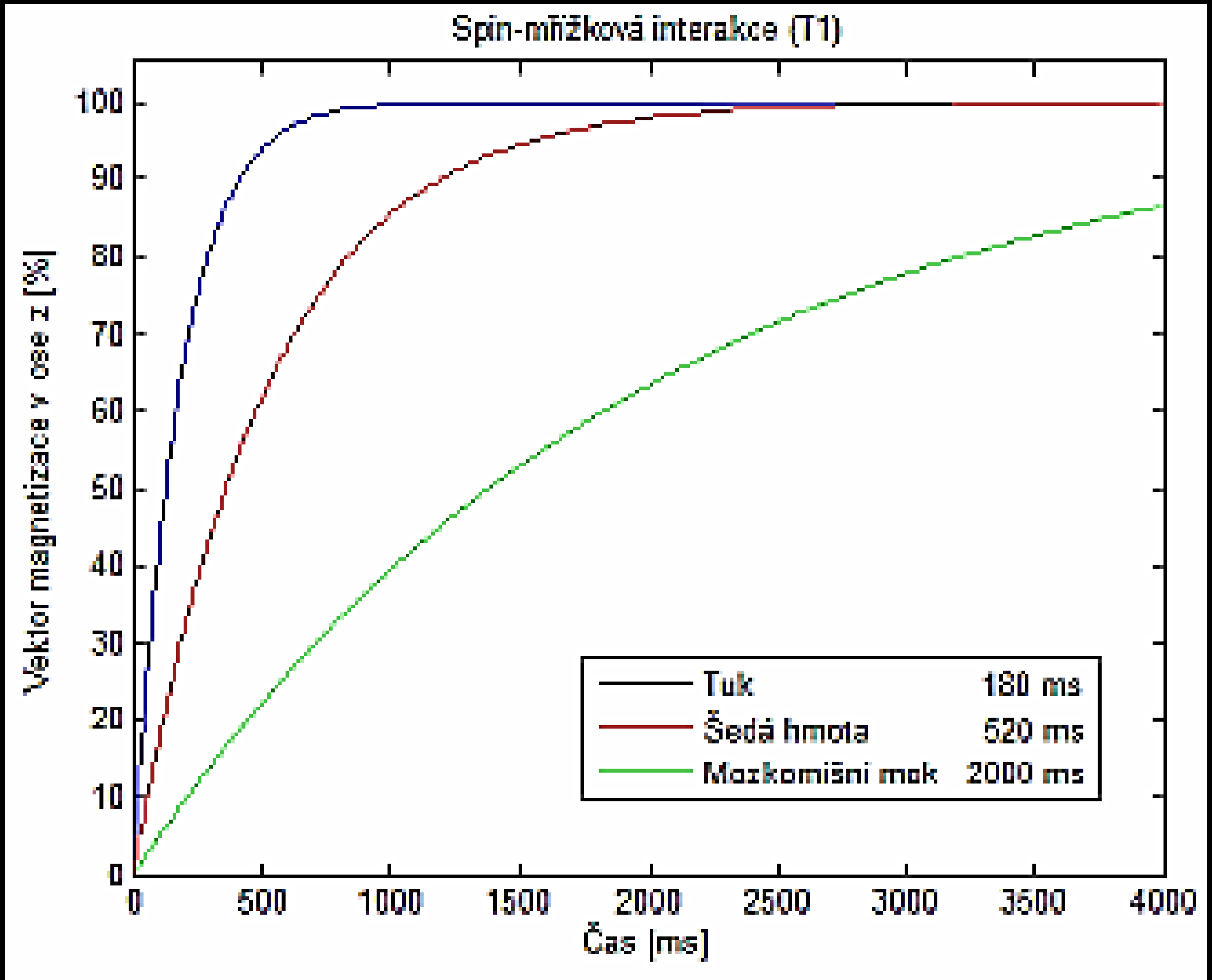




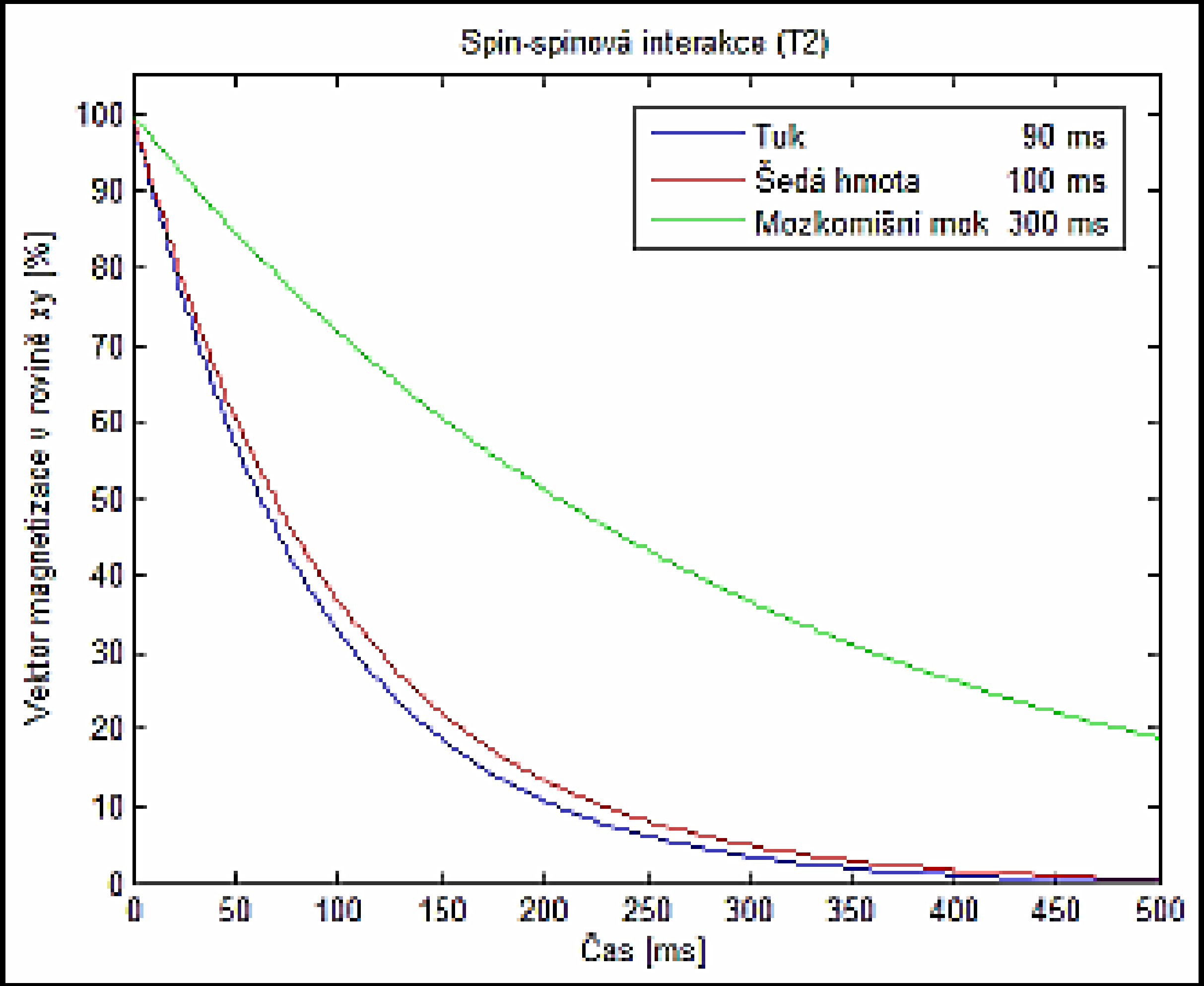
RELAXATION

Typ látky	T_1 [ms]	T_2 [ms]
tuk	250	60
sval	900	50
krev	1400	100-200
Mozek		
šedá hmota (GM)	950	100
bílá hmota (WM)	600	80
cerebrospinální tekutina (CSF)	2000	250

RELAXATION



Spin-mřížková interakce (T1)
Vektor magnetizace v ose z [%]
Čas [ms]
Tuk 180 ms
Šedá hmota 520 ms
Mozkomíšní mok 2000 ms

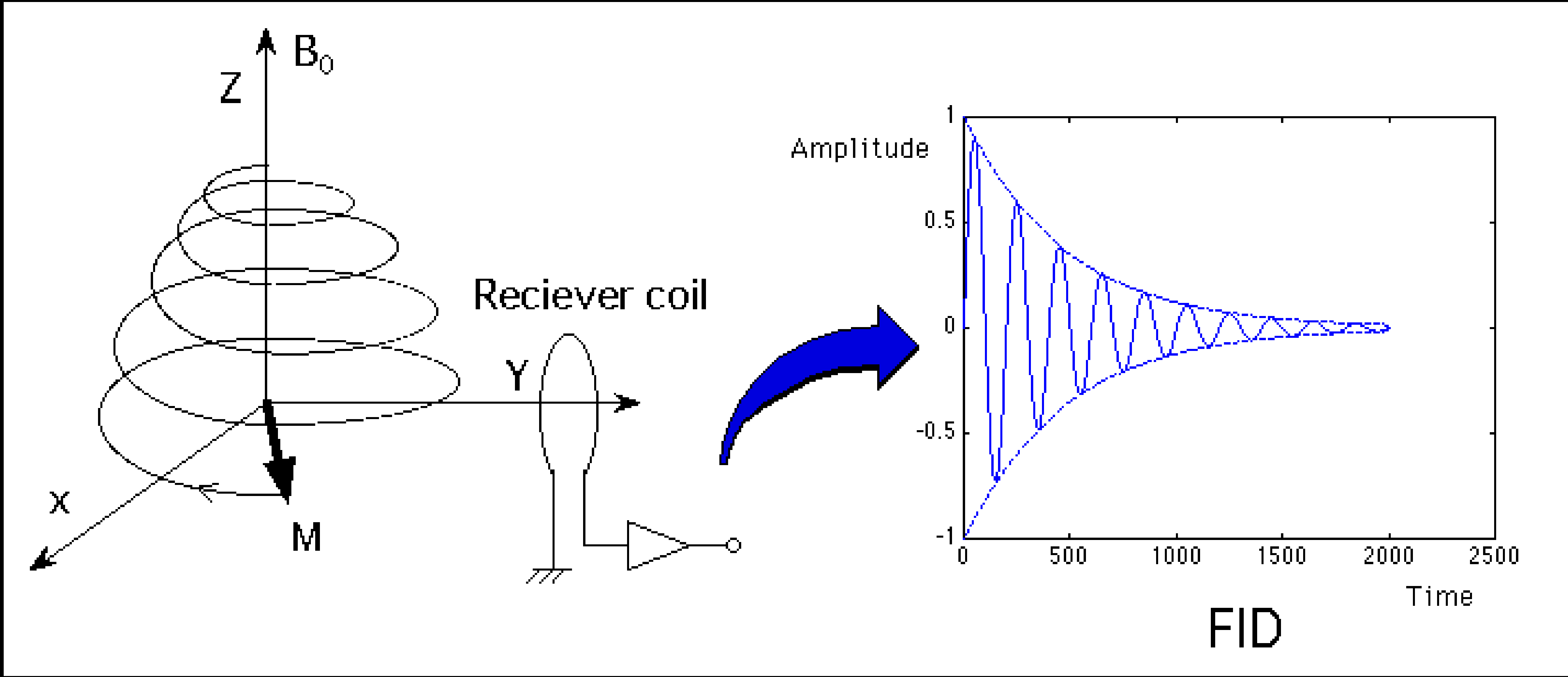


Spin-spinová interakce (T2)
Vektor magnetizace v rovině xy [%]
Čas [ms]
Tuk 90 ms
Šedá hmota 100 ms
Mozkomíšní mok 300 ms

SIGNAL

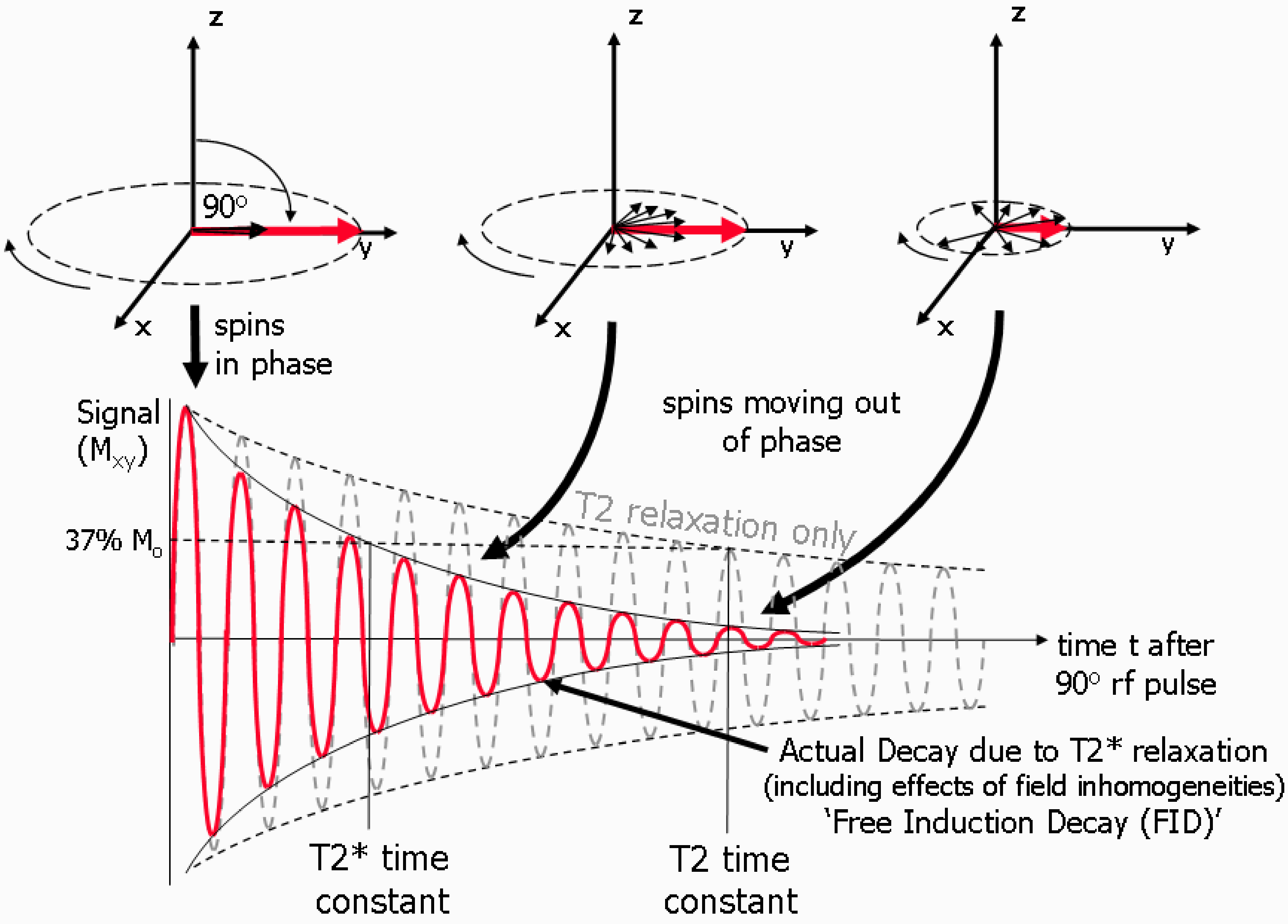
- Signal detection is based on electromagnetic induction:
- If the magnetic induction flux changes through the coil, the induced electromotive voltage is induced in it.
- When the magnetization changes, the magnetic induction flux changes, and an alternating current of Larmor frequency is induced in the detection coils.
- The amplitude of the voltage is proportional to the magnetization and therefore the density of the nuclei.
- Free Induction Decay FID is a periodic damped function.
- $$FID = M_0 \cos(\omega_0 t)\, e^{-\frac{t}{T_2^*}}$$

SIGNAL



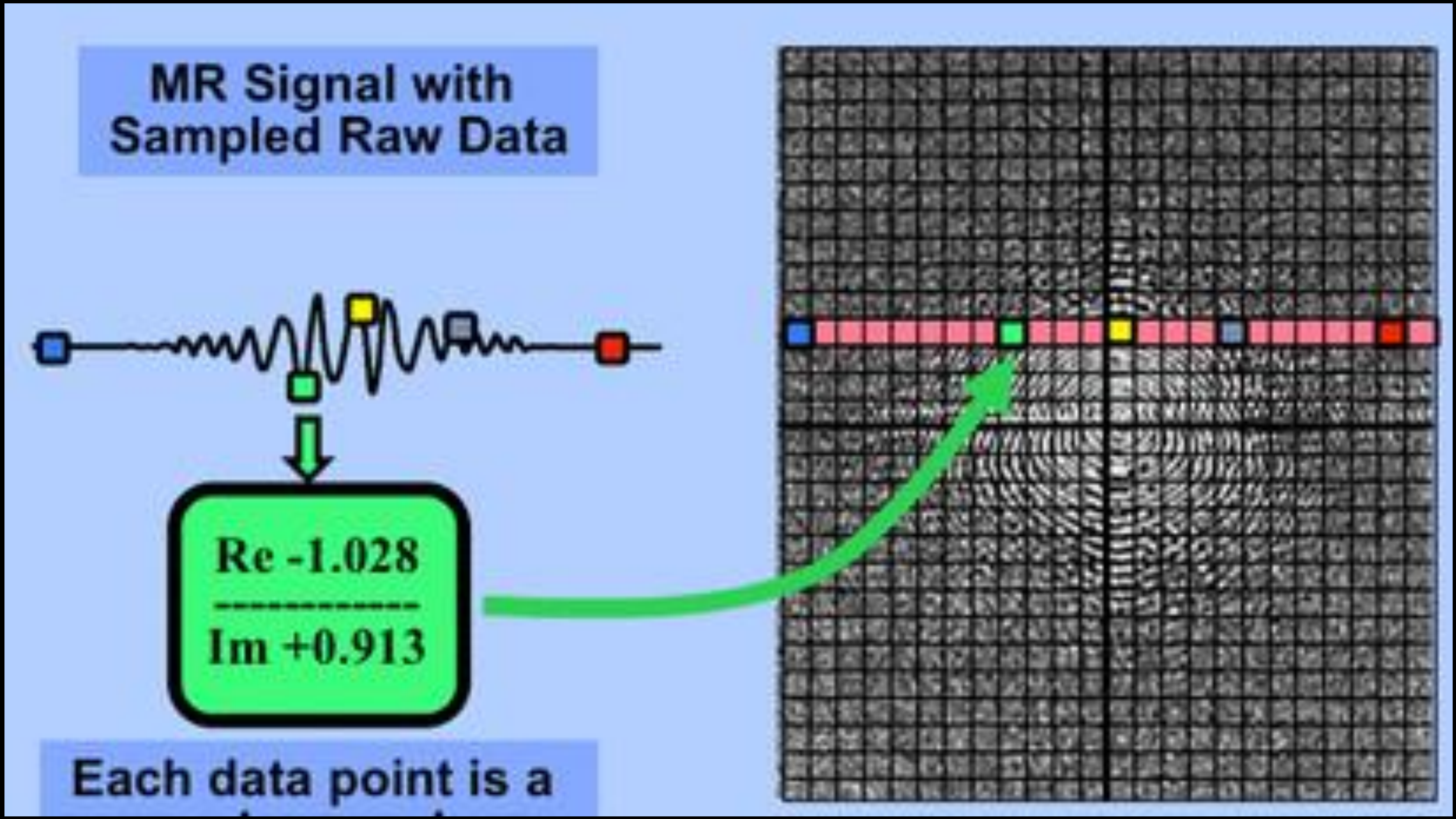
B0
Z
Reciever coil
Y
X
M
Amplitude
1
0.5
0
-0.5
-1
0
500
1000
1500
2000
2500
Time
FID

SIGNAL

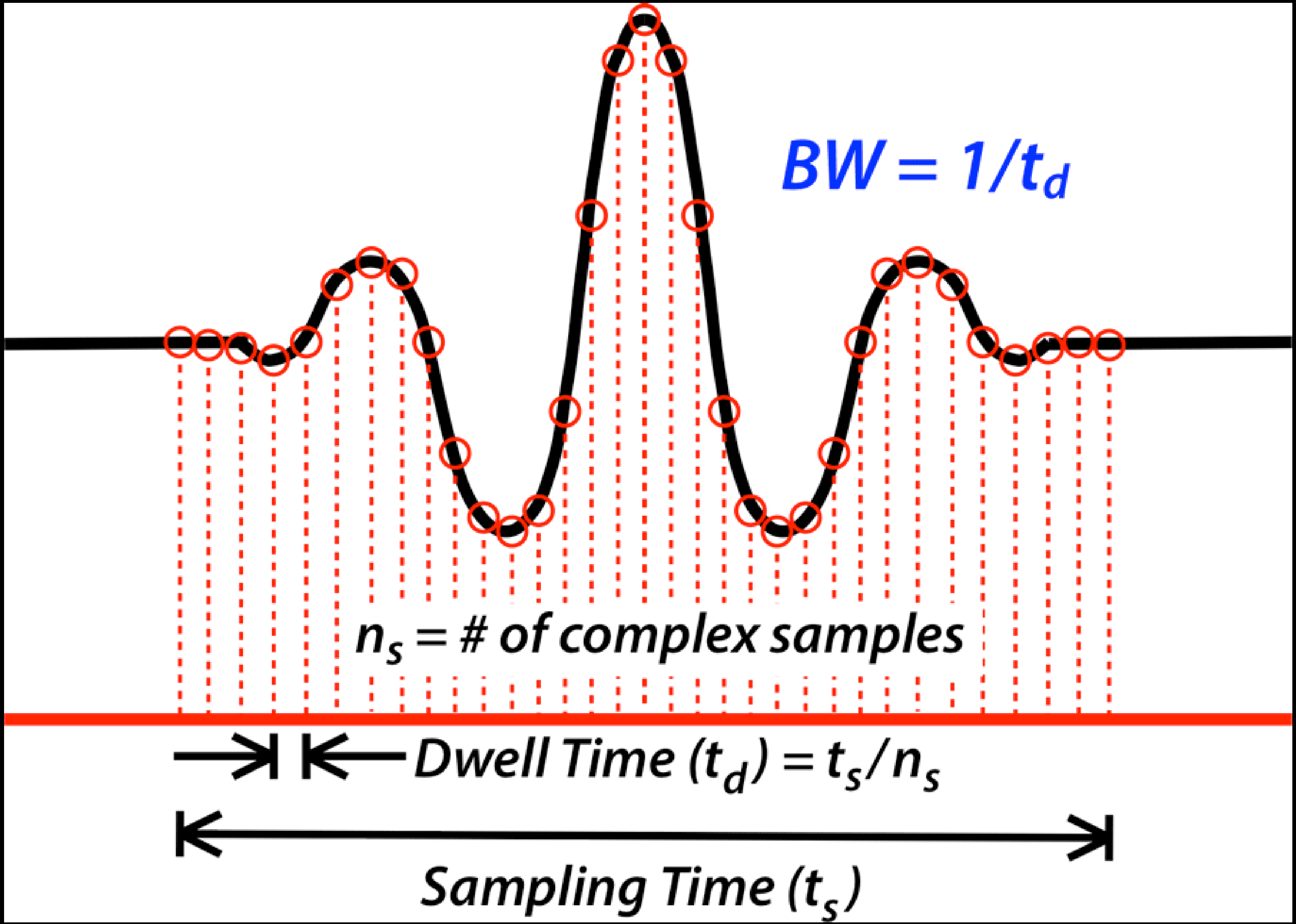


z
z
z
90°
y
y
y
x
x
x
spins
in phase
spins moving out
of phase
Signal
(M_{xy})
37% M_o
T2 relaxation only
time t after
90° rf pulse
Actual Decay due to T2* relaxation
(including effects of field inhomogeneities)
'Free Induction Decay (FID)'
T2* time
constant
T2 time
constant

SIGNAL


MR Signal with
Sampled Raw Data
Re -1.028
Im +0.913
Each data point is a

BANDWIDTH



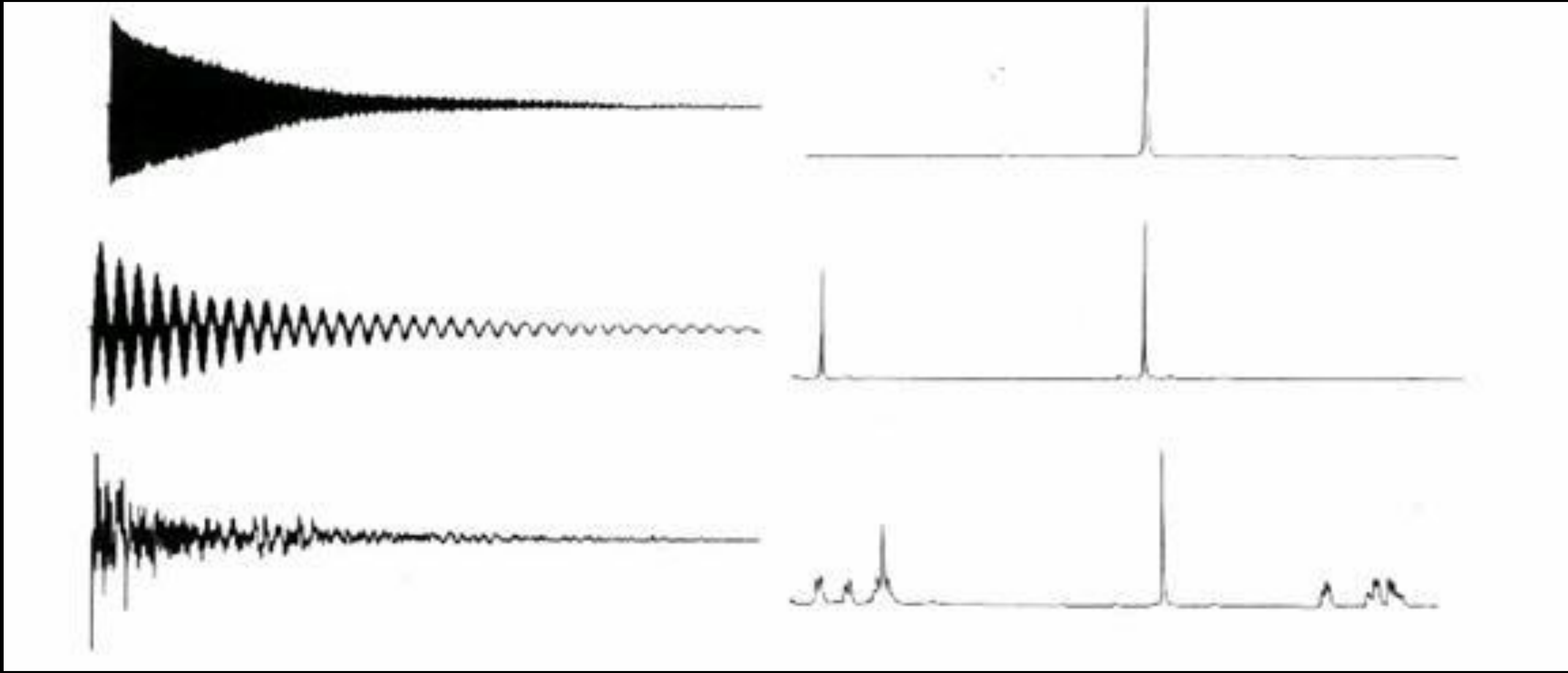
$BW = 1/t_d$
n_s = # of complex samples
Dwell Time (t_d) = t_s/n_s
Sampling Time (t_s)

FOURIER TRANSFORM

- A Fourier transform is applied to the signal.
- What does the Fourier transform do?
- Converts a signal from the time domain to the frequency domain.
-

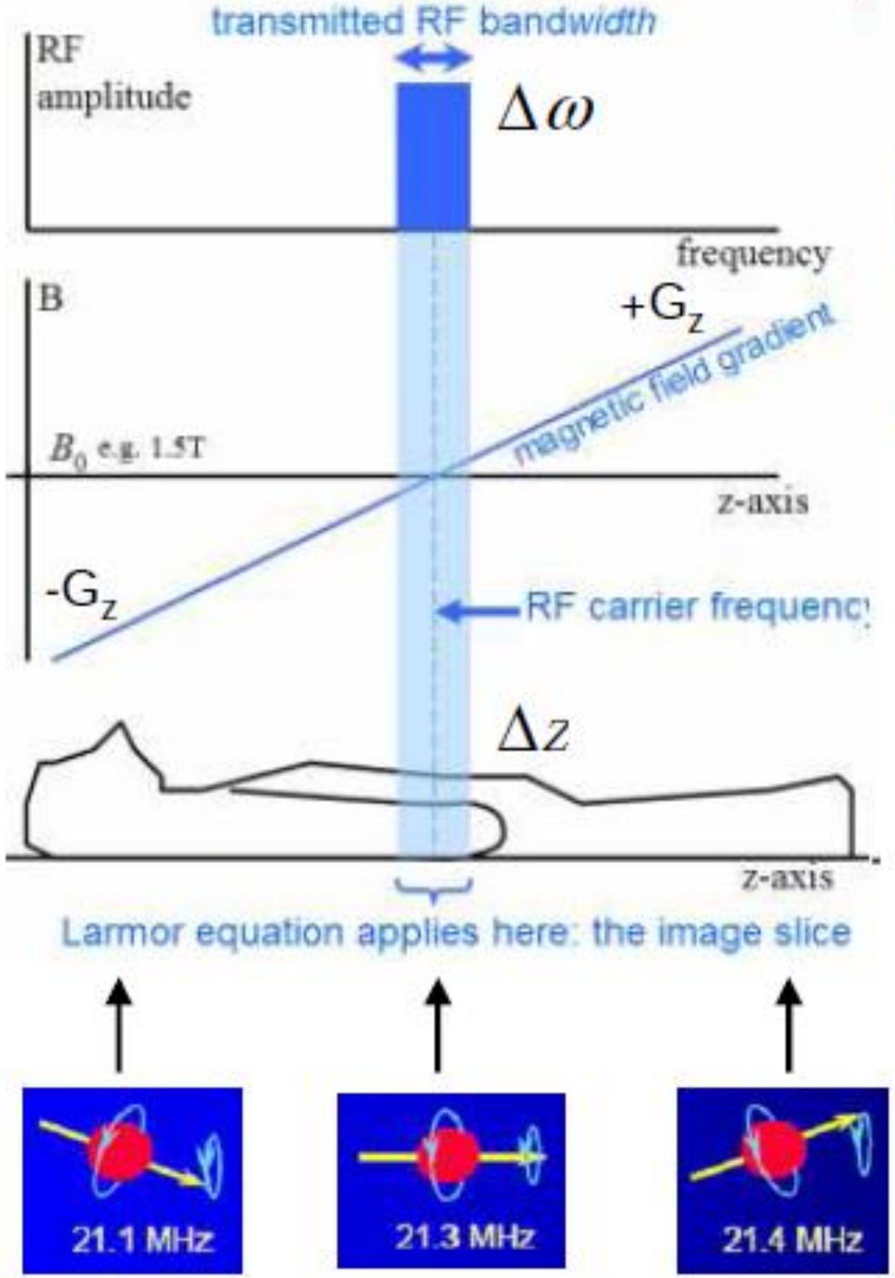
$$\boldsymbol{S(\omega) = \int_{-\infty}^{\infty} s(t)e^{-i\omega t}dt}$$

FOURIER TRANSFORM

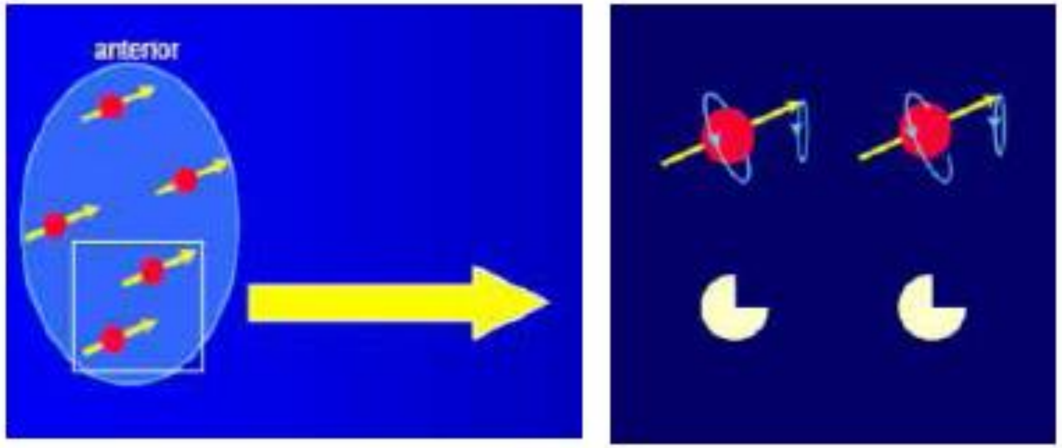


POSITIONAL CODING

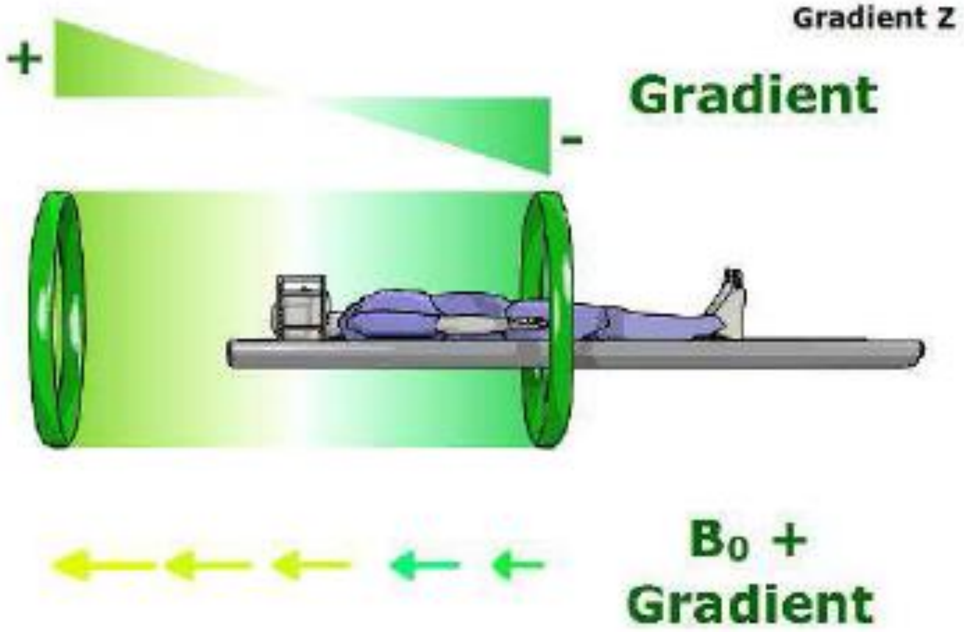
- But how do we know exactly where we are detecting the signal from?
- Because we detect the signal from the entire investigated area at the same time, the spatial information in the FID signal is lost.
- We need to include information about the location of the signal source artificially in the signal.
- For this we use three gradient coils.
- We place these gradient coils so that they produce a variable but time-constant magnetic field in space.
- The magnetic induction of this field is significantly smaller than the outer field B0.
- The variability (gradient) of these fields is determined exactly for the needs of the experiment (knowledge of the gradient in the x, y, z axes is essential).



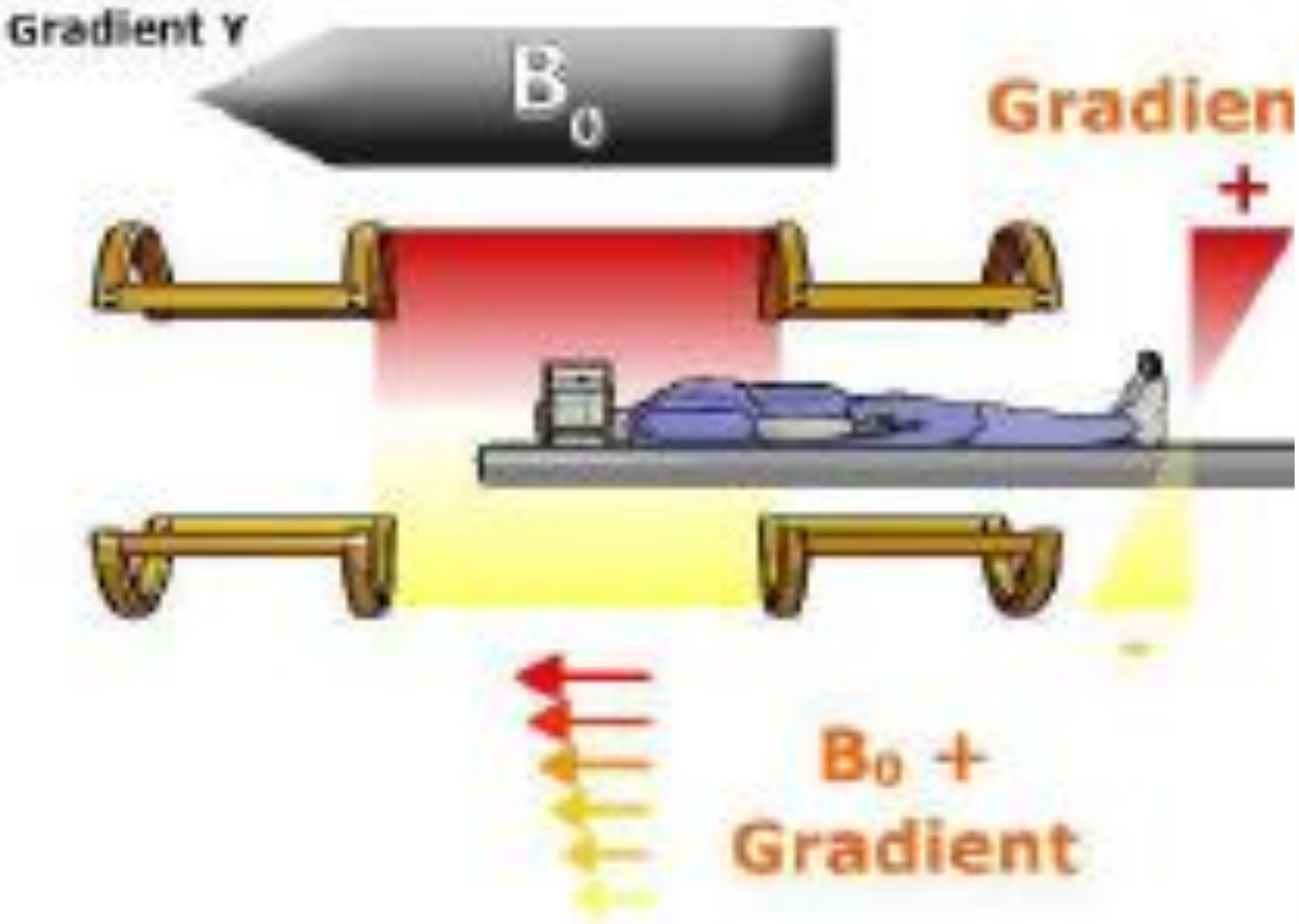
Nižší Vyšší



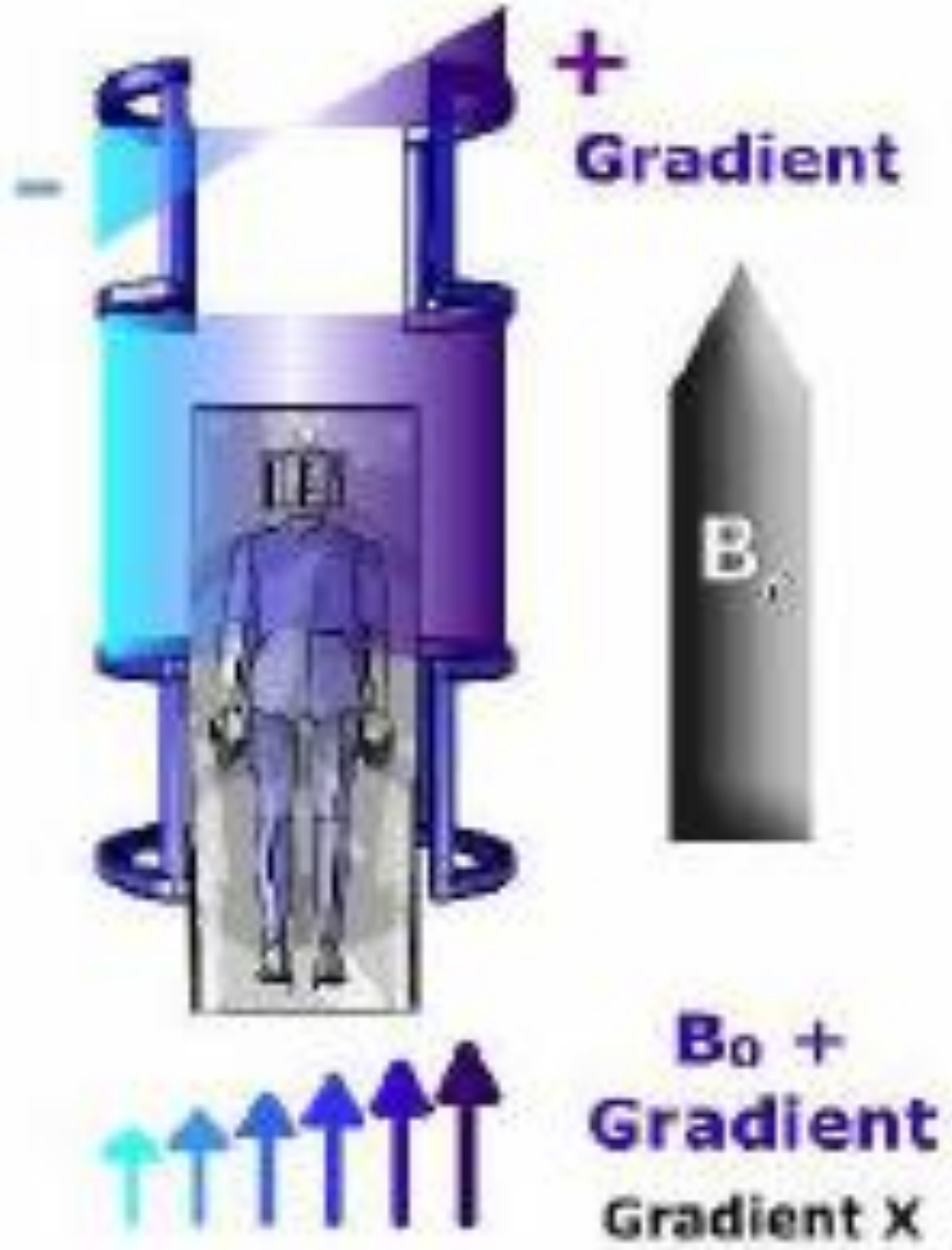
Všechna jádra uvnitř zvolené tomoroviny precesují se stejnou frekvencí i fází.



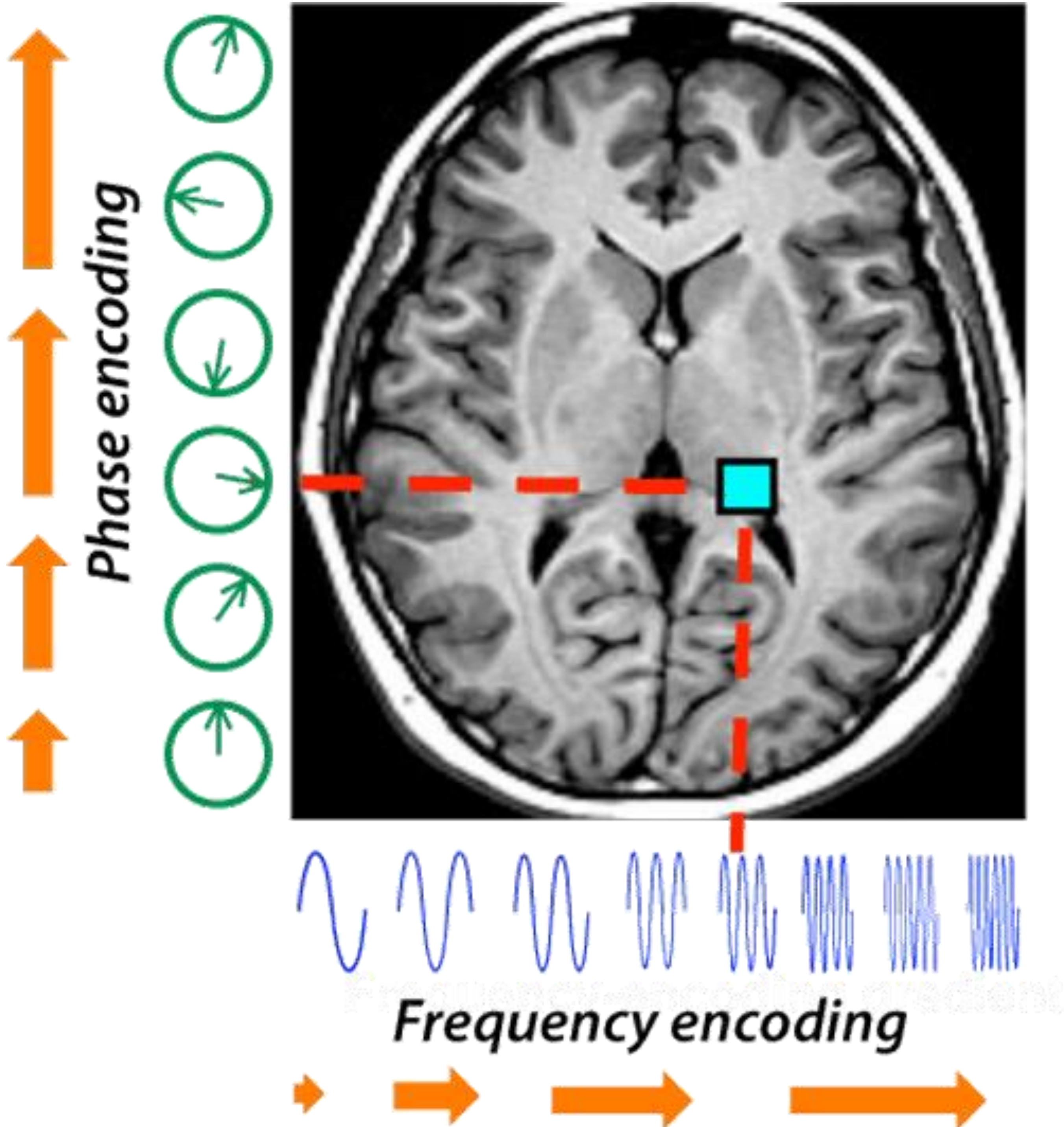
$$\Delta\omega = \gamma \cdot G_z \cdot \Delta z$$



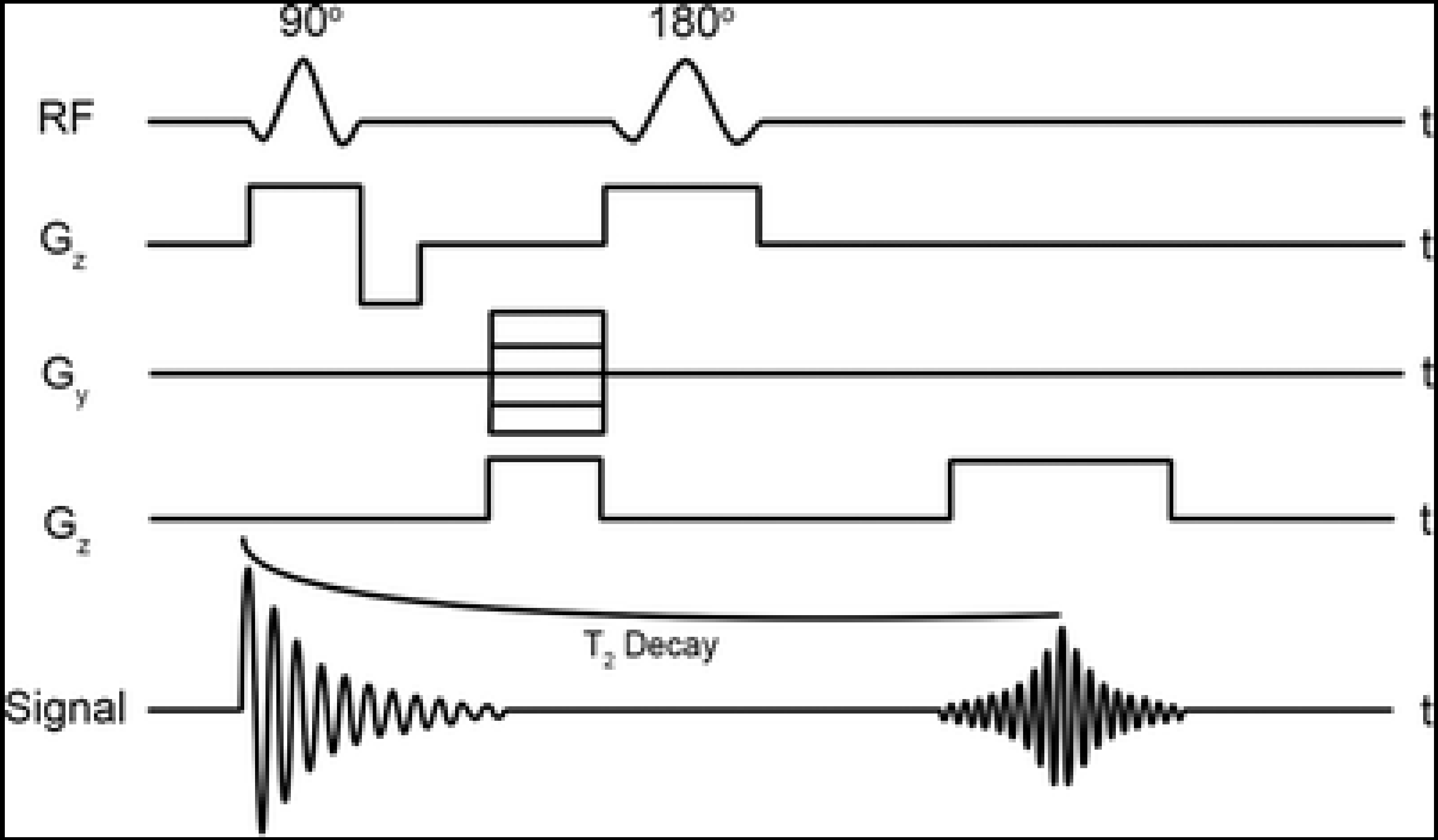
Gradient Y
B_0
Gradien
+
B_0 + Gradient



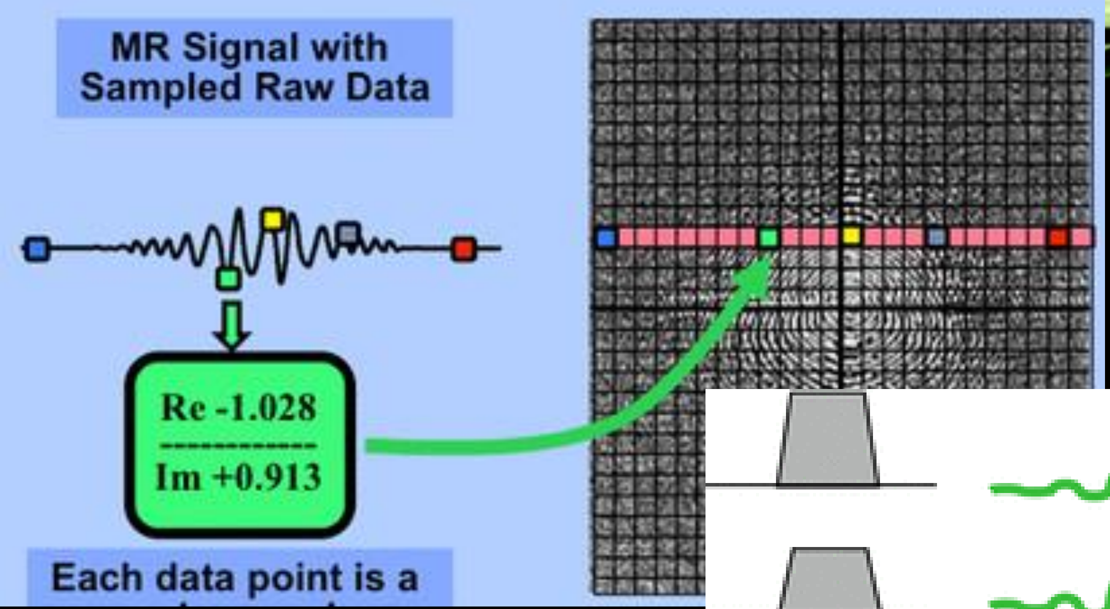
-
+
Gradient
B_0 + Gradient
Gradient X

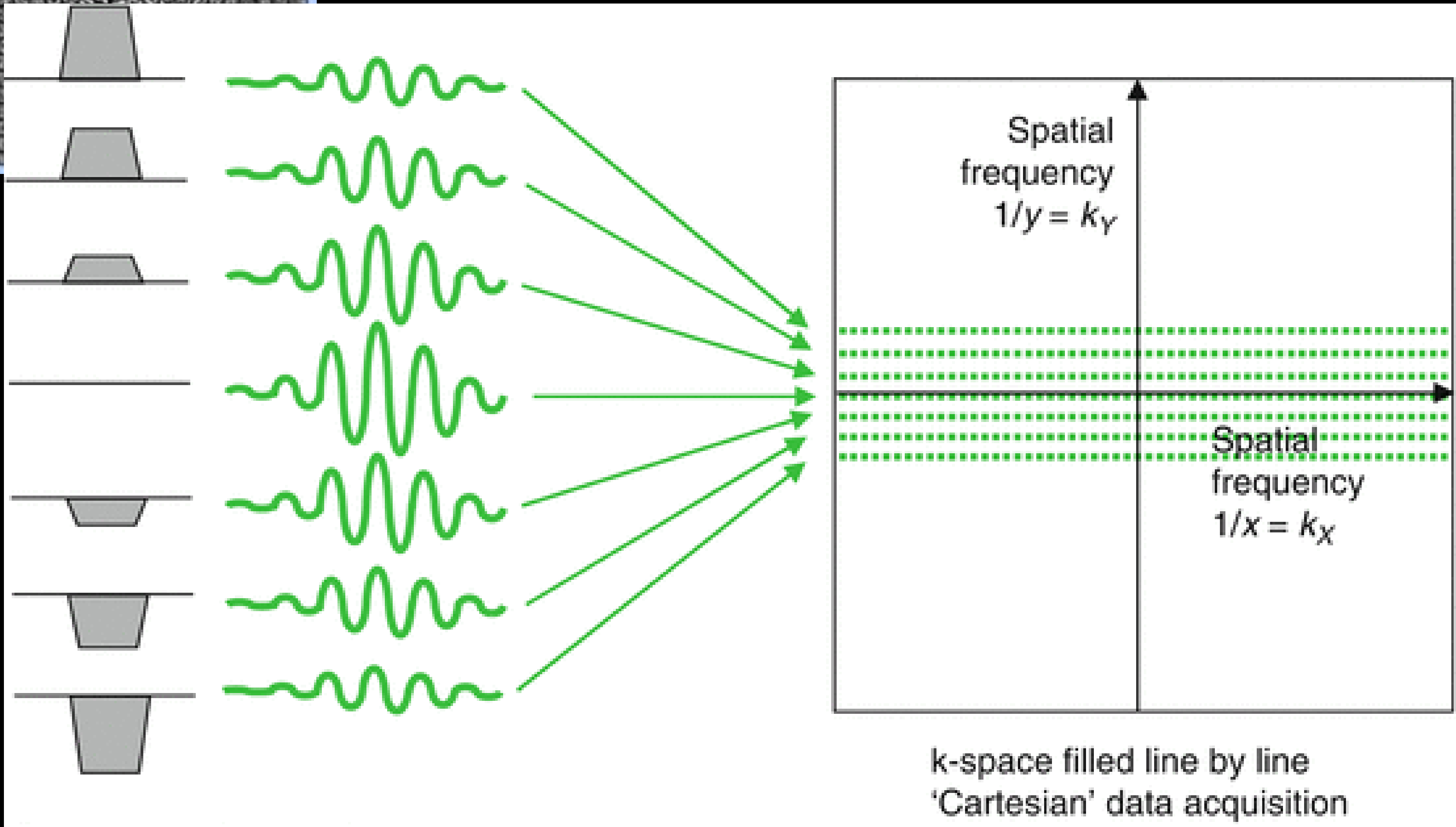

Phase encoding
Frequency encoding

PULSE SEQUENCE



PULSE SEQUENCE





SPATIAL RESOLUTION

- FOV (x*y)
- Number of frequencies in k-space
- Number of phases in k-space
-

$$Roz_x = \frac{FOV_x}{\#frek} \; ; \; Roz_y = \frac{FOV_y}{\#fází}$$

$$Roz_x = \frac{240}{256} = 0,93\,mm \; ; \; Roz_y = \frac{240}{192} = 1,25\,mm$$

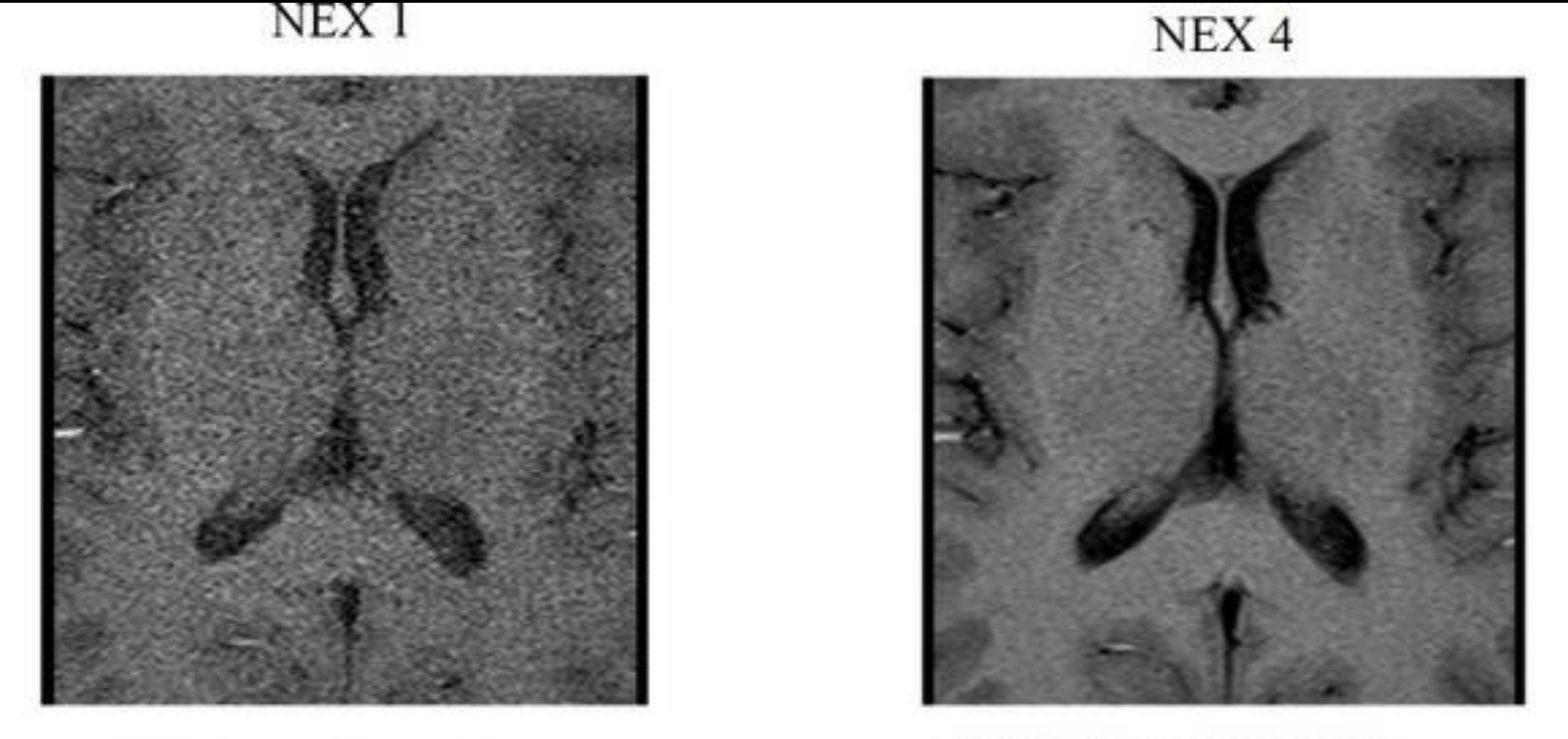
$$Roz_x = \frac{480}{324} = 1,48 \; ; \; Roz_y = \frac{280}{160} = 1,75\,mm$$

SNR

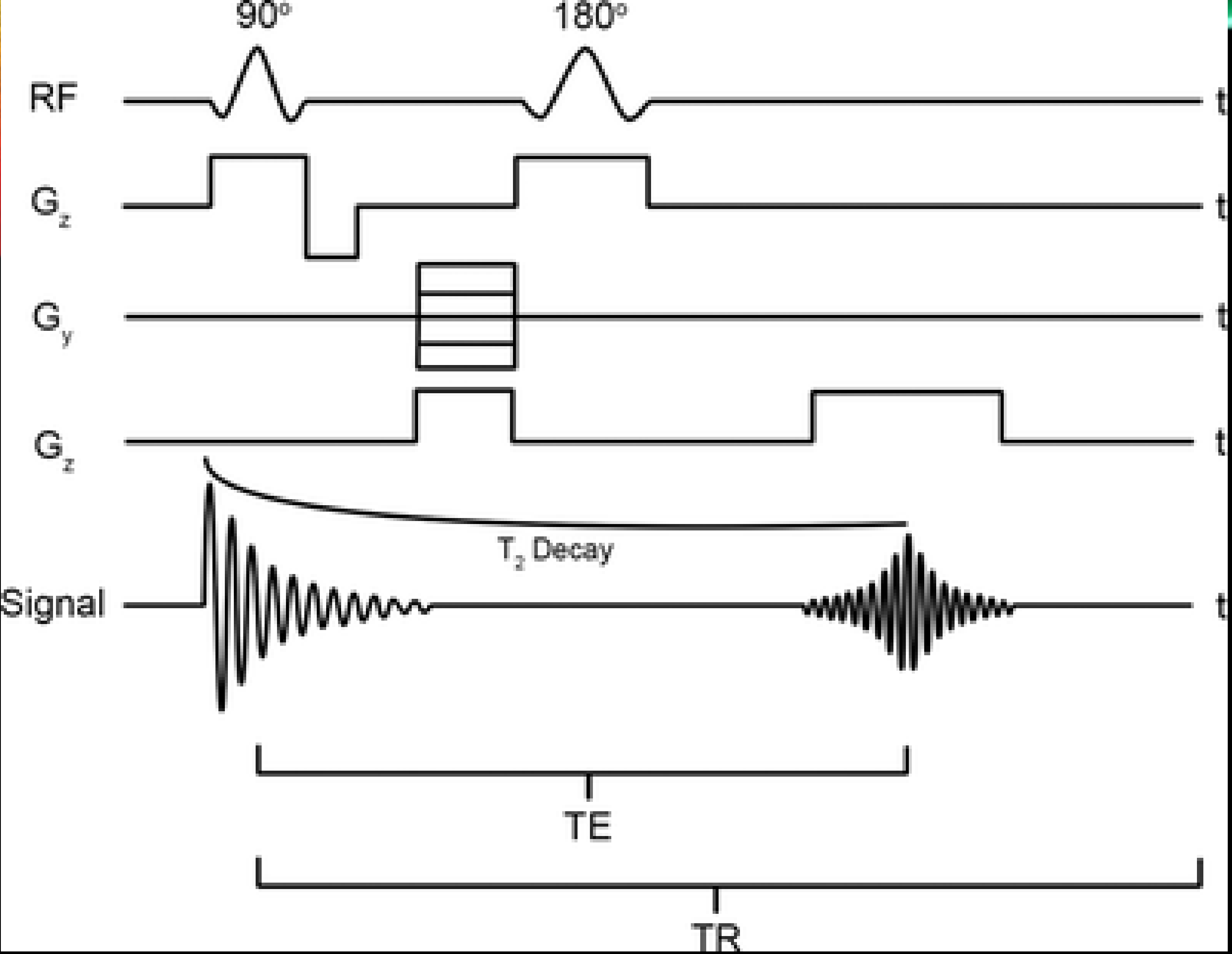
- Voxel size
-

$$SNR \sim V$$
$$SNR\ (0,93\ ;1,25;4) \sim 0,93 * 1,25 * 4 = 4,65$$
$$SNR\ (0,93\ ;1,25;3) \sim 0,93 * 1,25 * 3 = 3,48$$
$$SNR\ (0,8\ ;1;4) \sim 0,8 * 1 * 4 = 3,20$$

SIGNAL AVERAGING



$$SNR \sim \sqrt{NEX} \; ; \; t \sim NEX$$



SPIN ECHO (SE)

$$S \sim PD\left(1 - e^{-\frac{TR}{T_1}}\right)e^{-\frac{TE}{T2}}$$

SPIN ECHO

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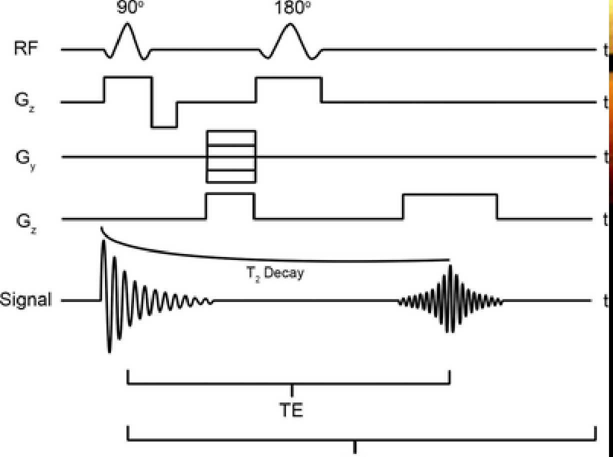
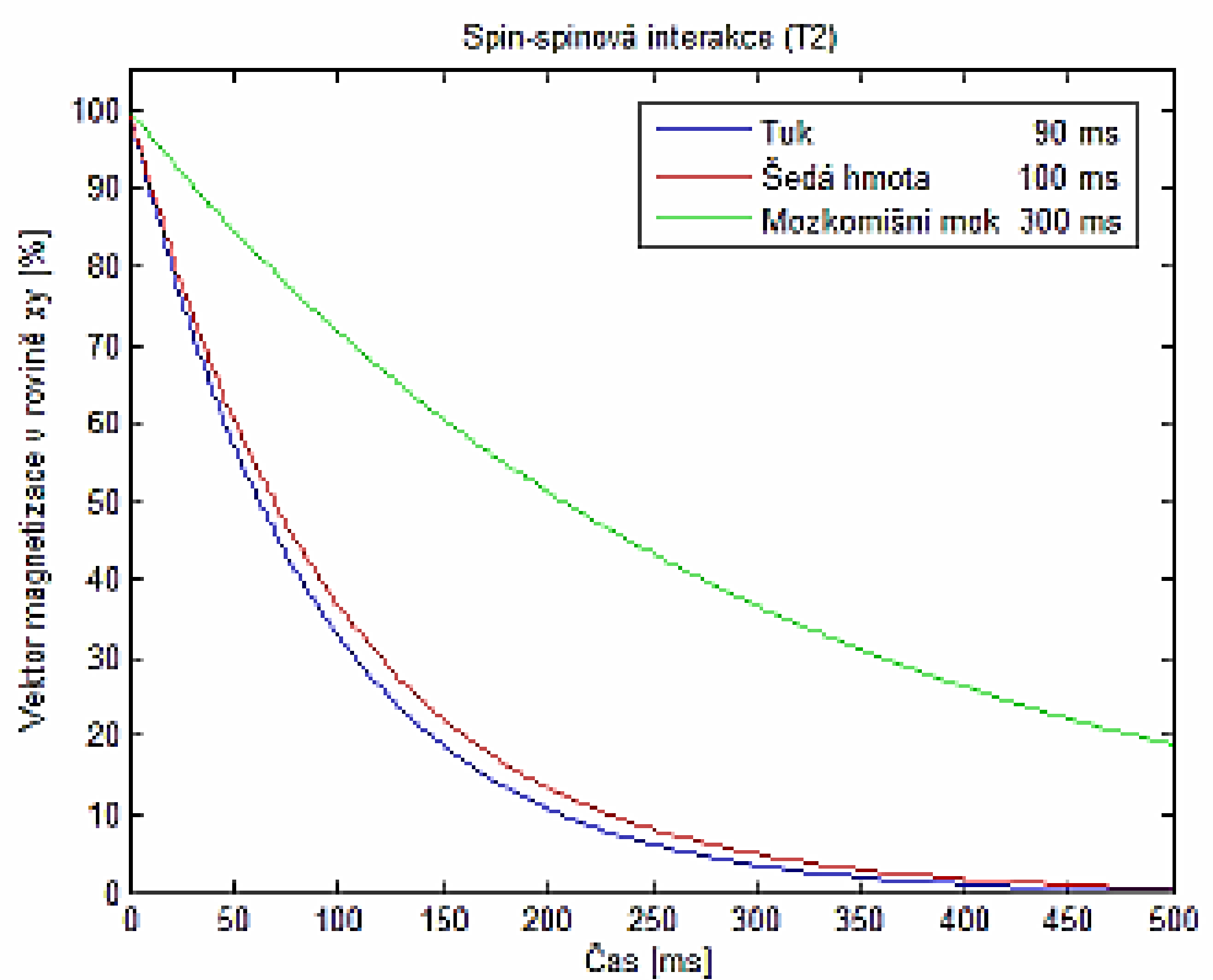
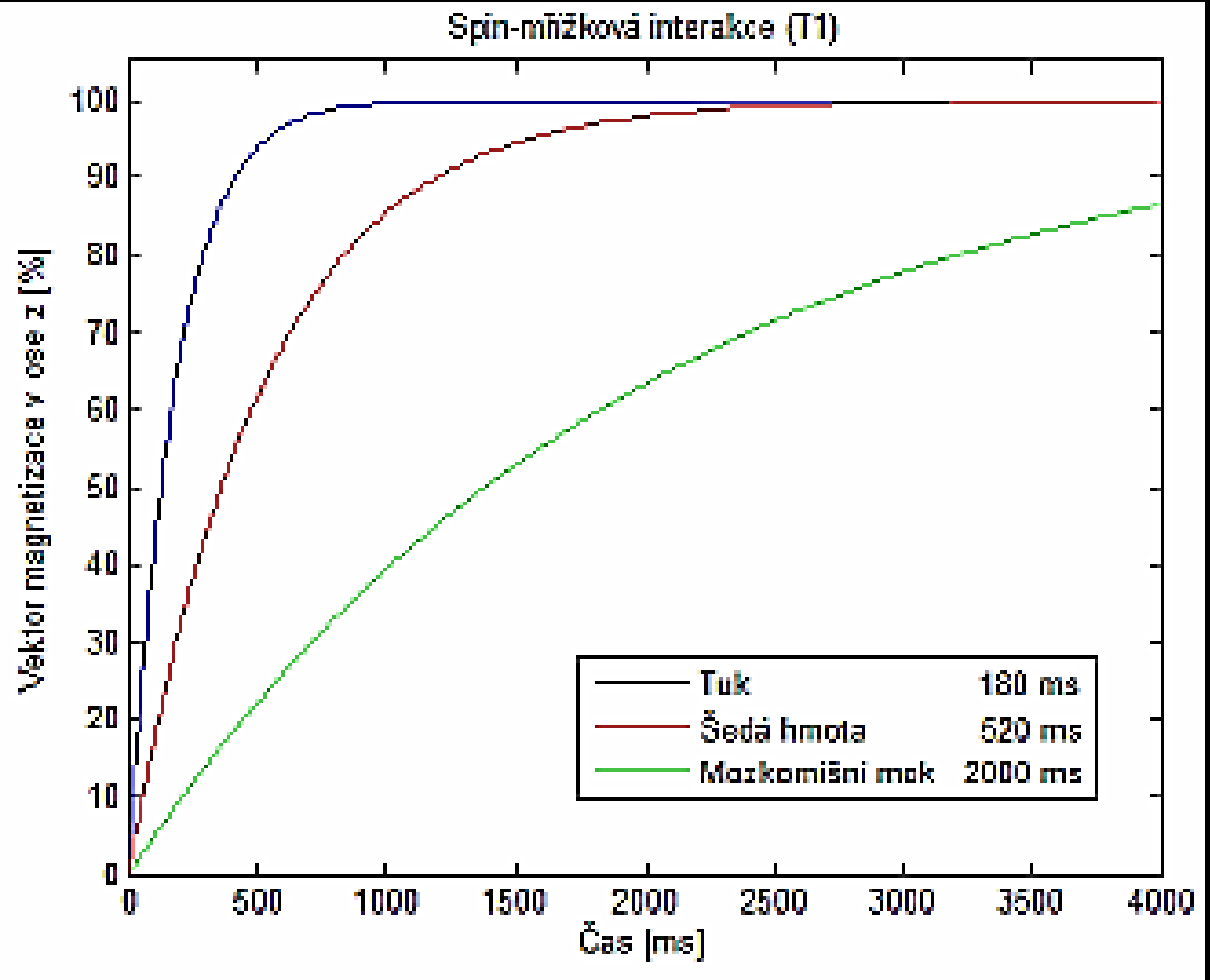


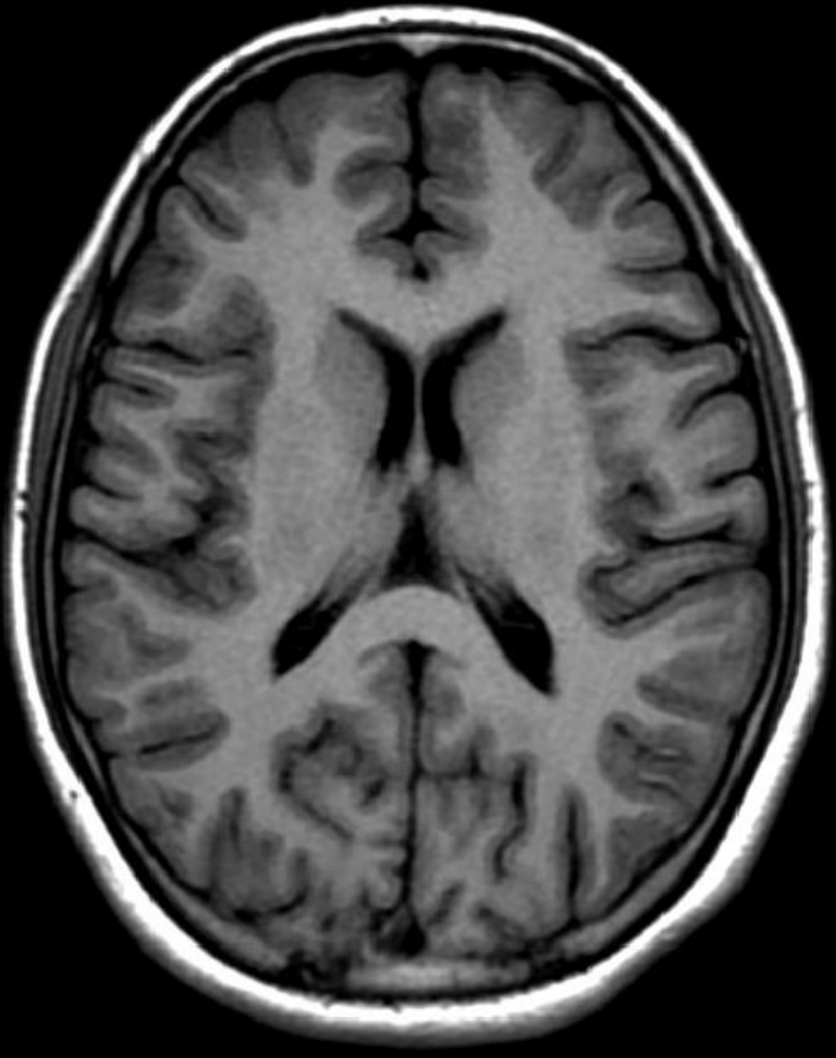




SPIN ECHO T1-W

$$S \sim PD\left(1 - e^{-\frac{TR}{T_1}}\right)e^{-\frac{TE}{T2}}$$

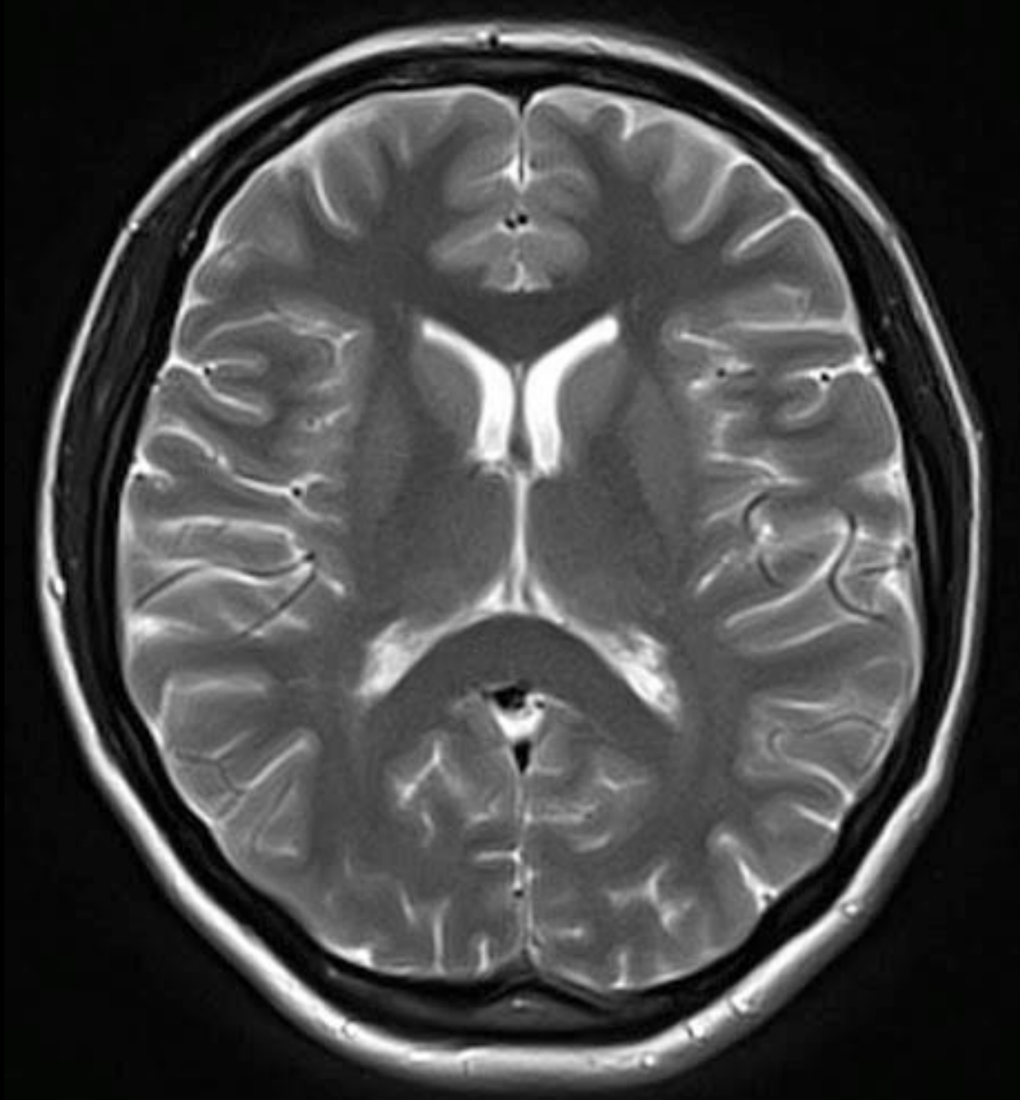
	CSF	GM	Tuk
TE	8	8	8
TR	600	600	600
T1	2000	520	180
T2	300	100	90
EXP(-TR/T1)	0,7408	0,315	0,0357
EXP(-TE/T2)	0,9737	0,923	0,9149
1-EXP(-TR/T1)	0,2592	0,685	0,9643
Součin	0,2524	0,632	0,8823



SPIN ECHO T2-W

$$S \sim PD\left(1 - e^{-\frac{TR}{T_1}}\right)e^{-\frac{TE}{T2}}$$

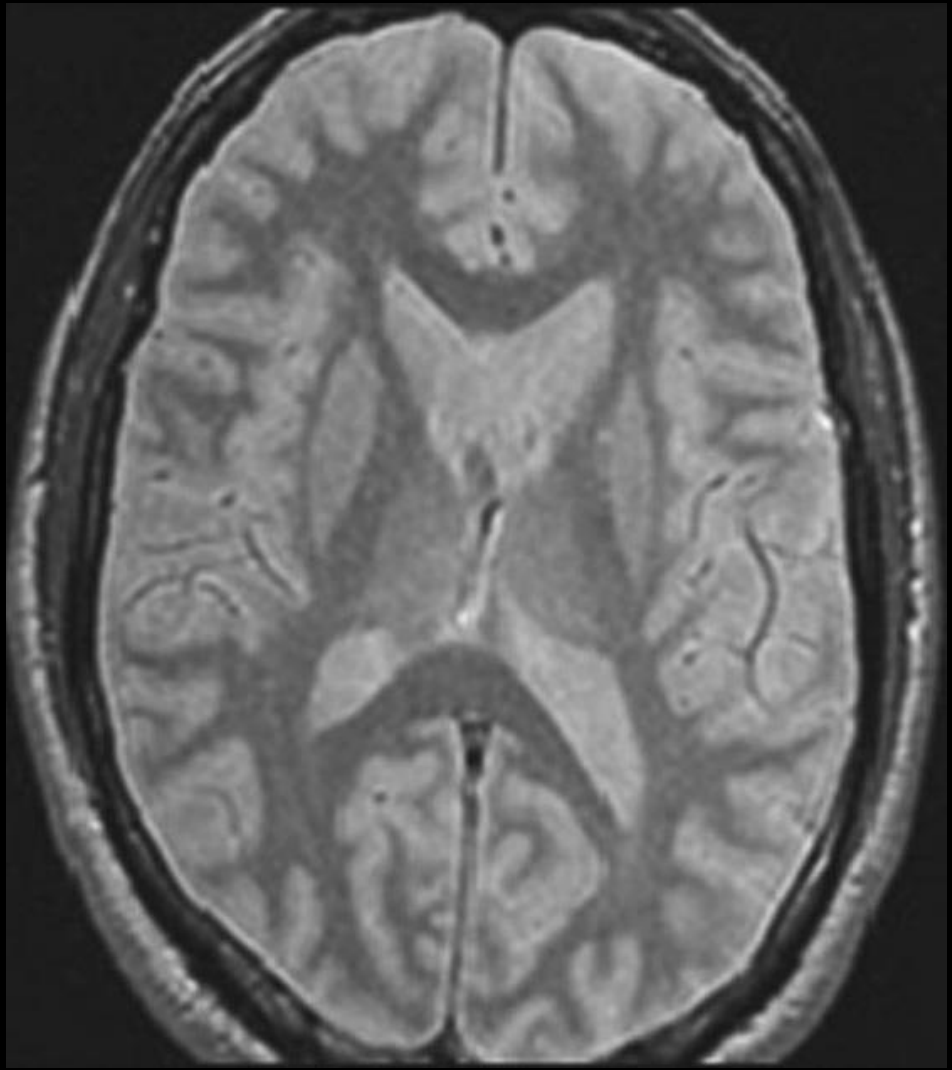
	CSF	GM	Tuk
TE	120	120	120
TR	6000	6000	6000
T1	2000	520	180
T2	300	100	90
EXP(-TR/T1)	0,0498	1E-05	3E-15
EXP(-TE/T2)	0,6703	0,301	0,2636
1-EXP(-TR/T1)	0,9502	1	1
Součin	0,6369	0,301	0,2636



SPIN ECHO PD

$$S \sim PD\left(1 - e^{-\frac{TR}{T_1}}\right) e^{-\frac{TE}{T2}}$$

	CSF	GM	Tuk
TE	8	8	8
TR	6000	6000	6000
T1	2000	520	180
T2	300	100	90
EXP(-TR/T1)	0,0498	1E-05	3E-15
EXP(-TE/T2)	0,9737	0,923	0,9149
1-EXP(-TR/T1)	0,9502	1	1
Součin	0,9252	0,923	0,9149



SPIN ECHO

$$S \sim PD\left(1 - e^{-\frac{TR}{T_1}}\right)e^{-\frac{TE}{T2}}$$

	CSF	GM	Tuk
TE	120	120	120
TR	600	600	600
T1	2000	520	180
T2	300	100	90
EXP(-TR/T1)	0,7408	0,315	0,0357
EXP(-TE/T2)	0,6703	0,301	0,2636
1-EXP(-TR/T1)	0,2592	0,685	0,9643
Součin	0,1737	0,206	0,2542

SPIN ECHO ACQUISITION SPEED

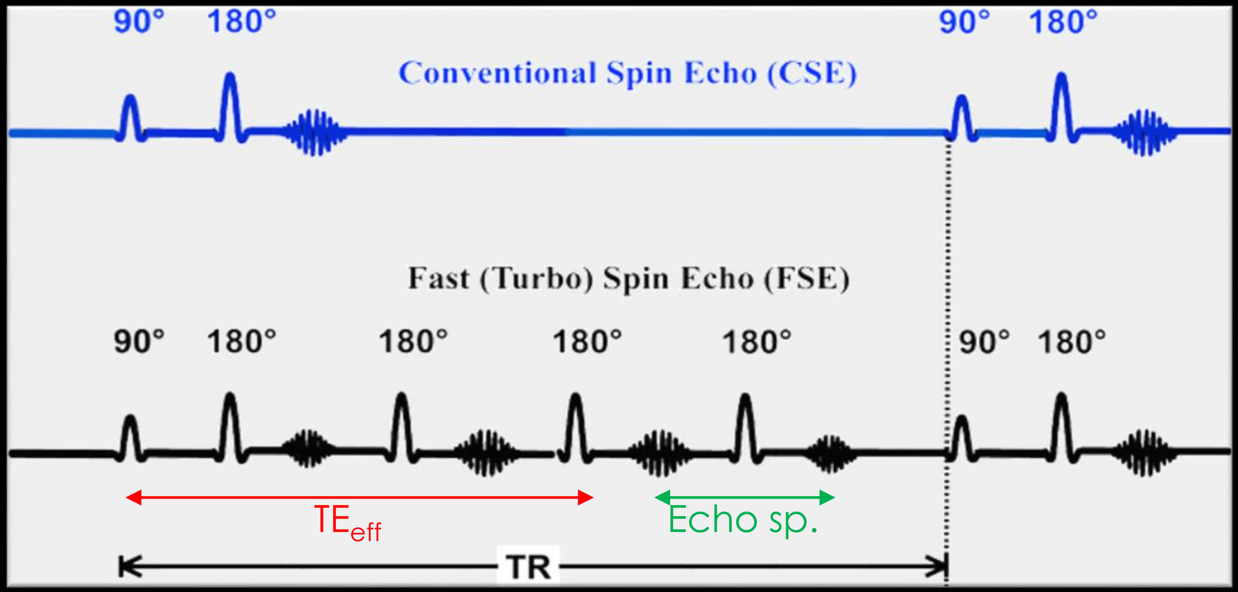
- Tr
- Number of averagings
- Number of rows of k-space
-

$$t = TR * \#phase * NEX$$
$$t(600ms, 256, 1) = 0,6 * 256 * 1 = 153,6s$$
$$t(4000, 256, 1) = 4 * 256 * 1 = 1024\ s$$
$$t(500, 512, 4) = 0,5 * 512 * 4 = 1024\ s$$

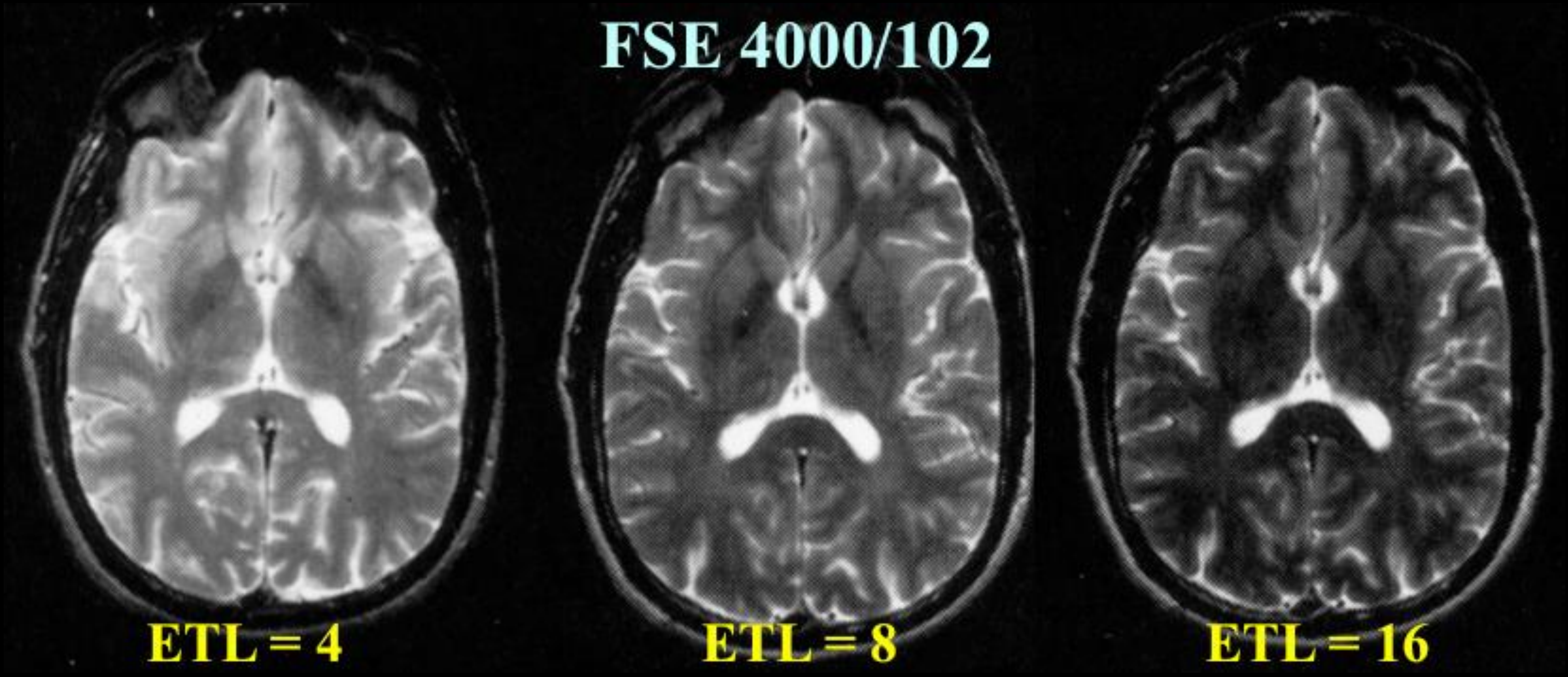
TURBO SPIN ECHO ACQUISITION SPEED

- TR, TF
- Number of averagings
- Number of rows of k-space
- High SAR
-

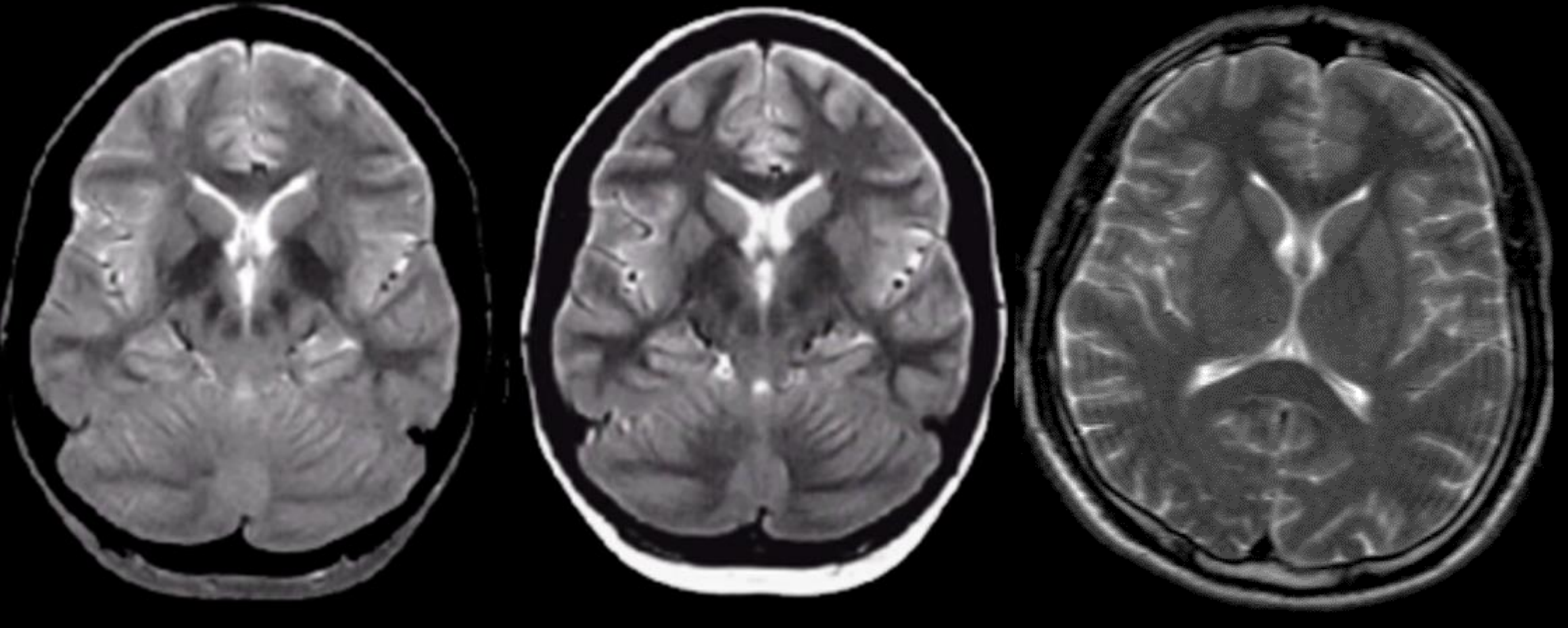
$$t = TR * \#phase * NEX / TF$$
$$t(600ms, 256, 1, 4) = 0,6 * 256 * 1/4 = 38s$$
$$t(4000, 256, 1, 18) = 4 * 256 * 1 = 56,8\ s$$
$$t(500, 512, 4, 4) = 0,5 * 512 * 4 = 256\ s$$



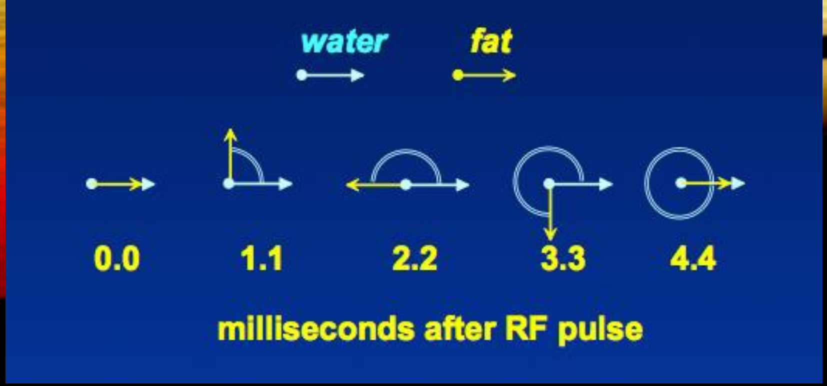
TURBO SPIN ECHO

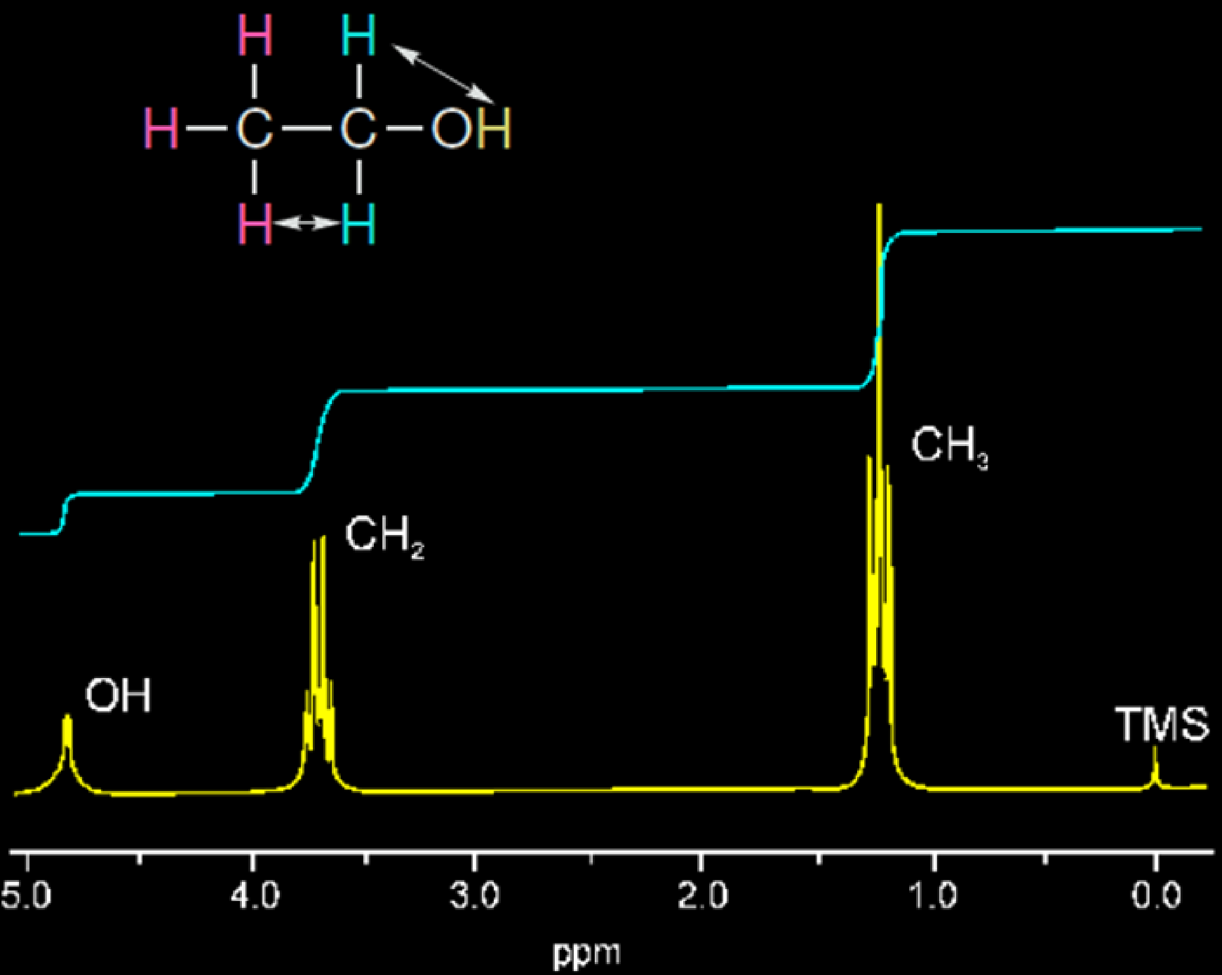


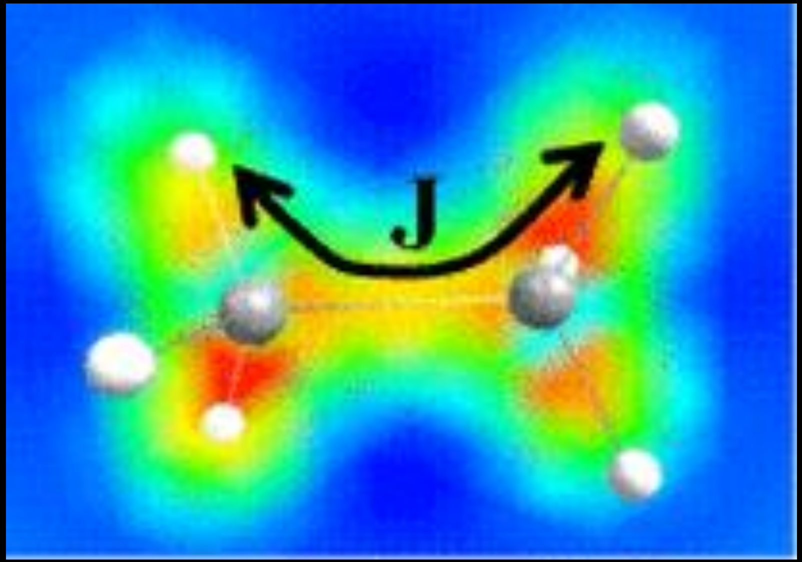
SE VS TSE

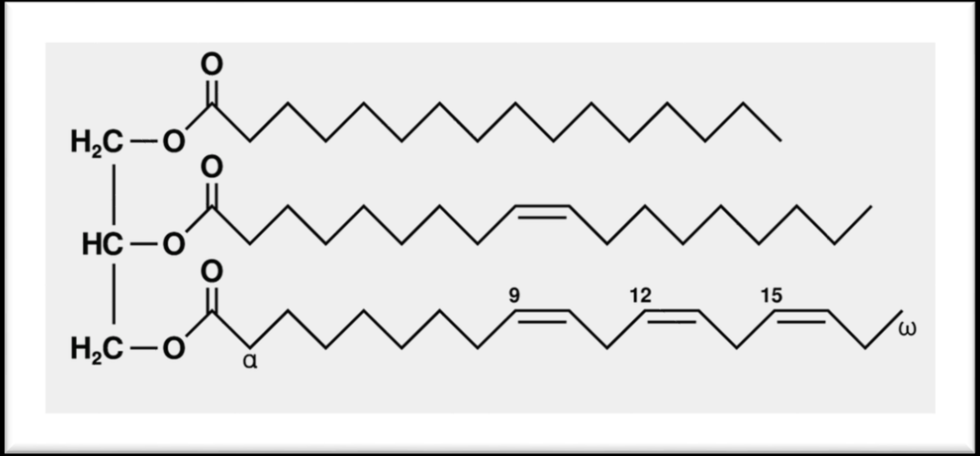


CH SHIFT, J-COUPLING



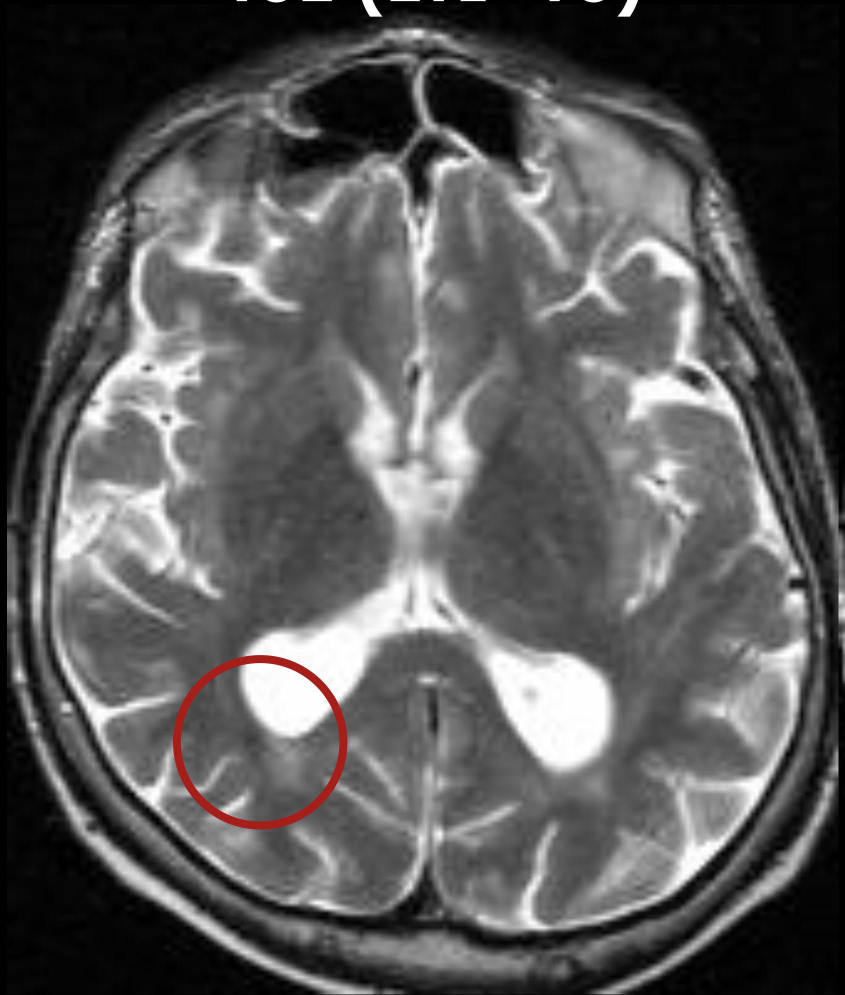






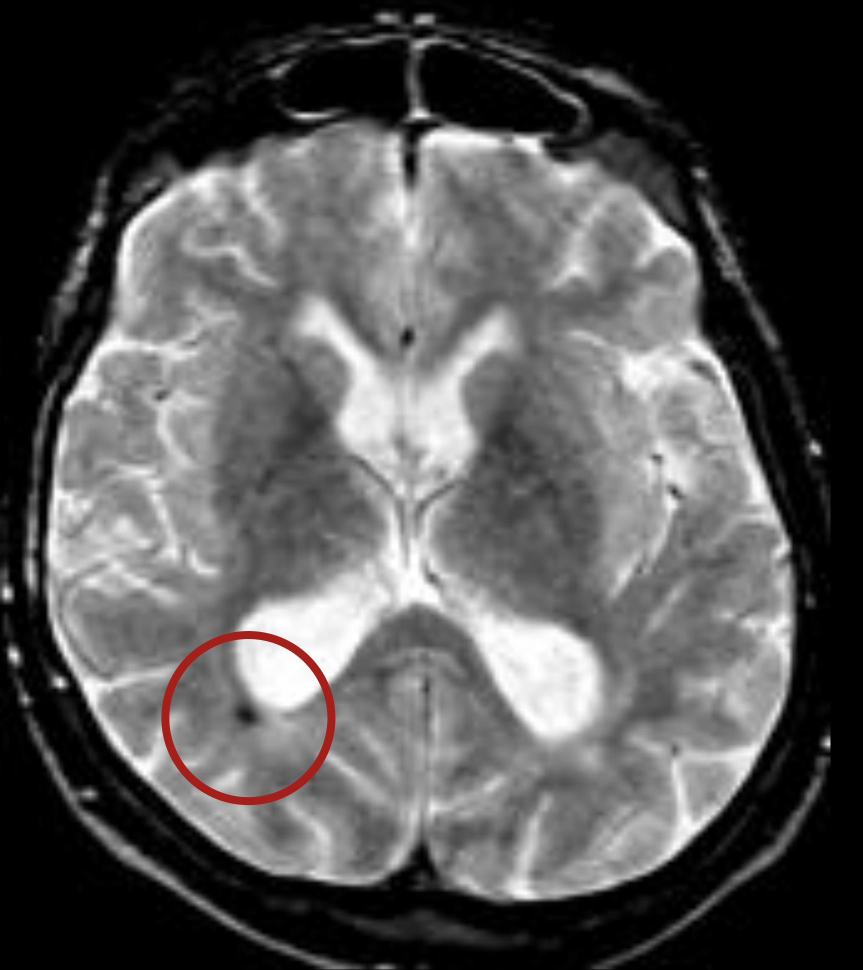
SE vs TSE - Susceptibility

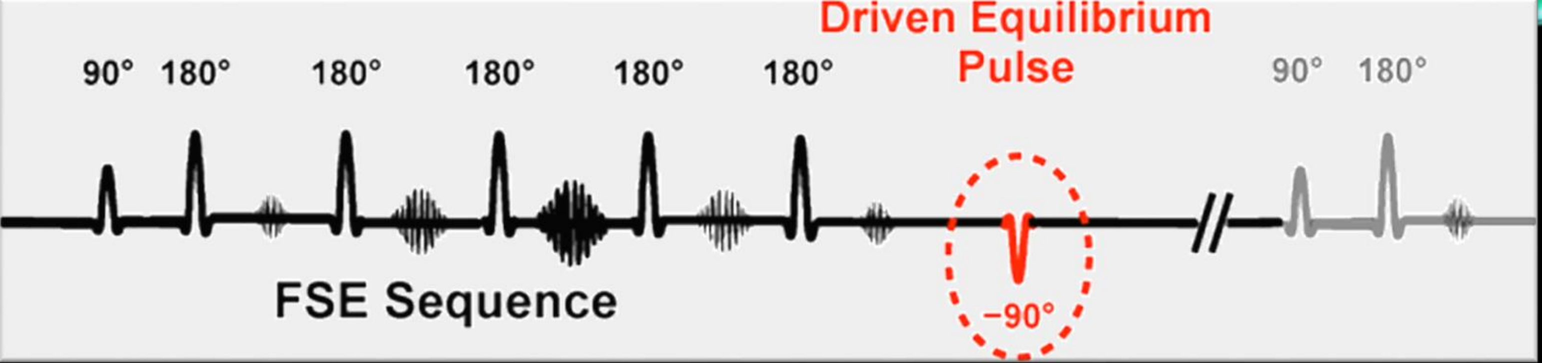
TSE (ETL=15)



TSE (ETL=5)

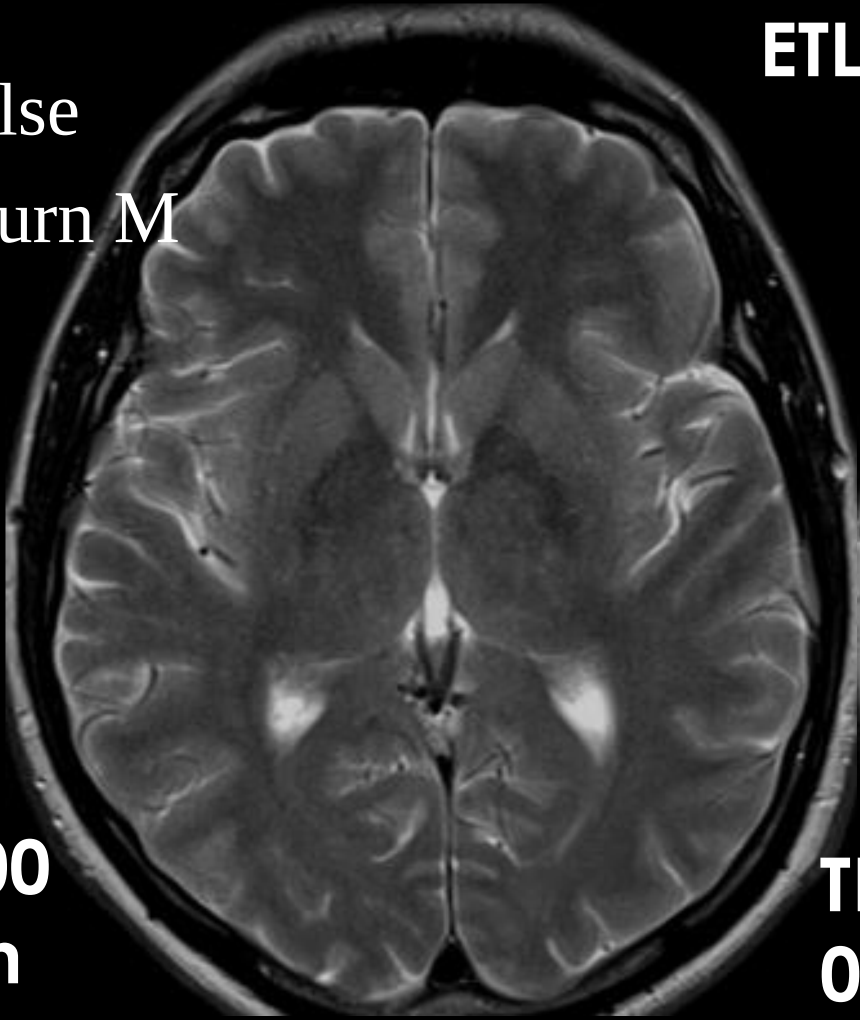
SE

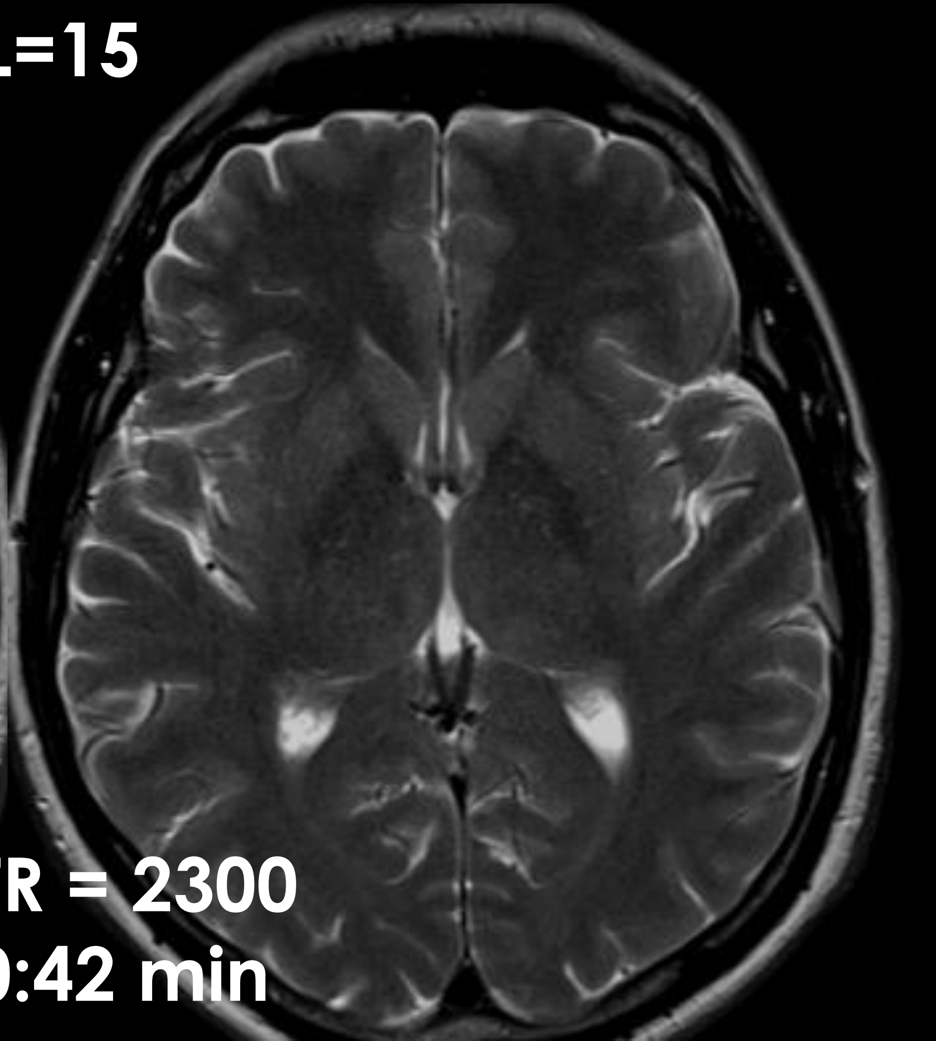




TSE DRIVE/FRFSE

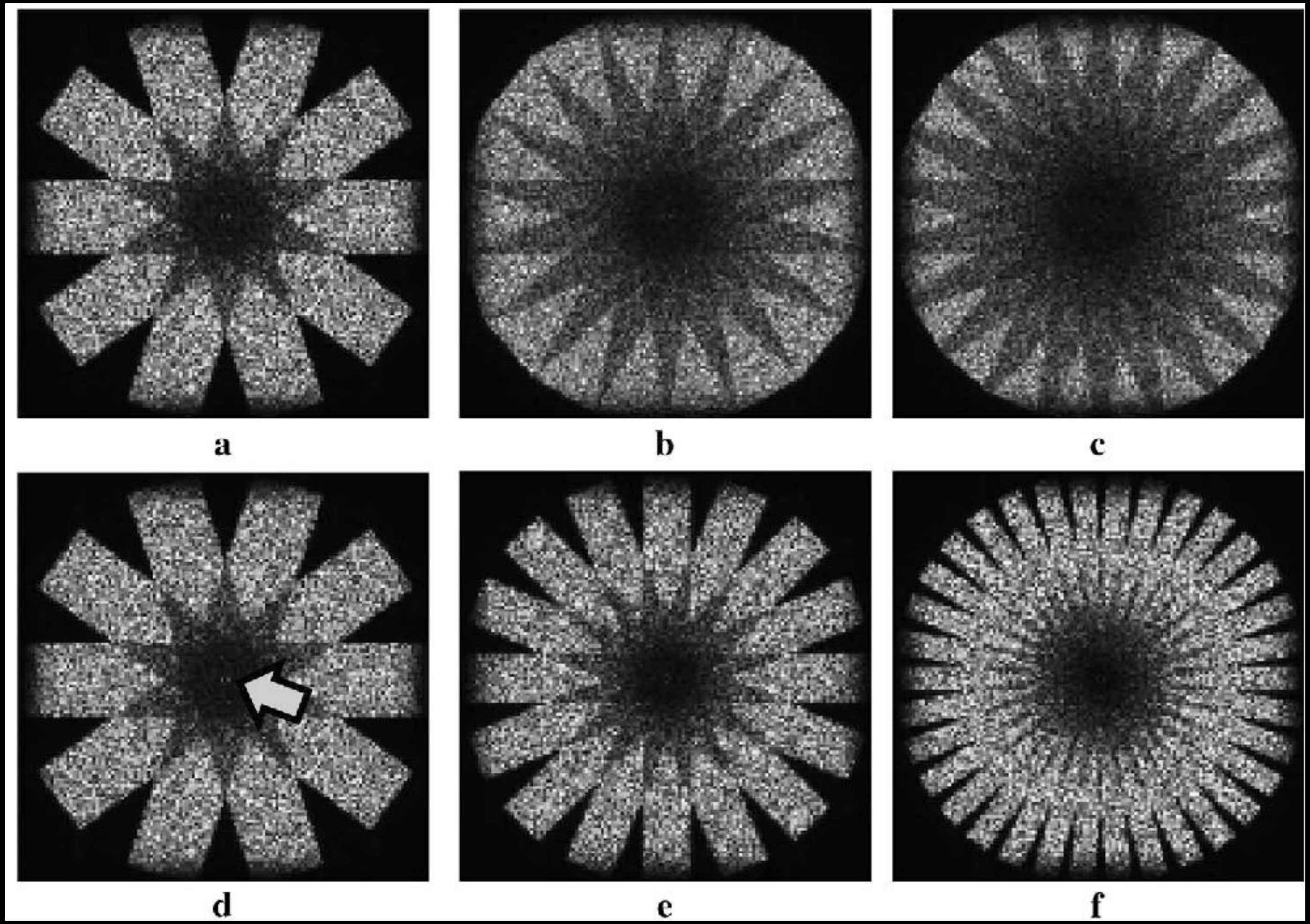
- Additional -90° pulse
- Acceleration of return M
- shorter TR
-



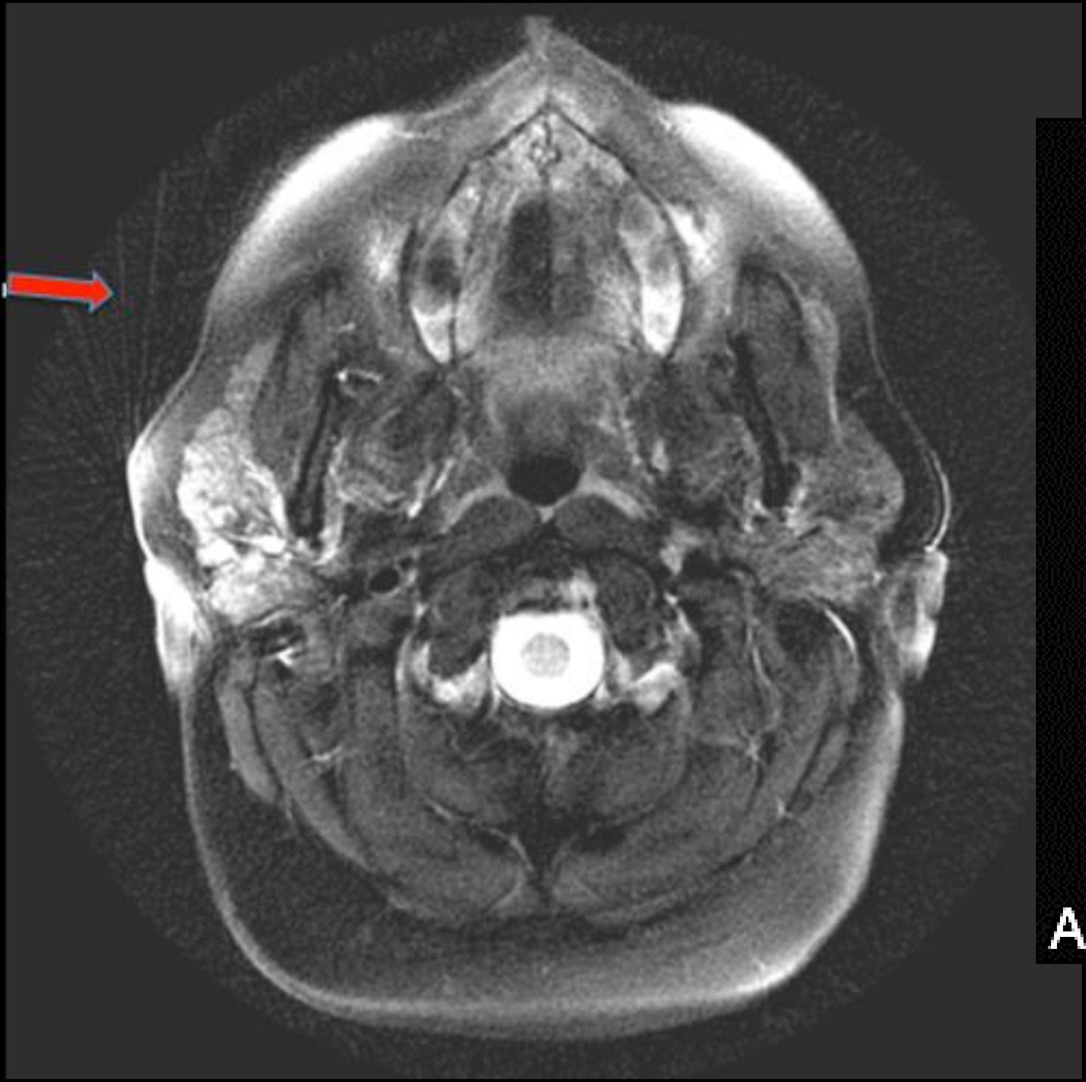


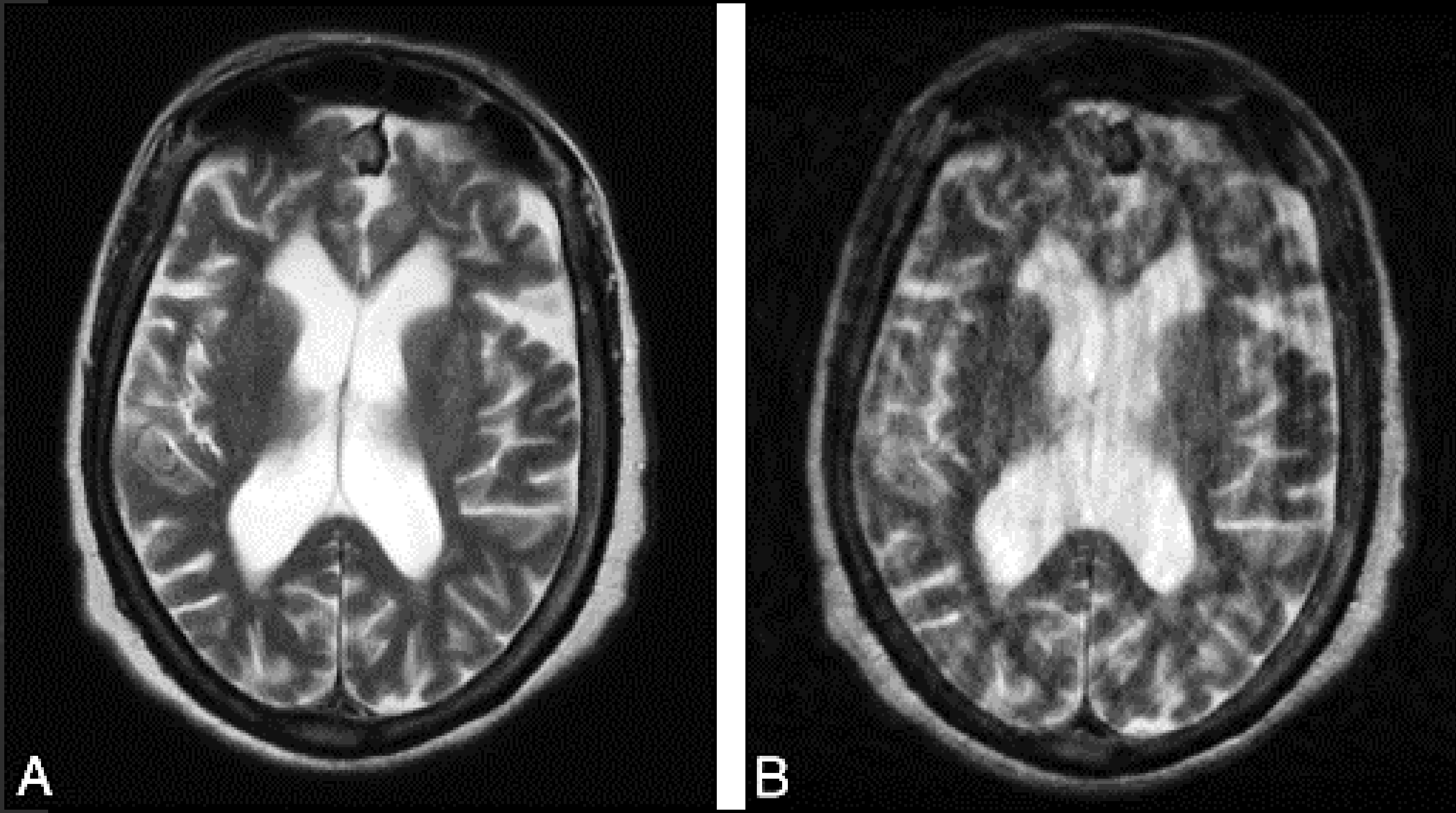
TSE MULTIVANE/PROPELER

- Radial scoop of k-space
- Center resampled
- Margins undersampled
- Less sensitive movement
- Increased blur
- Creation of artifacts
- Longer acquisitions



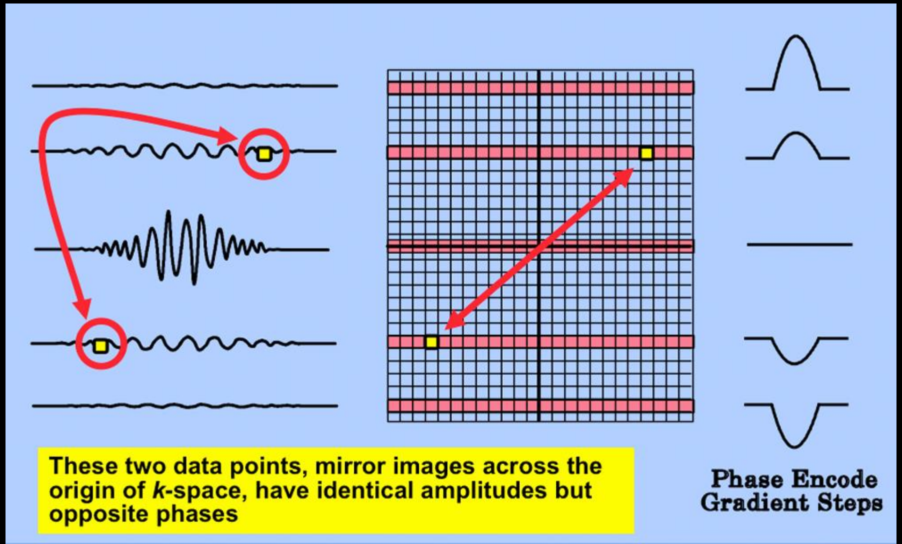
TSE MULTIVANE/PROPELER

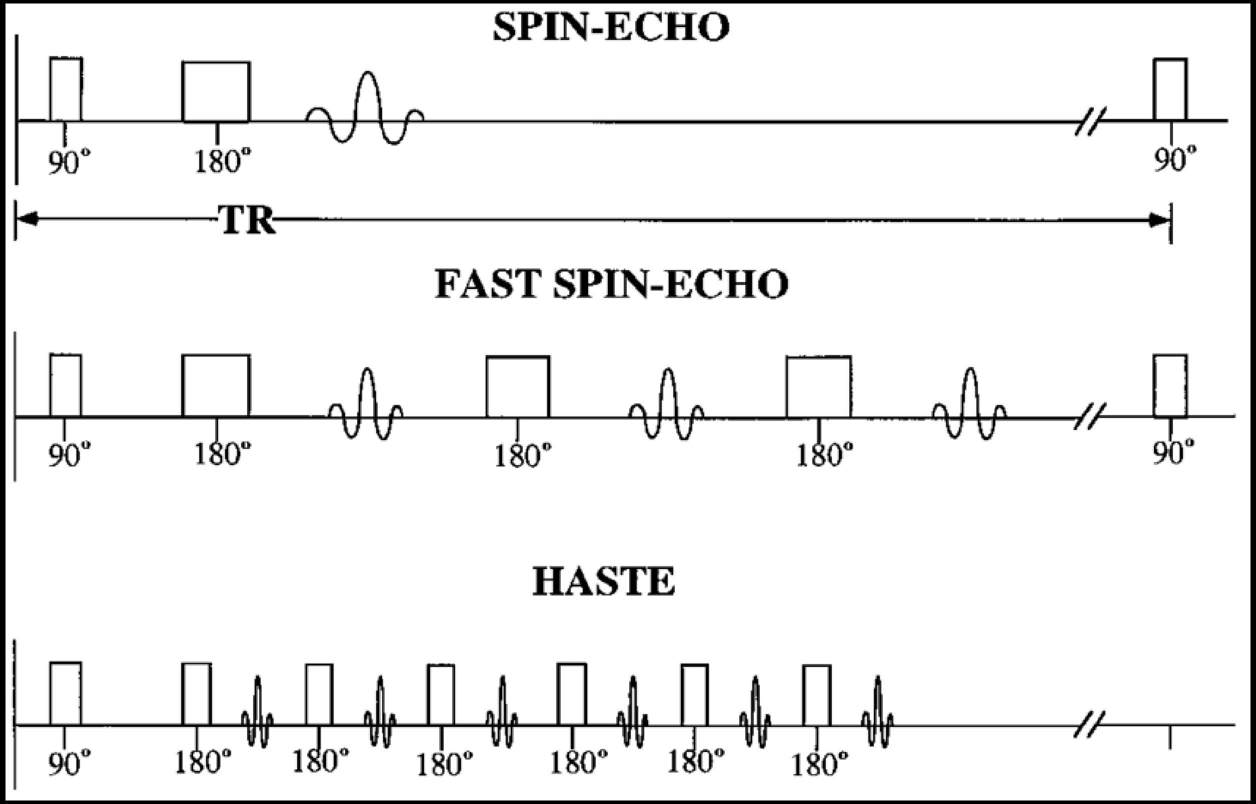




SINGLE SHOT TSE

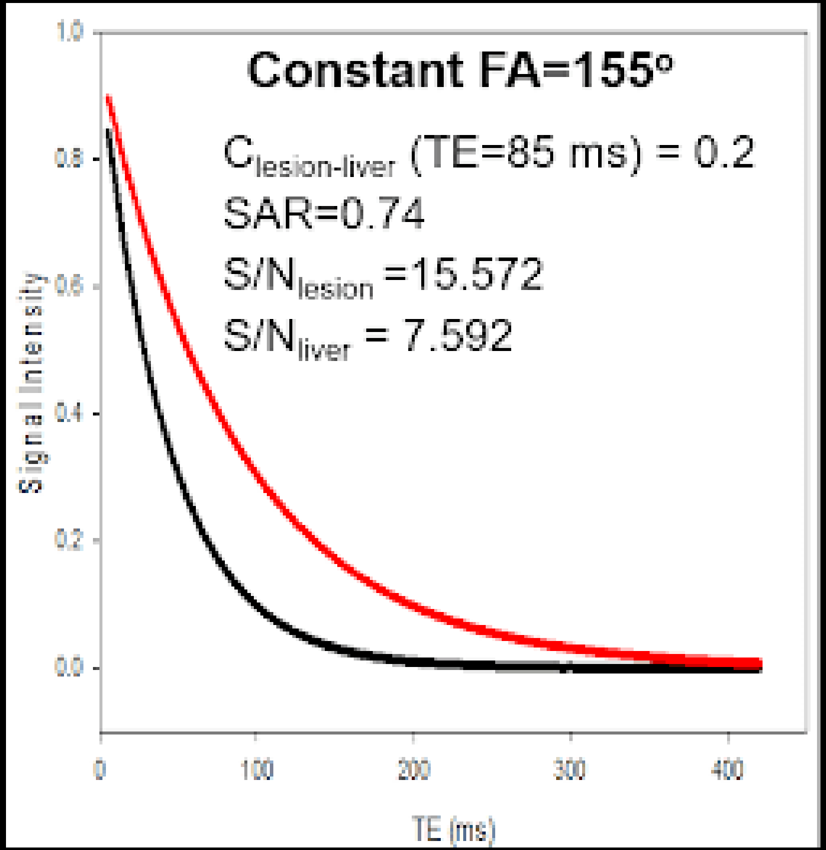
- High ETL, partial k-space scoop
- High SAR
- Decrease in SNR
- Very fast pick-up (~1s)

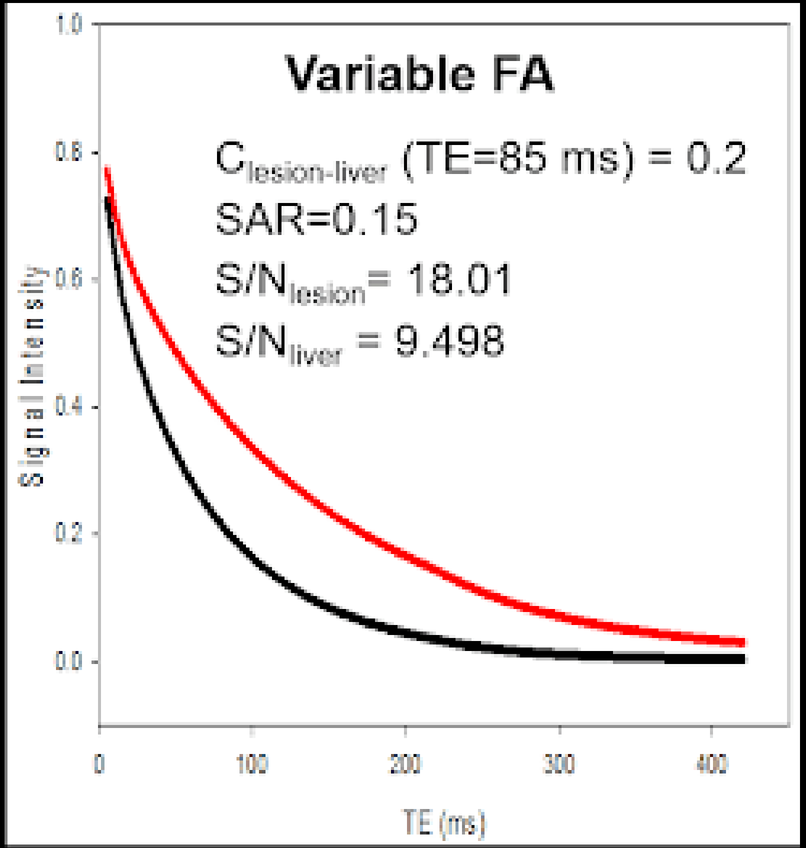




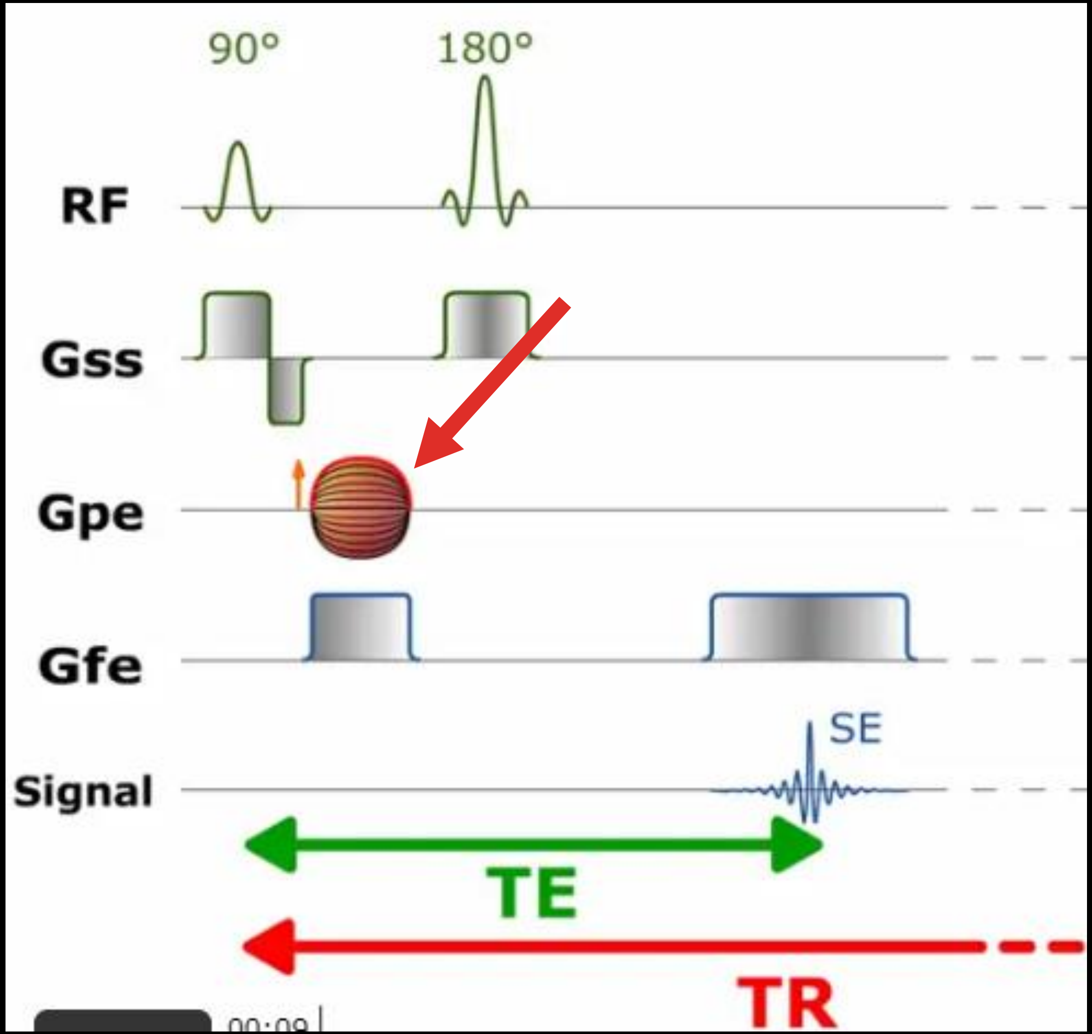
SINGLE SHOT TSE

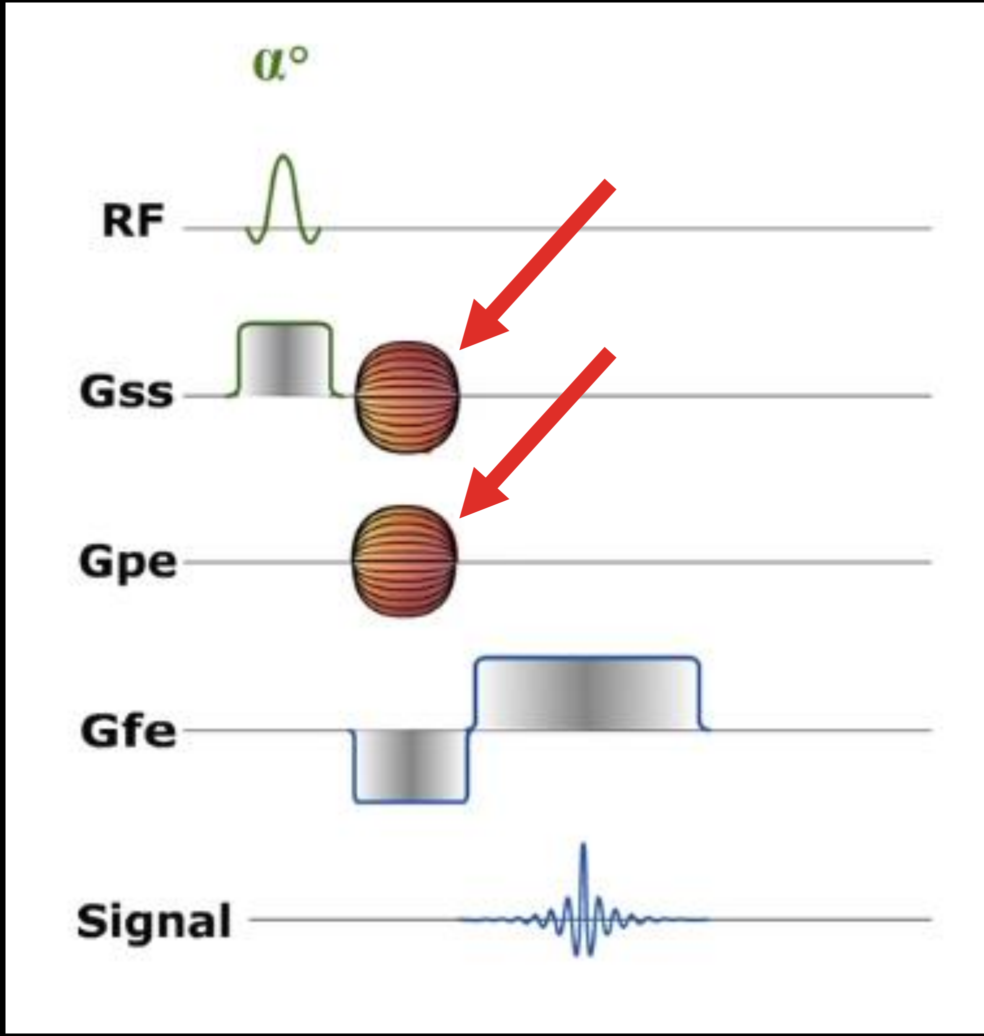
- Reducing SAR > replacing 180° pulses
-





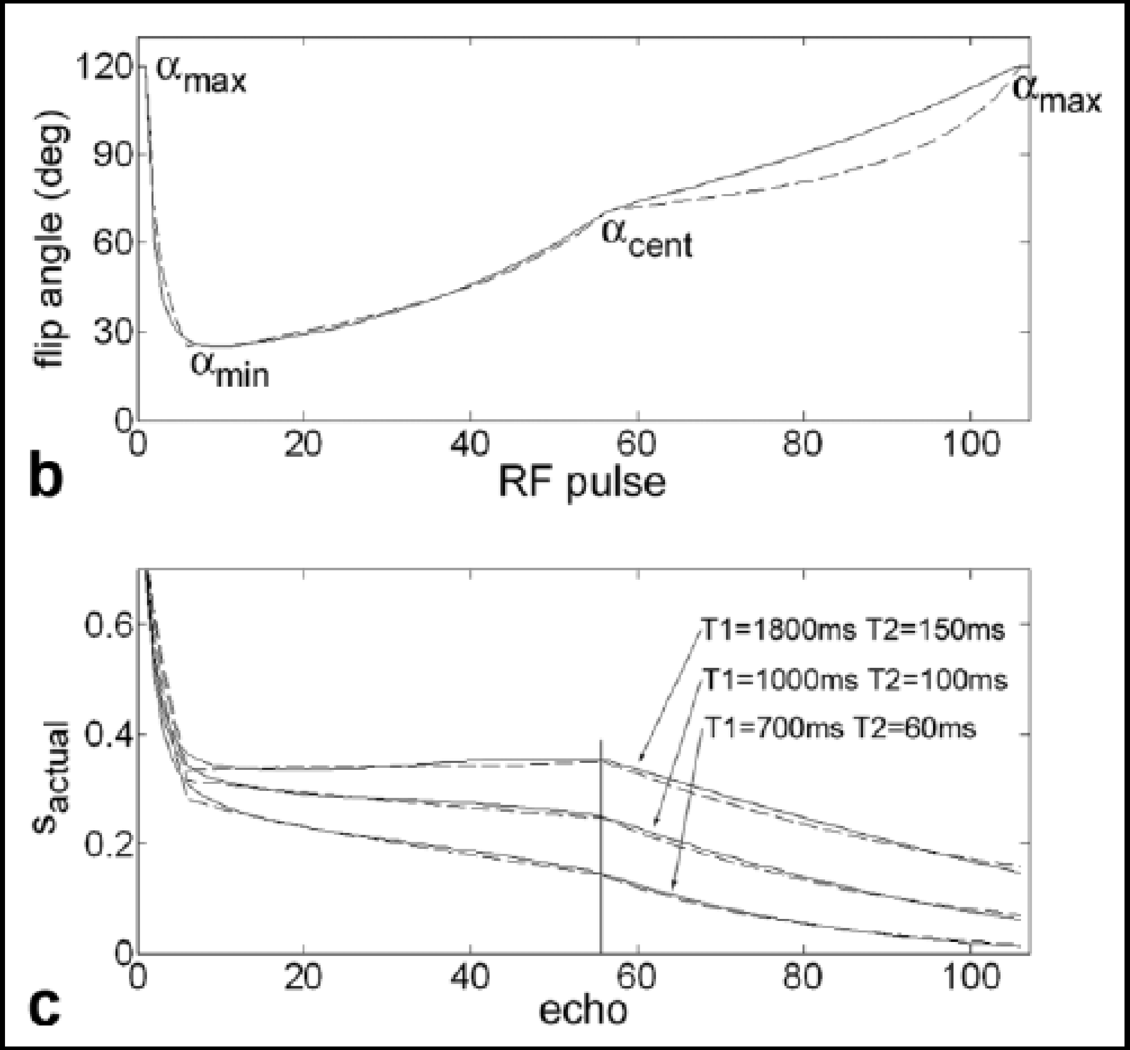
2D VS 3D

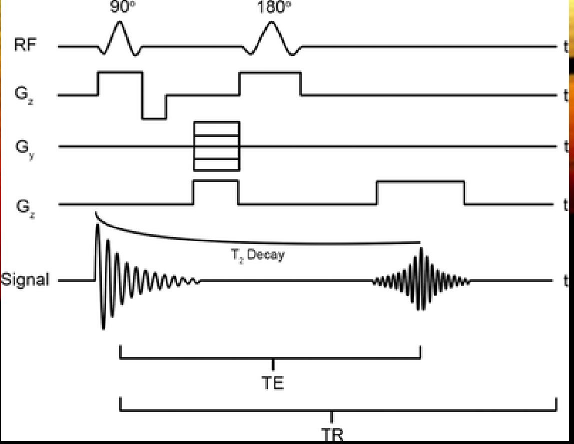




CUBE/VISTA

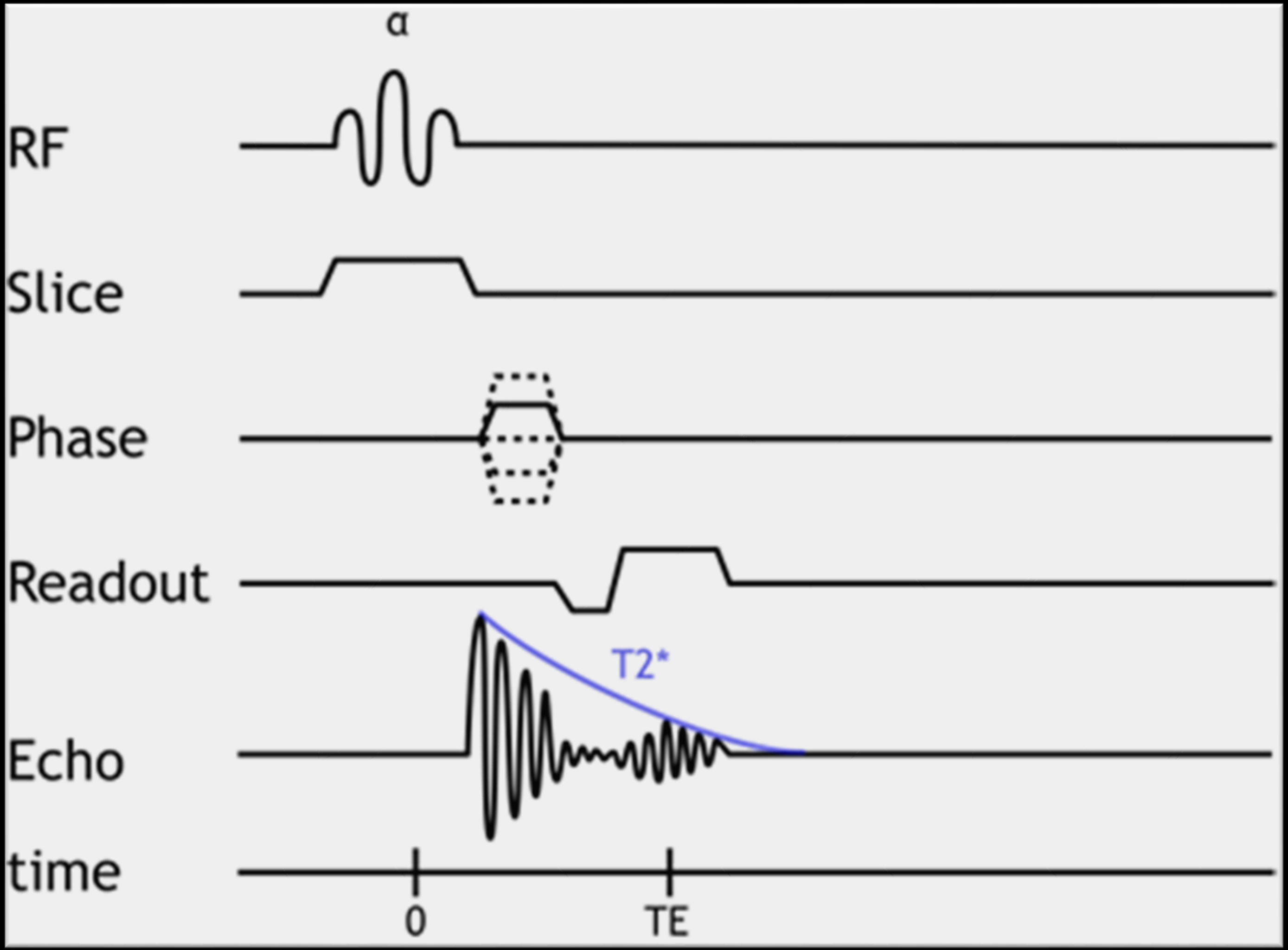
- 3D sequence
- Variable refoc. angle
- Lower SAR
- High ETL
- High resolution
- Less metal. Artifacts
- Long acquisition. time (>5min)





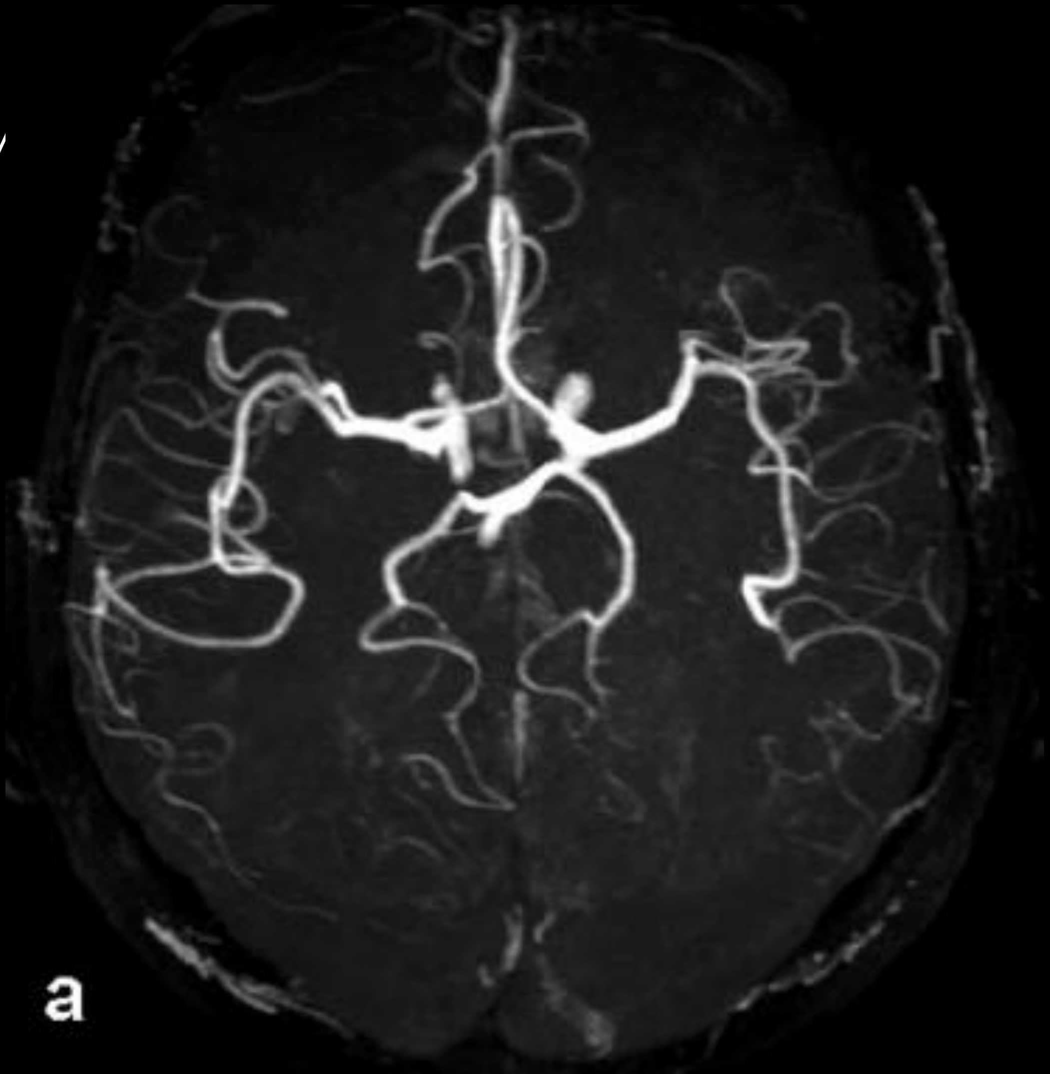
GRADIENT ECHO

- α < 90° = shorter TR
- T2 -> T2*
- Sensitive to inhomogeneities
- Lower SAR
- Quick acquisition
- 2 basic families
- No/coherent GRE

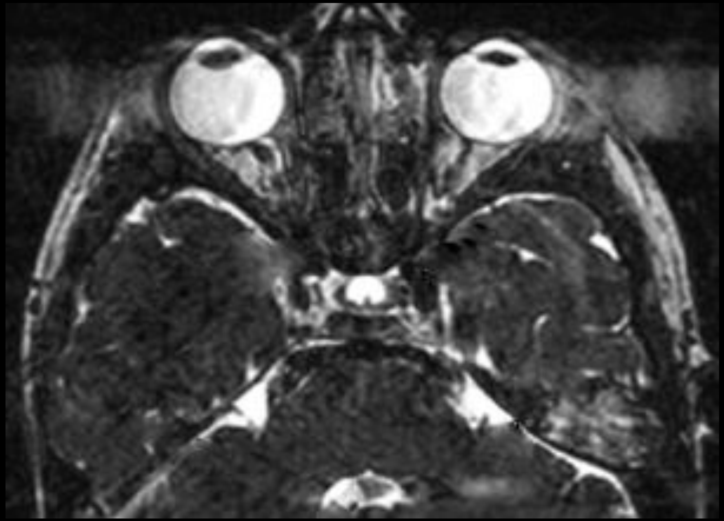


COHERENT GRE (FFE/GRE/FISP)

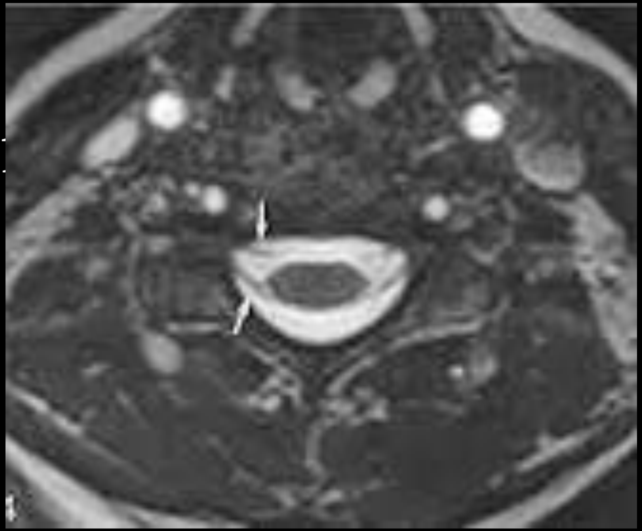
- Preserves the transverse component M
- Signal T2/T1 weighted
- Low tissue contrast
- Flowing blood high signal
- TOF MRA



KOH GRE (T2 FFE/FSPGR/PSIF)

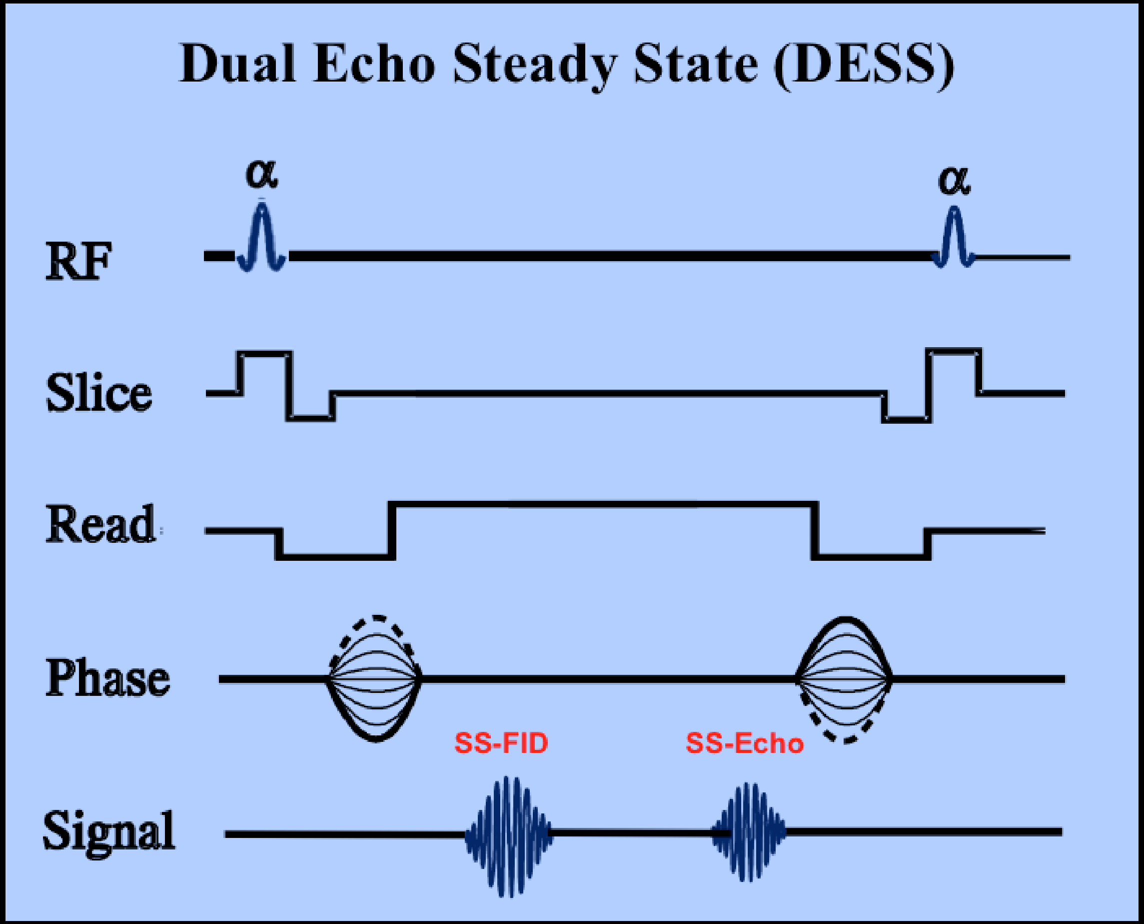


- SE sequence generated by GRE
- Sequence of α-pulses and grad.
- TE > TR
- Low SNR
- Quick measurement
- Extremely sensitive to the movement of spins in the

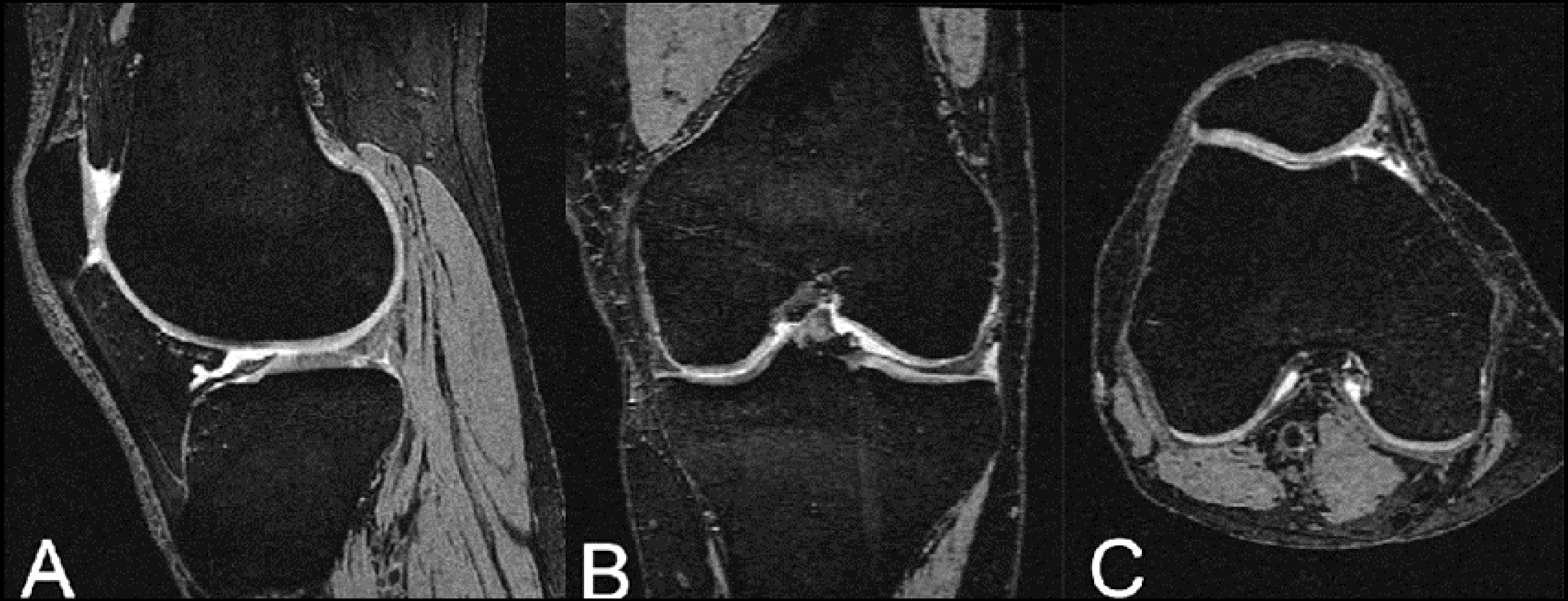


KOH GRE (MENSA/DESS)

- "Sum" of FISP (GRE) and PSIF (SE)
- Unique contrast
- Use in MSK
- Cartilage/fluid/bone
-

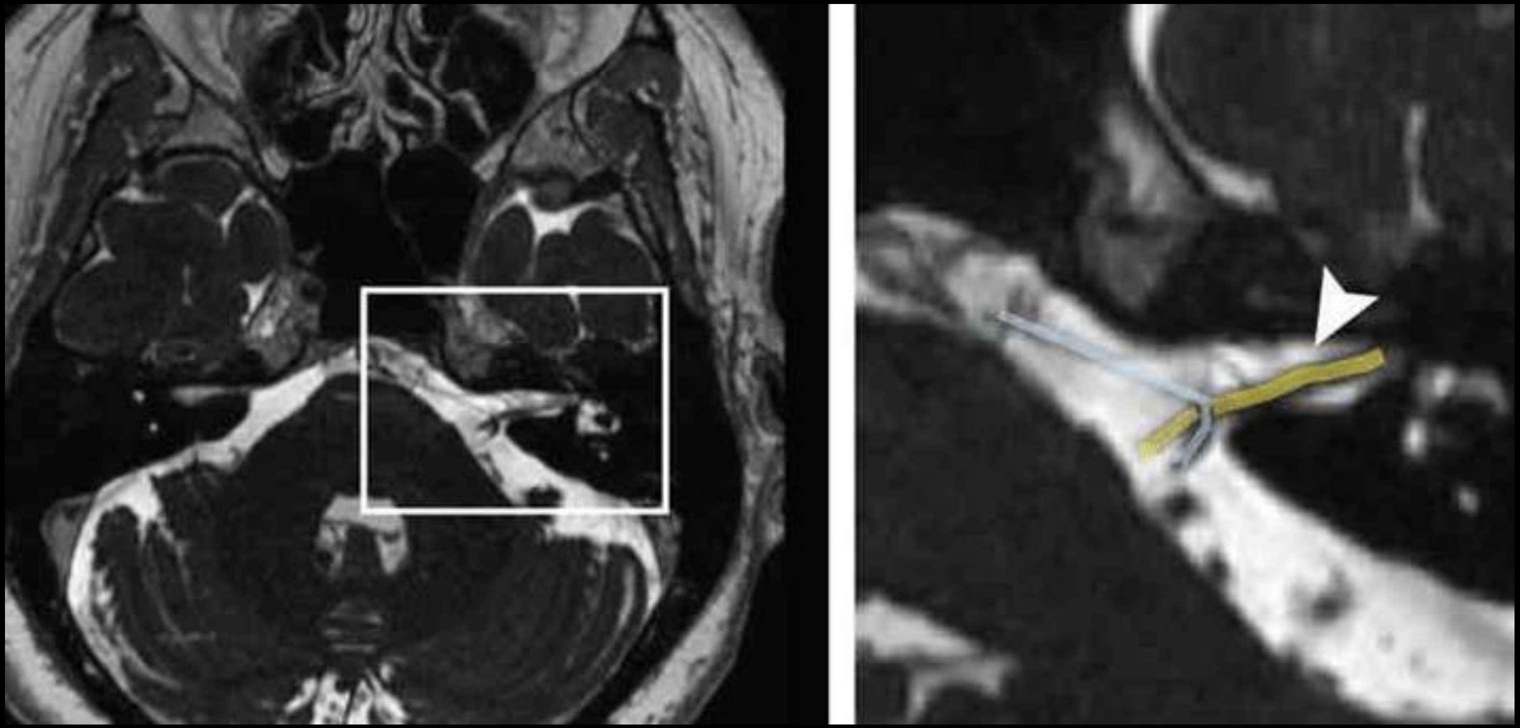


KOH GRE (MENSA/DESS)

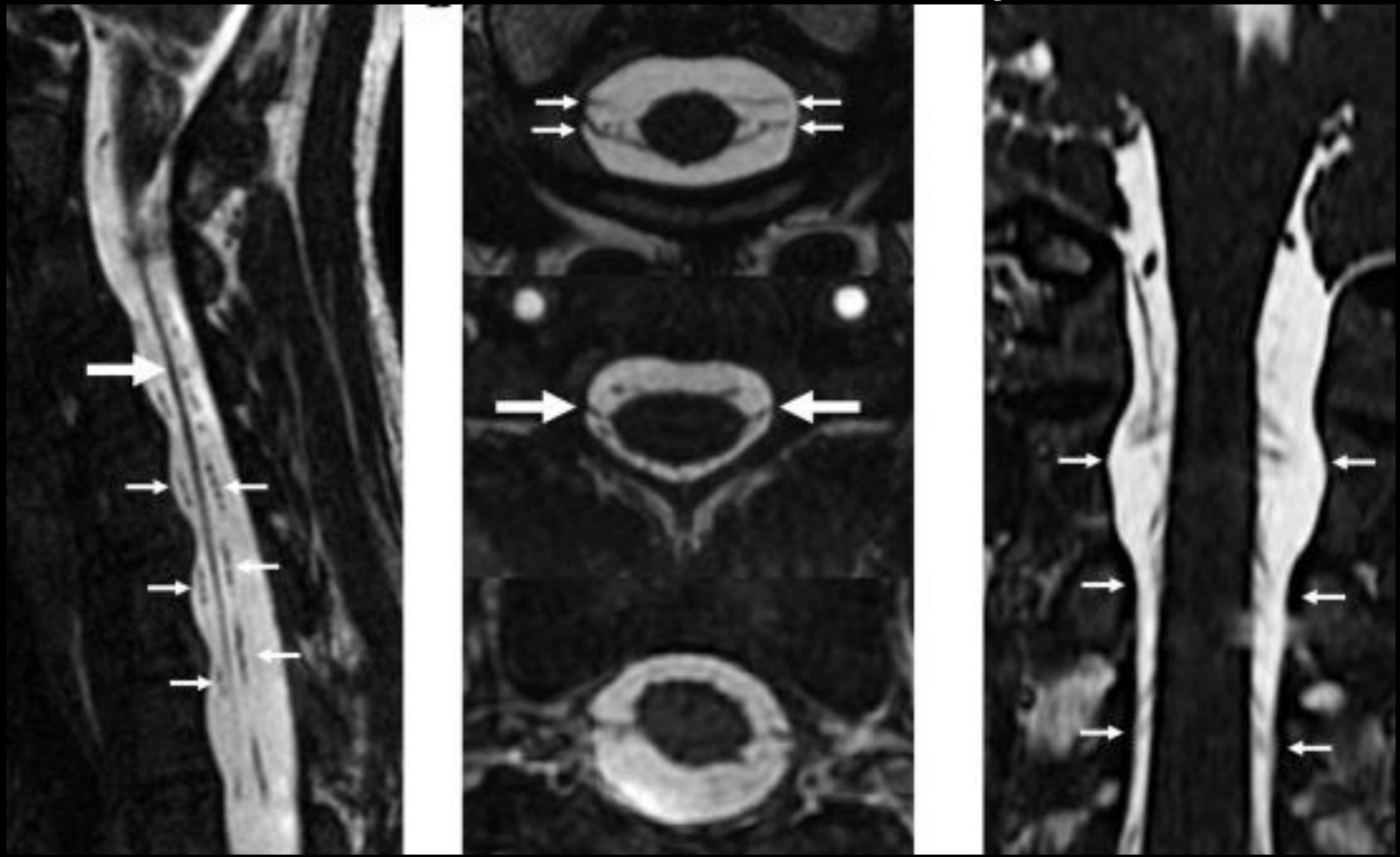


KOH GRE (FIESTA-C/CISS)

- Combination of FISP (GRE) and PSIF (SE)
- SCISS = (S1 + (-1)nS2) / 2
- Neuro-vascular contact
- MR cisternography
-



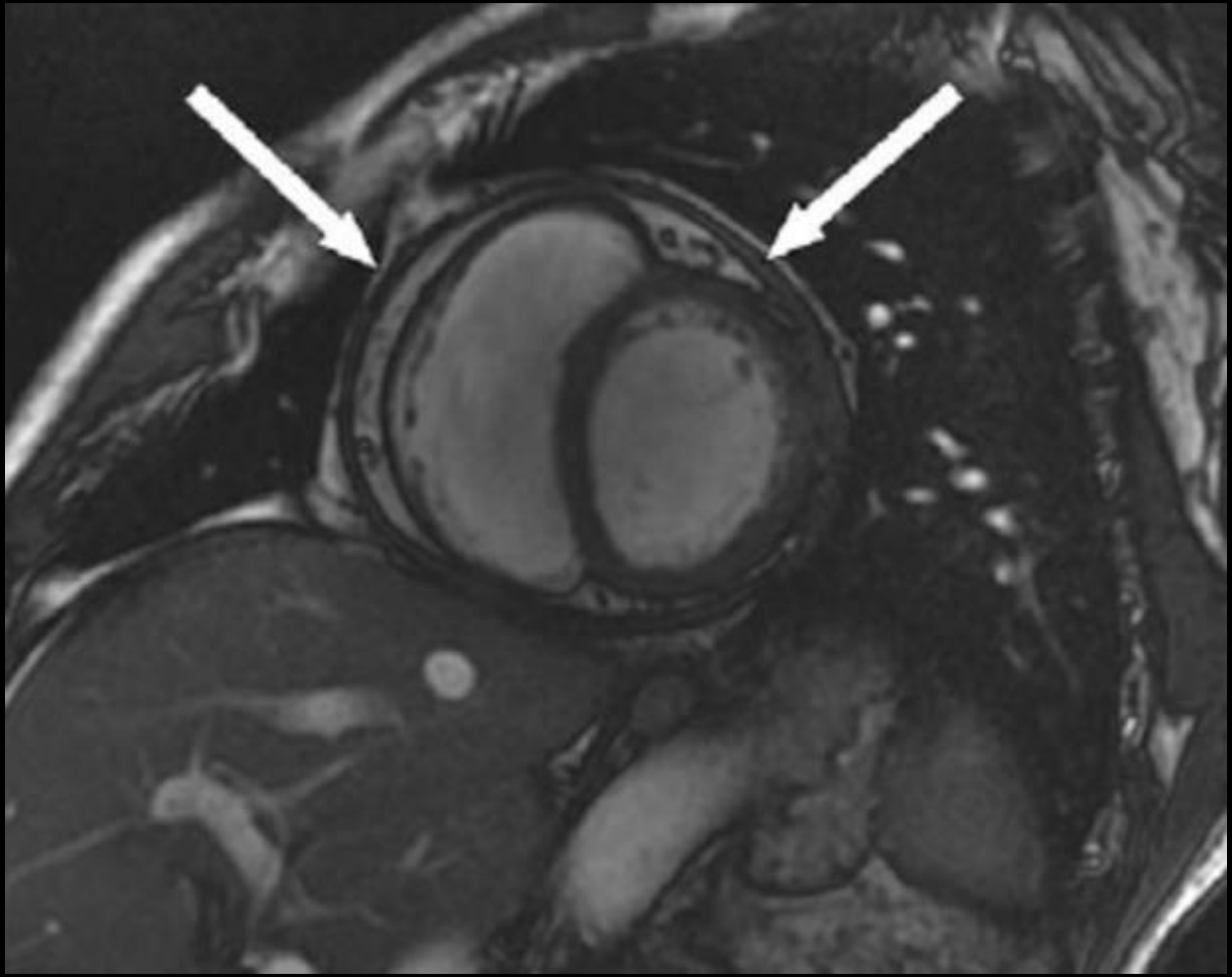
KOH GRE (FIESTA-C/CISS)



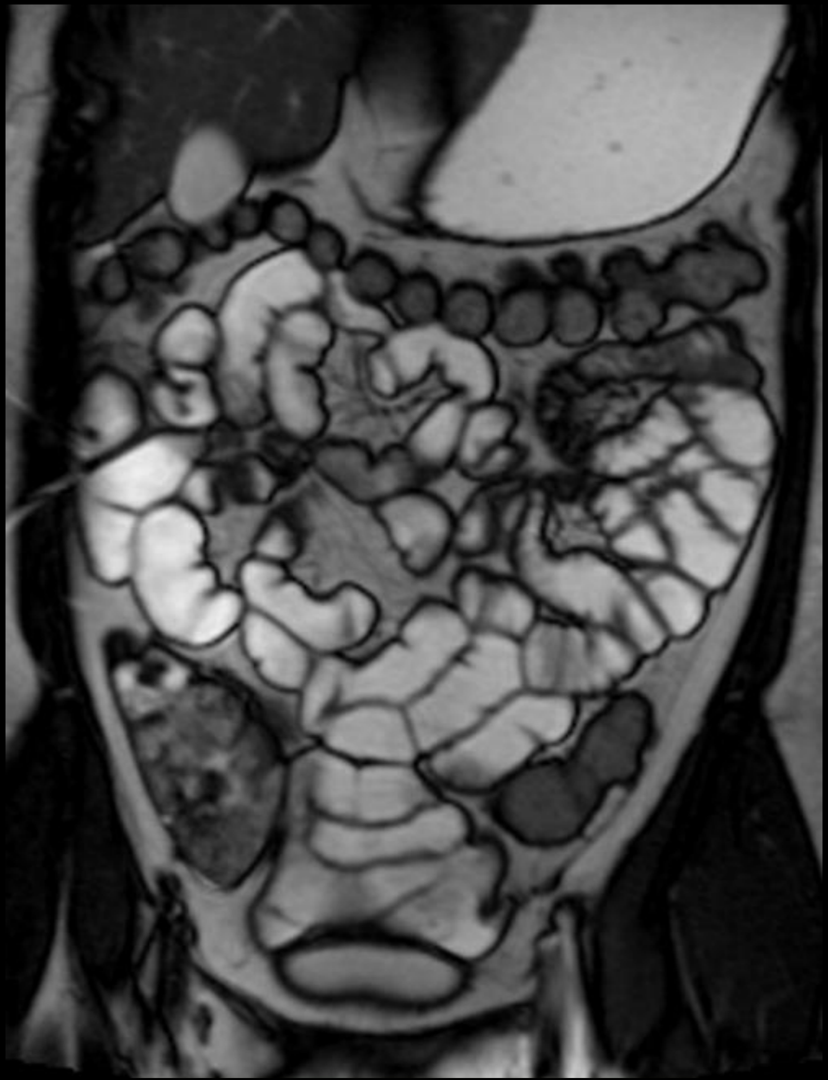
KOH GRE (FIESTA/BFFE)

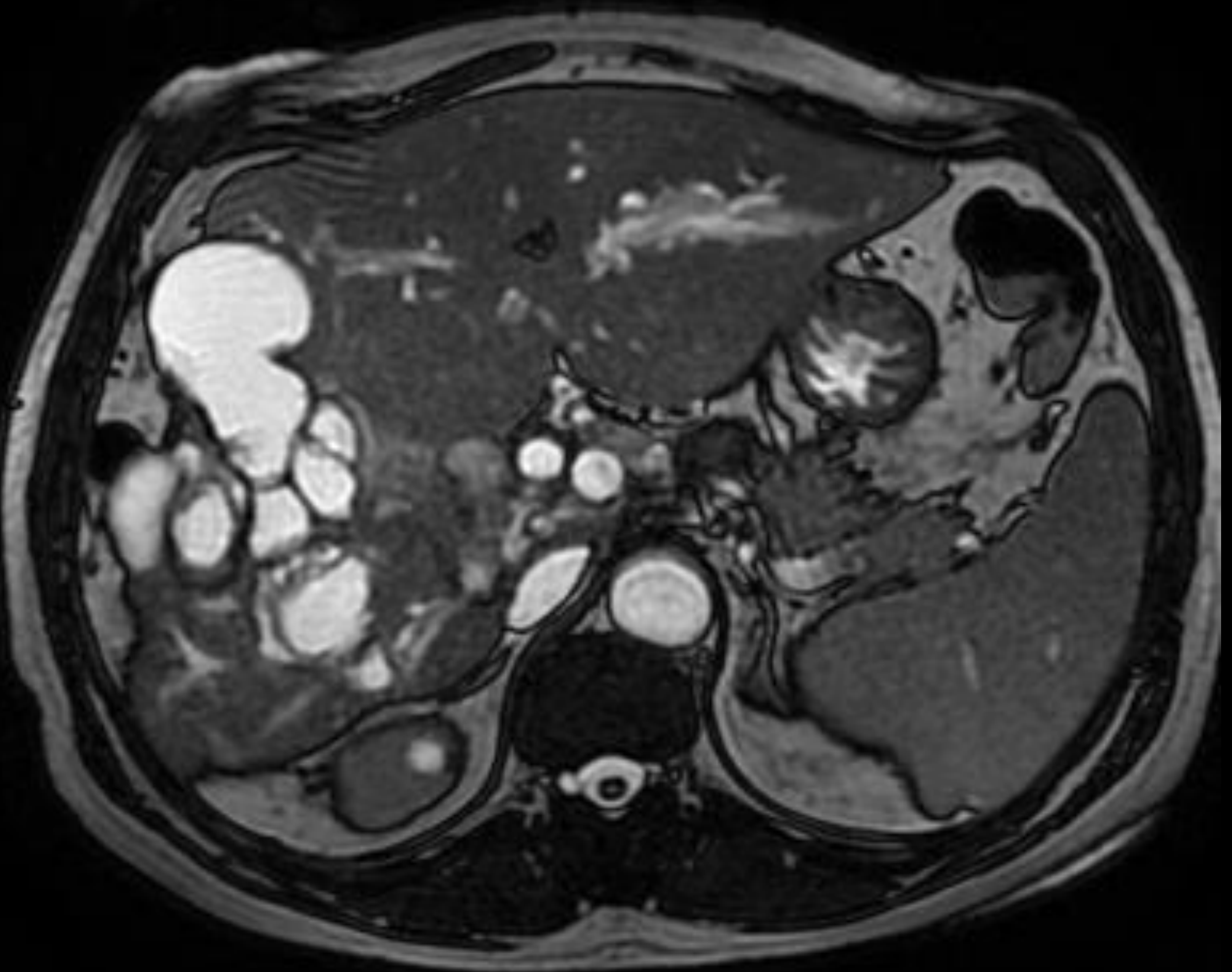
- Balanced sequence of all GRETs
- Very fast
- Less sensitive to turbulence
- Extremely sensitive to inhomogeneities B0 (~1/TR)
- Stronger field = bigger problem
- Cardio
- Quick display of the abdomen
-

KOH GRE (FIESTA/BFFE)



KOH GRE (FIESTA/BFFE)



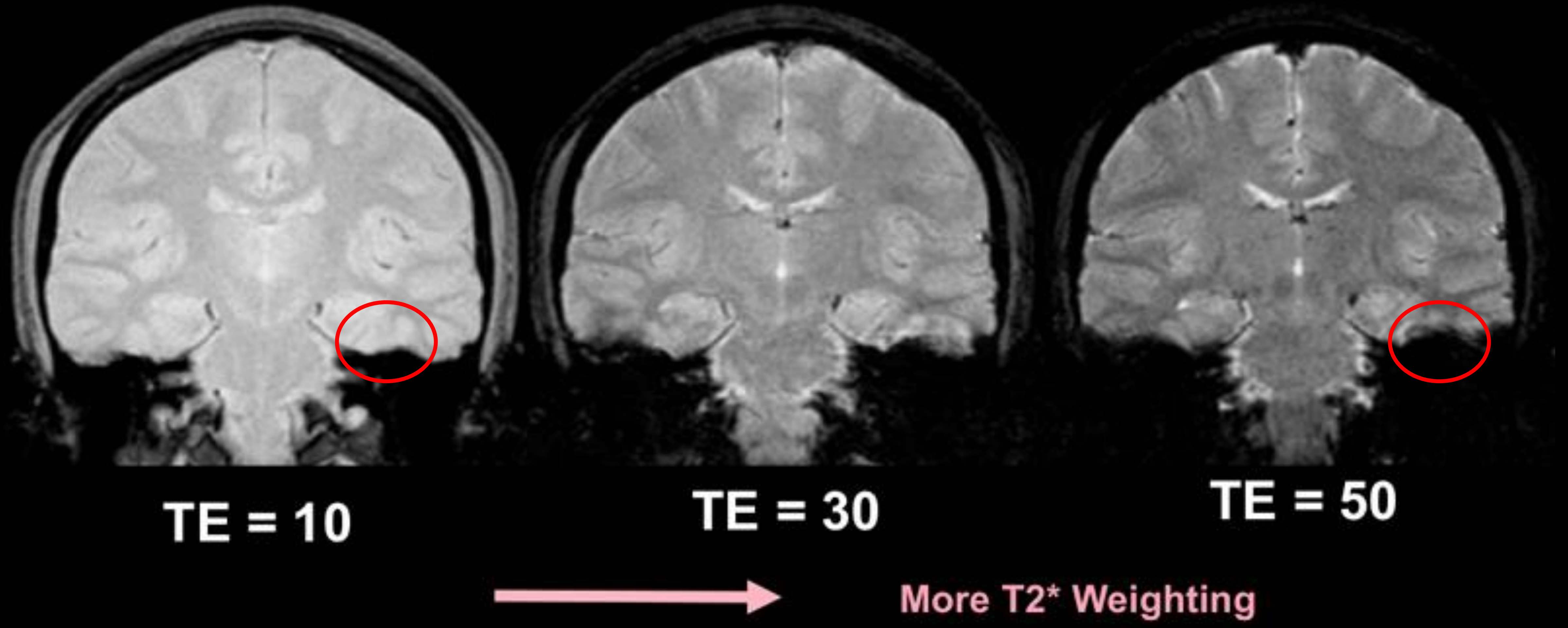


NEKOH GRE (FSPGR/T1FFE)

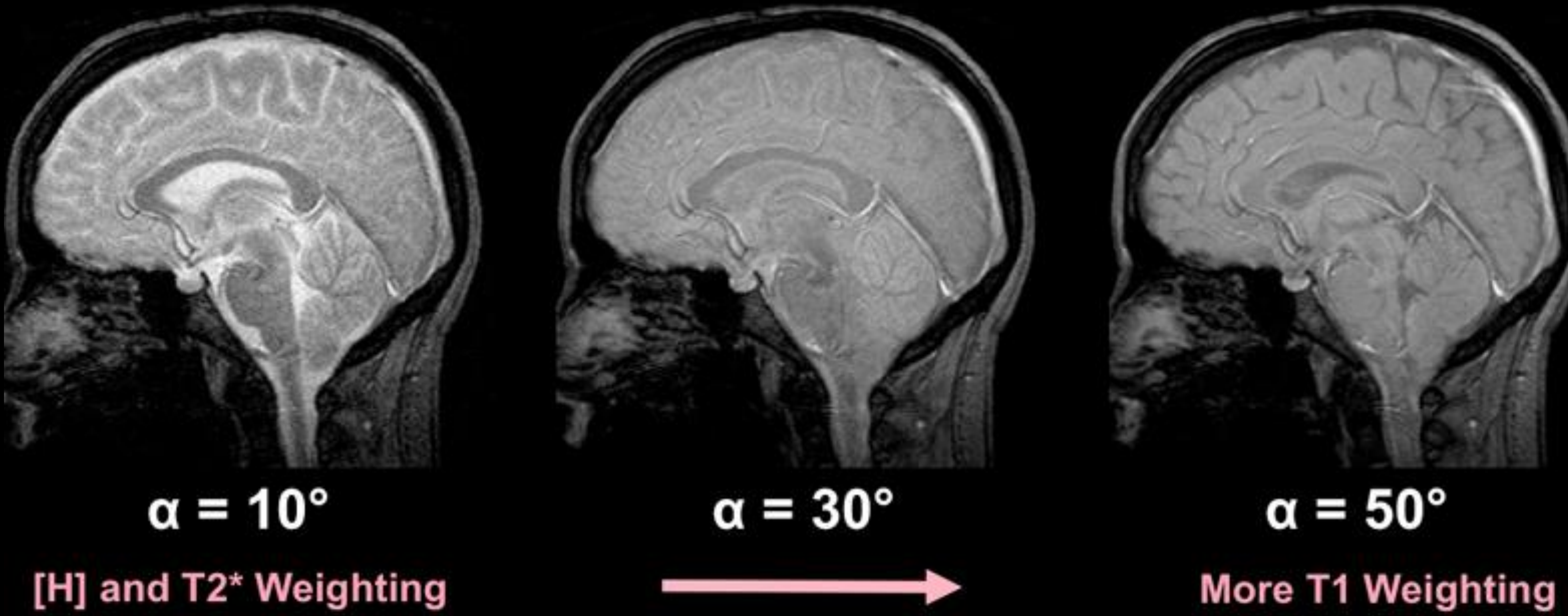
- Does not preserve the transverse component M┴
- Signal T1 or T2* weighted
- Quick Sequence
- Detection of haemosiderin/calcification
- Contrast MRA
- T2* significantly shorter than T2
- Very sensitive to mag. inhomogeneities
- Suscept. art. increase in size with a larger TE
-

Vážení	TE	TR	a
PD	Min	300-600 ms	10-20°
T1	Min	100-300 ms	30-70°
T2*	15-50 ms	300 – 600 ms	10-20°

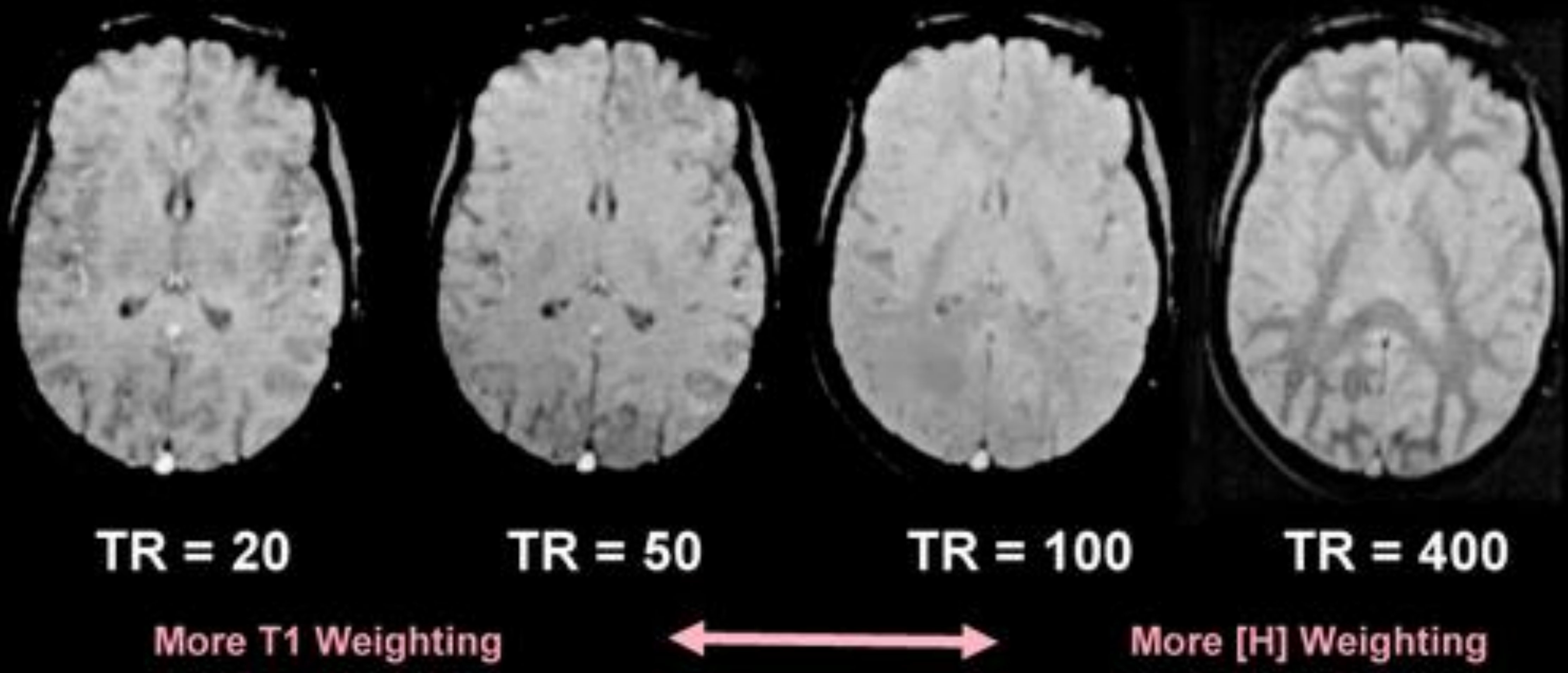
NEKOH GRE (FSPGR/T1FFE)



NEKOH GRE (FSPGR/T1FFE)

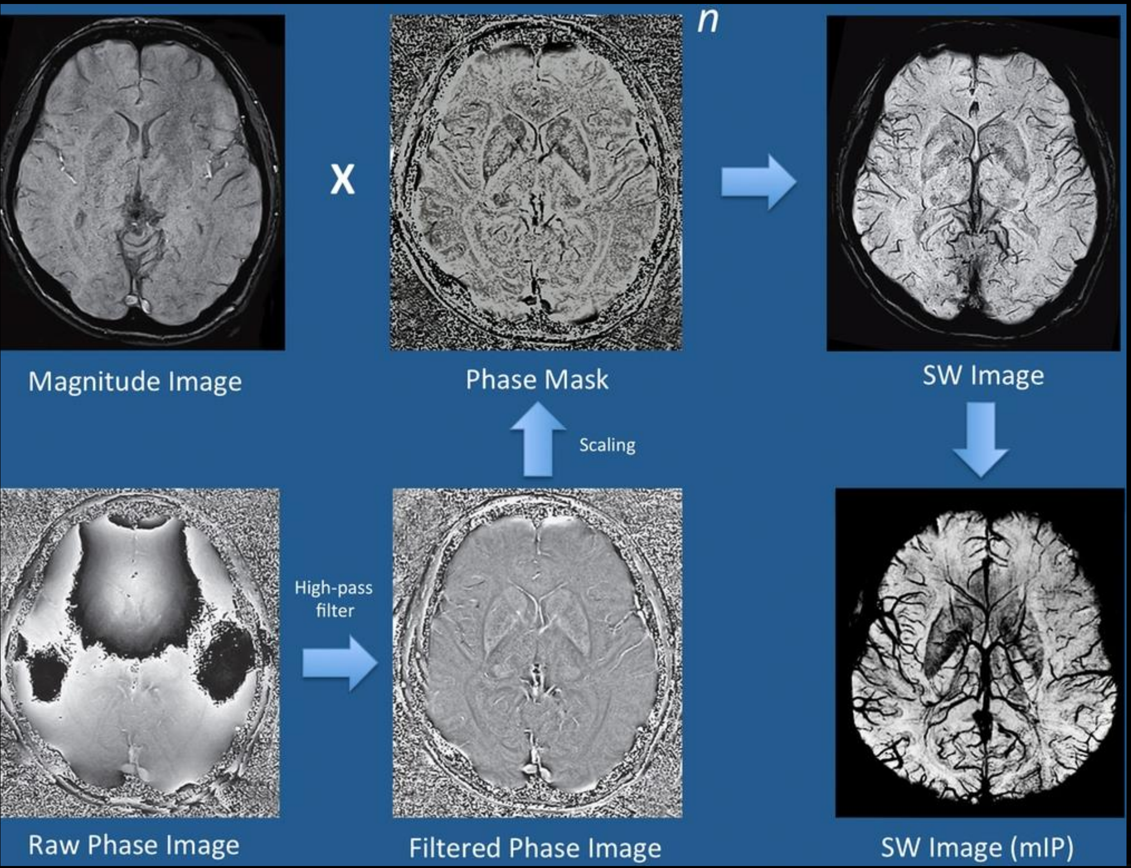


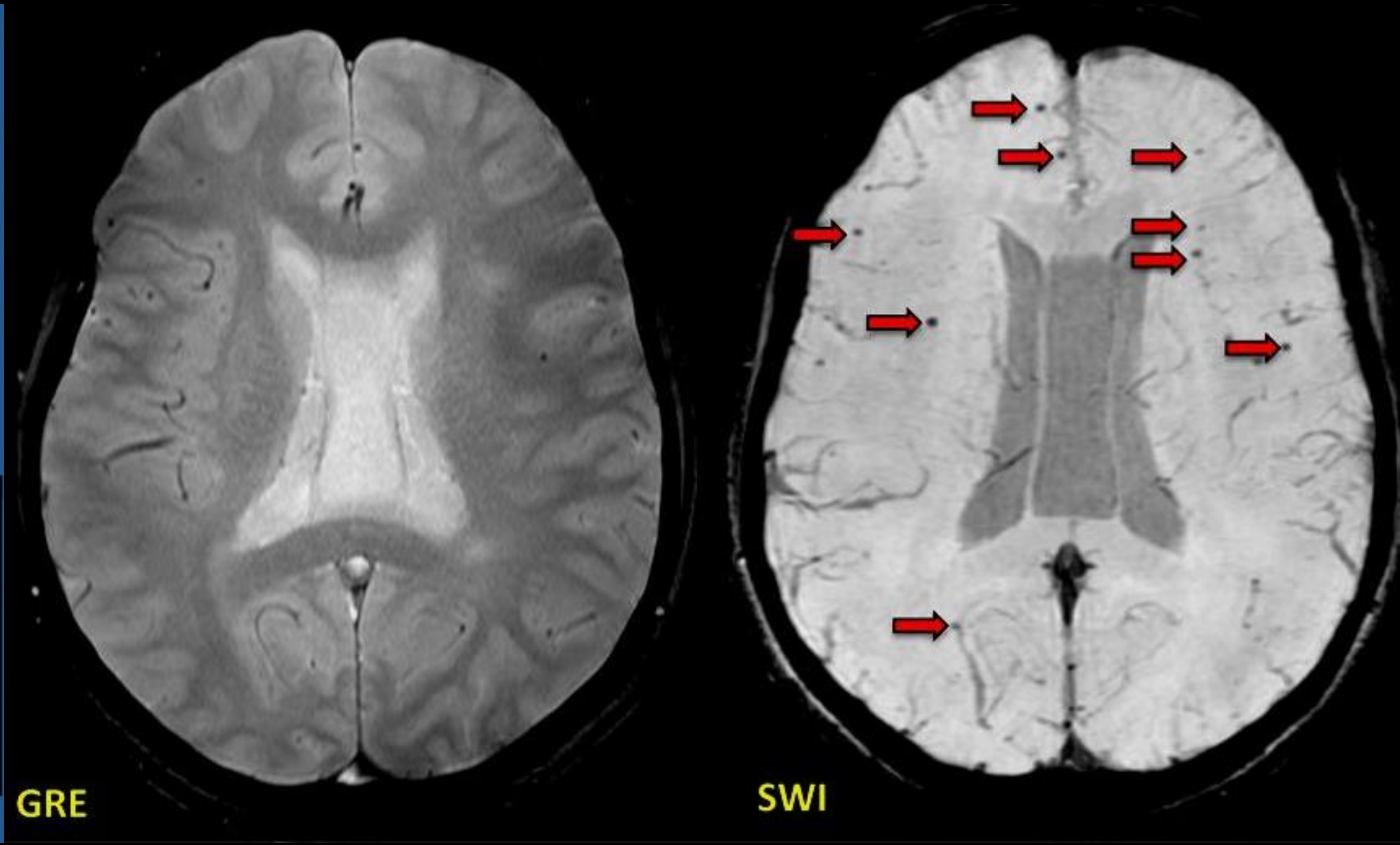
NEKOH GRE (FSPGR/T1FFE)



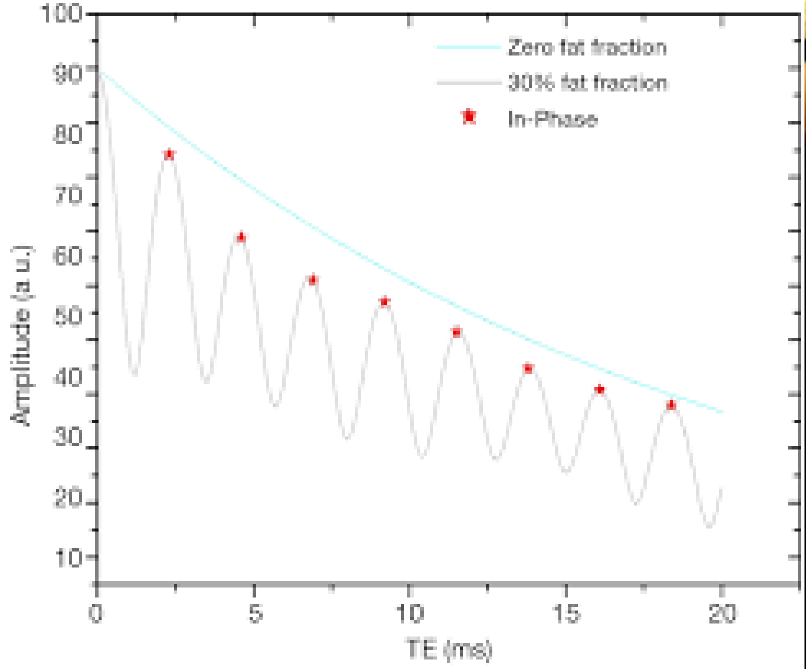
NEKOH GRE (FSPGR/T1FFE)

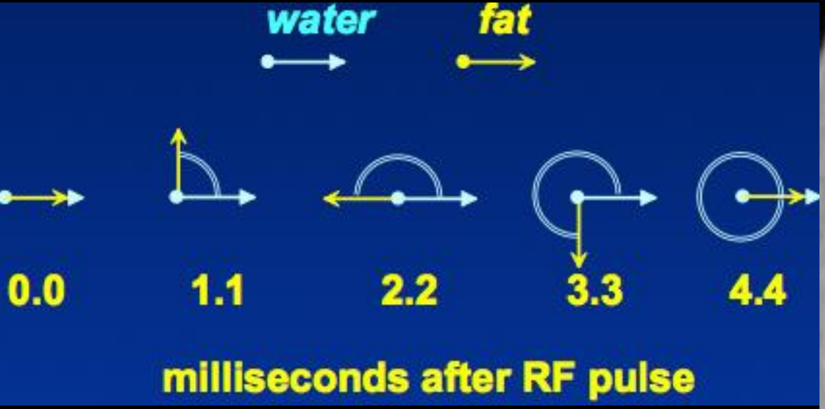
NEKOH GRE (SWAN/SWI)



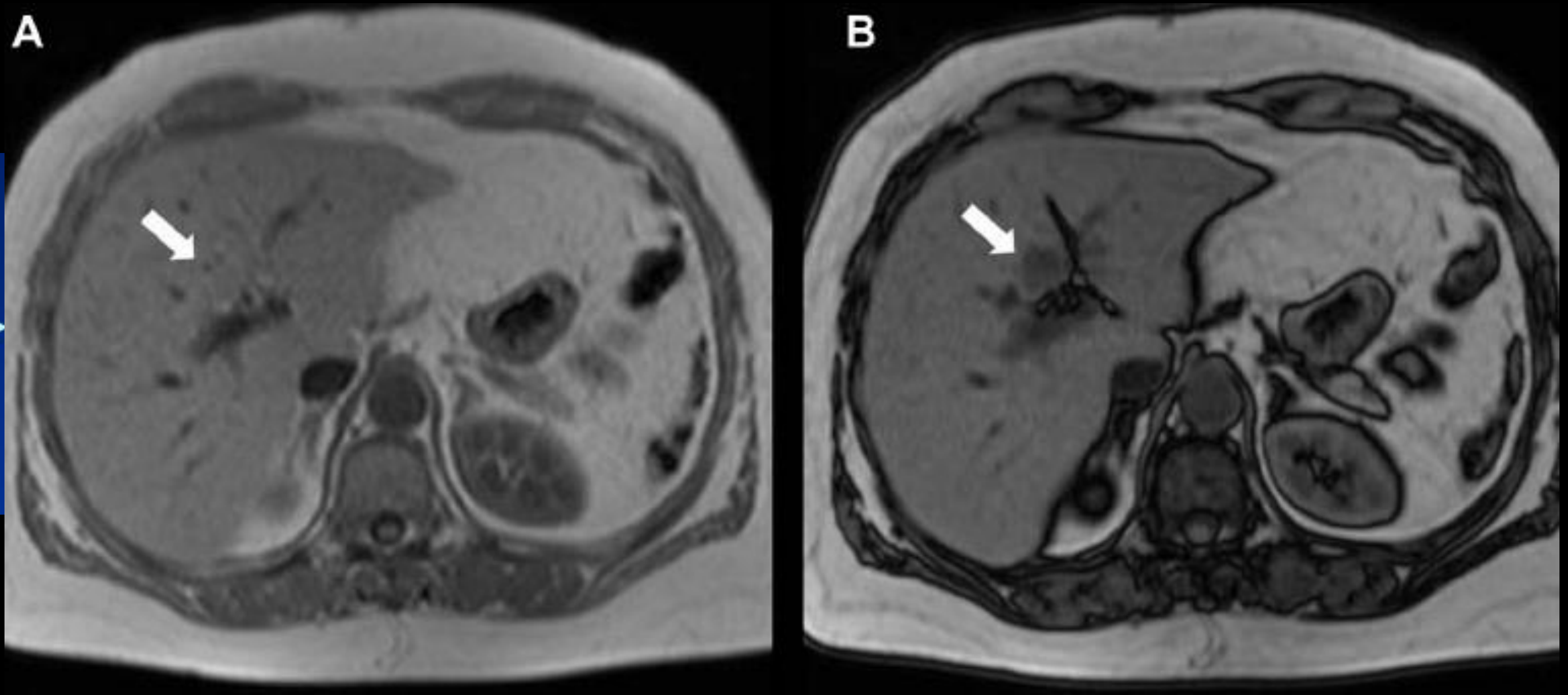


NEKOH GRE (IN/OUT PHASE)

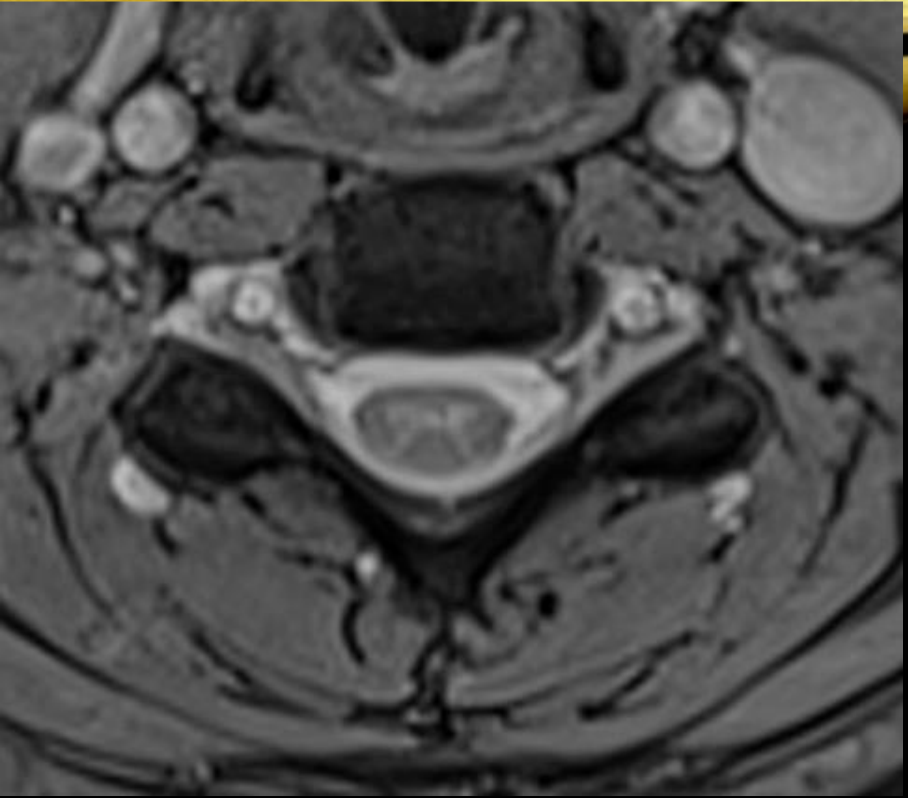


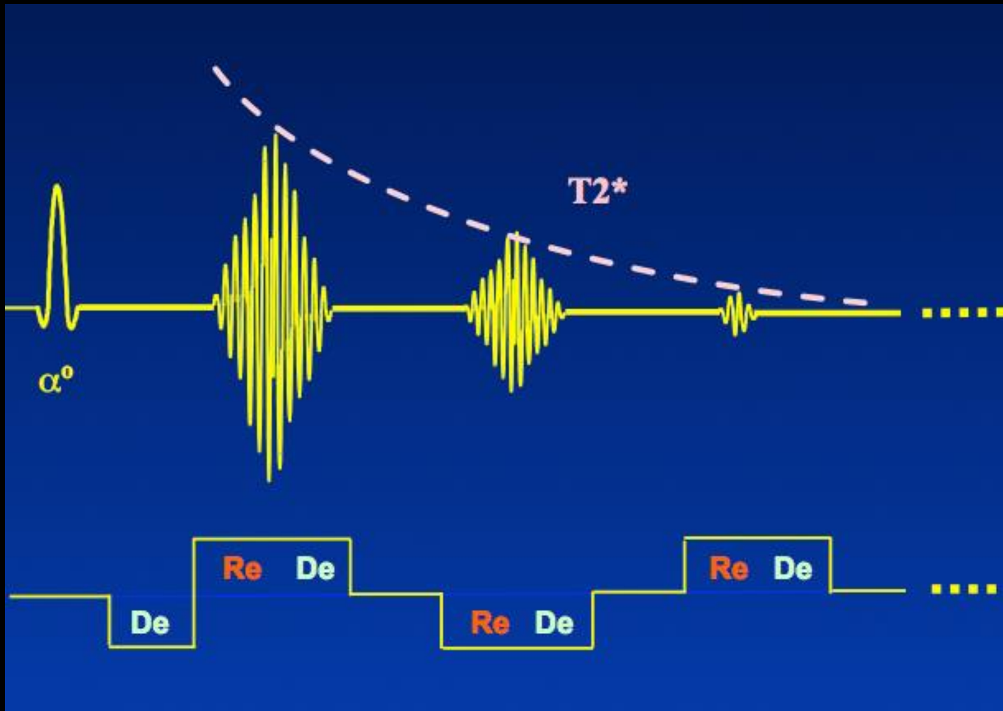


Dependence on B0

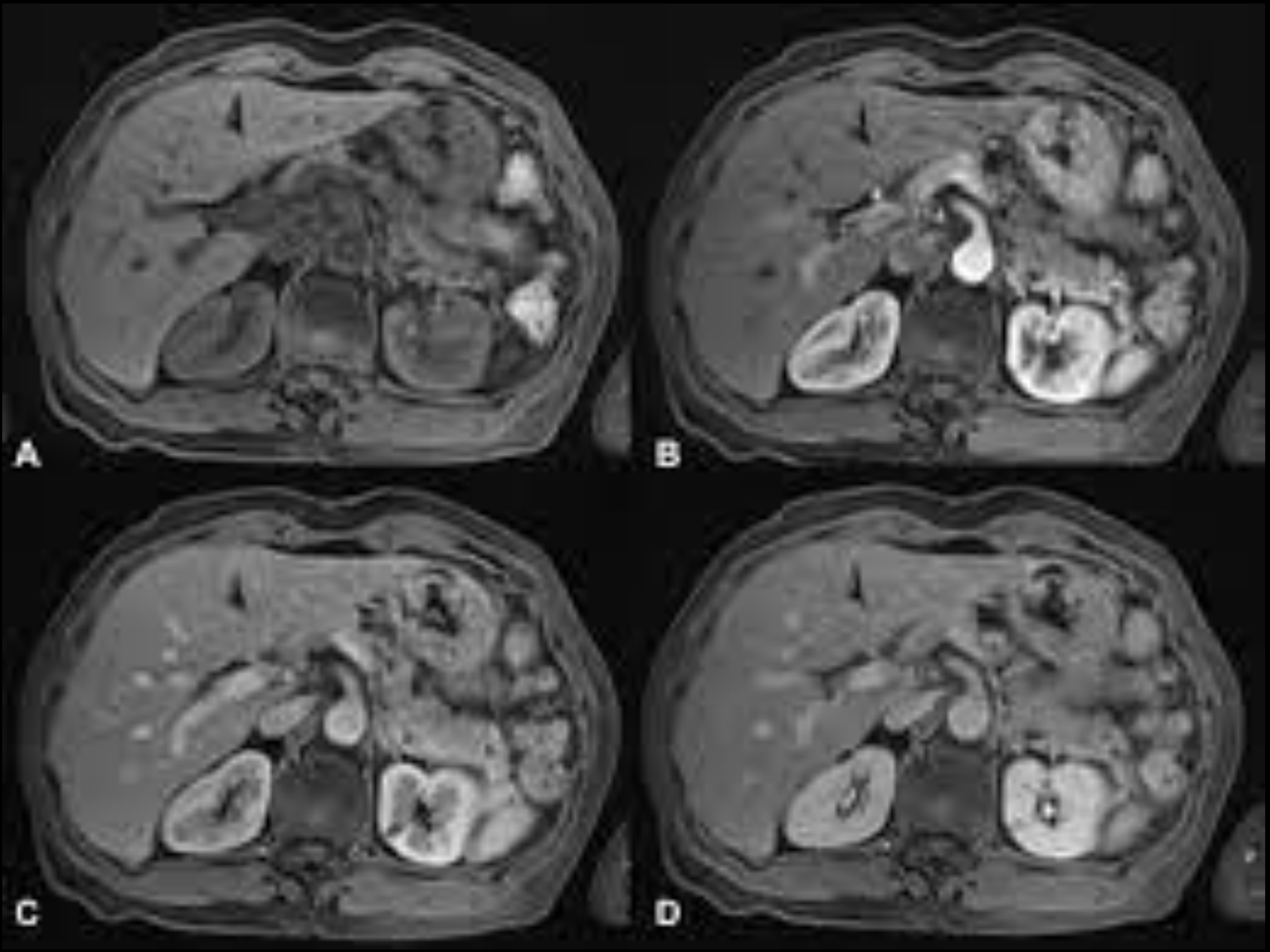


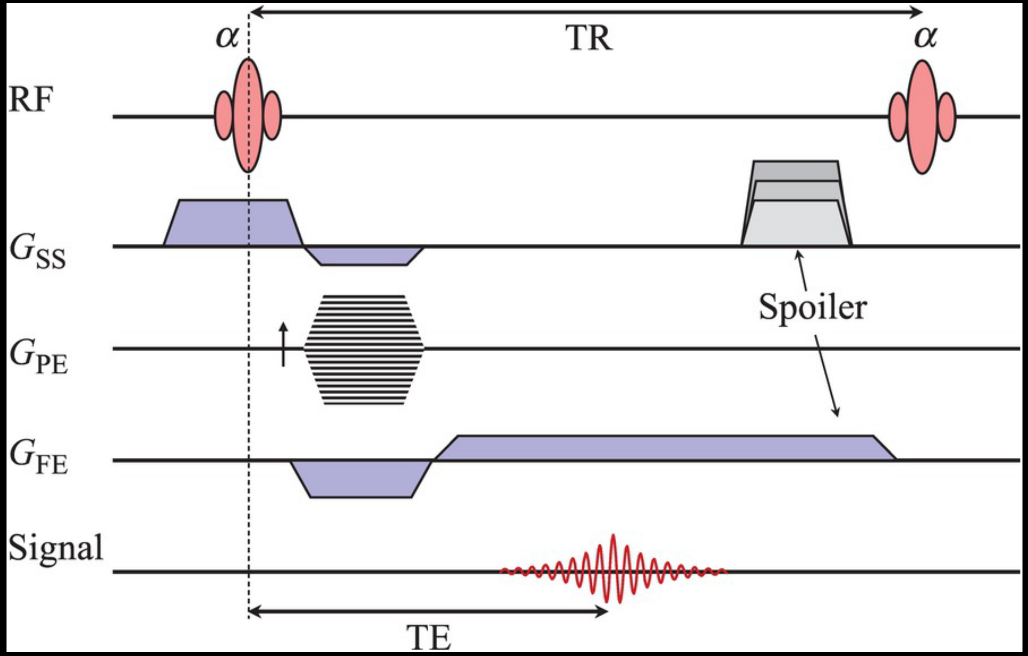
NEKOH GRE (M-FFE/MERGE)





NEKOH GRE (THRIVE/LAVA)





Very short TR (~5 ms) and TE (~1ms)
Fast data collection (~15 s)

Sequence	Siemens	GE	Philips	Hitachi	Toshiba
Generic Gradient Echo	GRE	GRE	FFE	GE	FE
RF-Spoiled GRE	FLASH	SPGR	T1-FFE	RSSG	T1-FFE
Coherent GRE with "FID" Refocusing	FISP	GRASS	FFE	SARGE (SG)	FE
Coherent GRE with "Echo" Refocusing	PSIF	SSFP	T2-FFE	TRSG	SSFP
Coherent GRE with Balanced "FID/Echo" Refocusing	True FISP	FIESTA	Balanced FFE	BASG	True SSFP
Coherent Balanced GRE using Dual-excitation	CISS	FIESTA-C	---	PBSG	---
Coherent Double GRE using Combined "FIDs" & "Echoes"	DESS	MENSA	---	---	---
Spoiled GRE using Combined Multiple FIDs	MEDIC	MERGE	M-FFE	---	---
Ultrafast GRE	TurboFLASH (2D) MP-RAGE (3D)	Fast GRE BRAVO (3D)	TFE 3D T1-TFE	RGE (2D) 3D-GEIR	Fast FE
Spoiled 3D GRE Variants	VIBE	FAME/LAVA	THRIVE	TIGRE	3D QUICK
GRE Plus SE with Combined Signal	TGSE	---	GRASE	---	Hybrid EPI

MR SAFETY

- Strong static and dynamic mag. Field
- According to FDA up to 8T for adults without risk
- Rapid changes dB/dt = > stimulation of the periphery. Nerves not heart muscle
- High-frequency RF pulses
- Most E converted to heat (cumulative)
- Specific Apsorption Rate (SAR, [W/kg])
- SAR < 4 W/kg = > no temperature increase
- SAR < 6 W/kg = > well tolerated
- Greater increase in T on the surface
- Noise
- Small space

MR SAFETY

- Noise
- Grows with B0 and gradient velocity
- Various noise reduction methods
- There may be a problem in psychiatric patients or pregnancy
- Small space
- Can be suppressed by open magnet design
- Closed magnets with larger gantry (70 cm)
- Calming down with medication or anesthesia

MR SAFETY

- Metal implants
- Dislocation of ferromagnetic due to B0
- Heating of el. conductive thanks to RF and grad. pulses
- Ferromagnetic material always absolute contraindications
- Non-ferromagnetic = artifacts in the image
- Some implants can only be used under certain conditions (B0, grad., SAR...)
-

MR SAFETY - CARDIO STIM.

- The patient must have a certificate with the stamp and signature of the attending physician that his pacemaker (including electrodes) is MR compatible.
- This confirmation must not be older than 3 days. A card about the type of pacemaker is not enough. In case of doubt, it is always necessary to contact the attending physician, it is possible to take an X-ray of the chest, which, however, must be indicated by the attending physician.
- The confirmation must include information that the pacemaker is set in MR compatible mode. The advantage is a direct printout from the calibration of the instrument. This confirmation shall not be older than 24 hours.
- The confirmation must include a statement from the attending physician that the patient does not have any other implants that would be a contraindication to the MR examination. Especially, for example, left electrodes, etc.
- The MR workplace must contain information on the conditions for MR examination in these patients for individual types of stimulators (e.g. the need for centration outside the chest, etc.).
- Either the patient brings them with him or they must already be available at the workplace.
- When measuring, the patient must be monitored using an ECG.

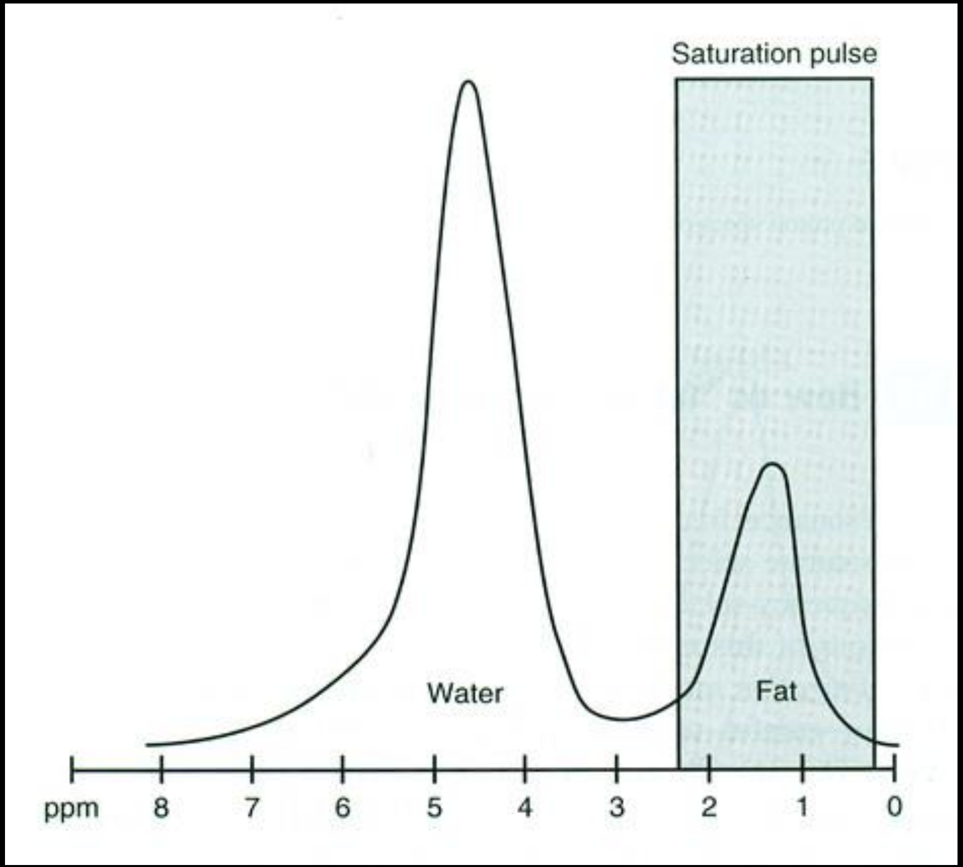
Absolutní kontraindikace	*Relativní kontraindikace (potenciálně nebezpečné)*	*Bezpečné*	*Není kontraindikace*
Implantovaný kardiostimulátor nebo defibrilátor (ICD)	Stenty (cévní výztuže), žilní filtry, kovový embolizační materiál a okludery méně než 6 týdnů po implantaci, pokud není písemně doložena jejich MR kompatibilita	Stenty (cévní výztuže), žilní filtry, kovový embolizační materiál a okludery 6 a více týdnů po implantaci	Písemné potvrzení výrobce implantátu o jeho plné MR kompatibilitě (kdekoli v těle pacienta) s písemným potvrzením operatéra, který jej implantoval
Ponechané elektrody po deplantaci kardiostimulátoru nebo defibrilátoru	Kloubní náhrady, osteosyntetický materiál a dentální implantáty méně než 6 týdnů po implantaci, pokud není písemně doložena jejich MR kompatibilita	Kloubní náhrady, osteosyntetický materiál a dentální implantáty 6 a více týdnů po implantaci, bez známek uvolňování (bez ohledu na použitý materiál)	Nitroděložní tělíska (IUD)
Aneuryzmatické cévní svorky (klipy), pokud není písemně doložena jejich MR kompatibilita	Kloubní náhrady a osteosyntetický materiál se známkami uvolňování	Náhrady srdečních chlopní s výjimkou cíleně udané MR nekompatibility	Stenty (cévní výztuže), žilní filtry, kovový embolizační materiál a okludery, pokud lze písemně doložit plnou MR kompatibilitu (bez ohledu na dobu implantace)
Elektronické implantáty (kochleární, inzulinová pumpa atd.), pokud není písemně doložena MR kompatibilita		Neaneuryzmatické chirurgické cévní svorky (hemostatické klipy) 6 a více týdnů po implantaci	
Kovová cizí tělesa z jiného než prokazatelně nemagnetického kovu :- intrakraniálně - intraorbitálně		Svorky na žlučových cestách 6 a více týdnů po operaci	

SIGNAL SUPPRESSION/AMPLIFICATION

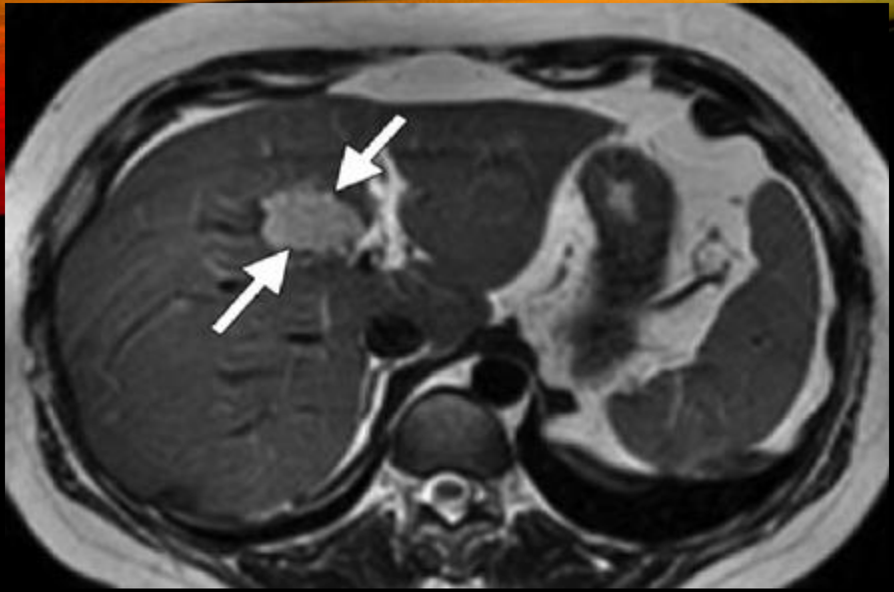
- Fat suppression
- FatSat
- STIR
- SPAIR
- Water suppression
- FLAIR/DIR
- Magnetizing transfer
- Fat-Water Separation – Dixon
- Water excitation
-

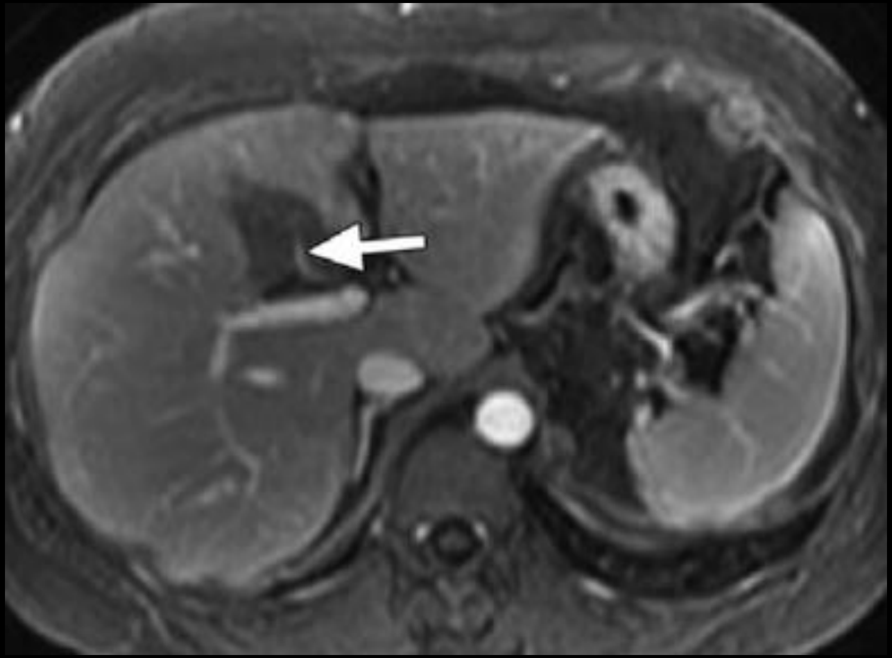
SPIR/FATSAT

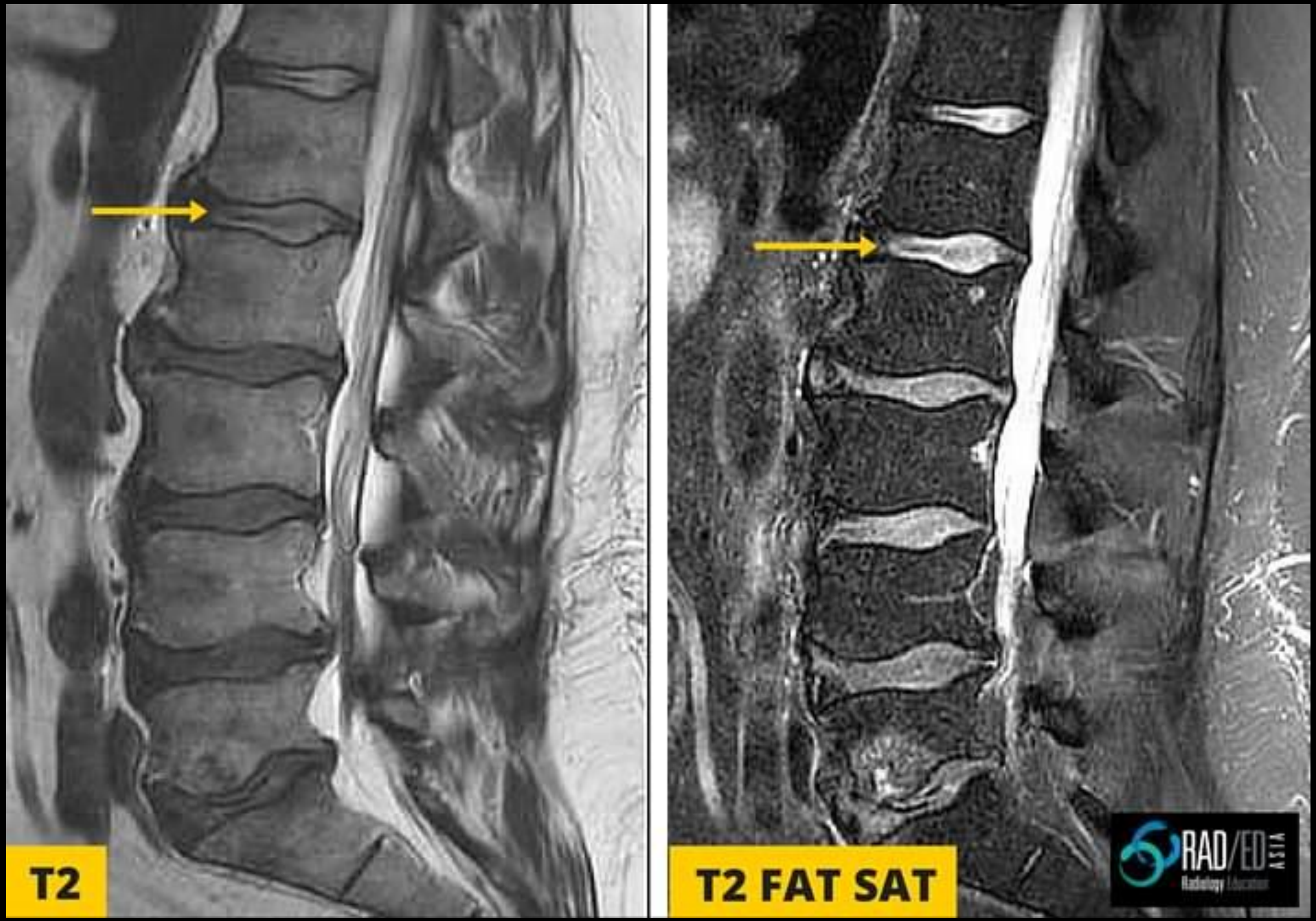
- Fat suppression (shift in fat frequency to water, selective RF, gradient pulse reset)
- Significantly does not extend TR
- Does not change the TE
- Does not affect the application of KL
- Very sensitive to field inhomogeneity
- Better separation in higher mags. Fields
-



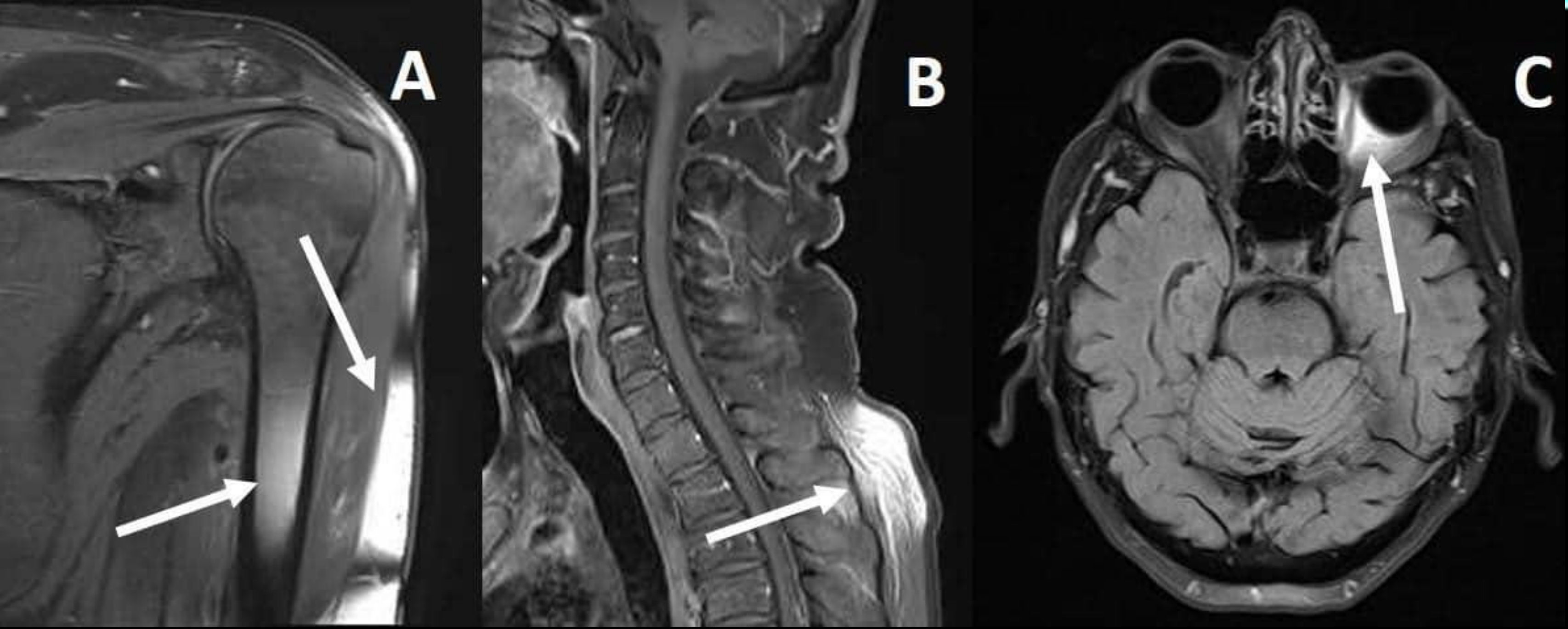
SPIR/FATSAT

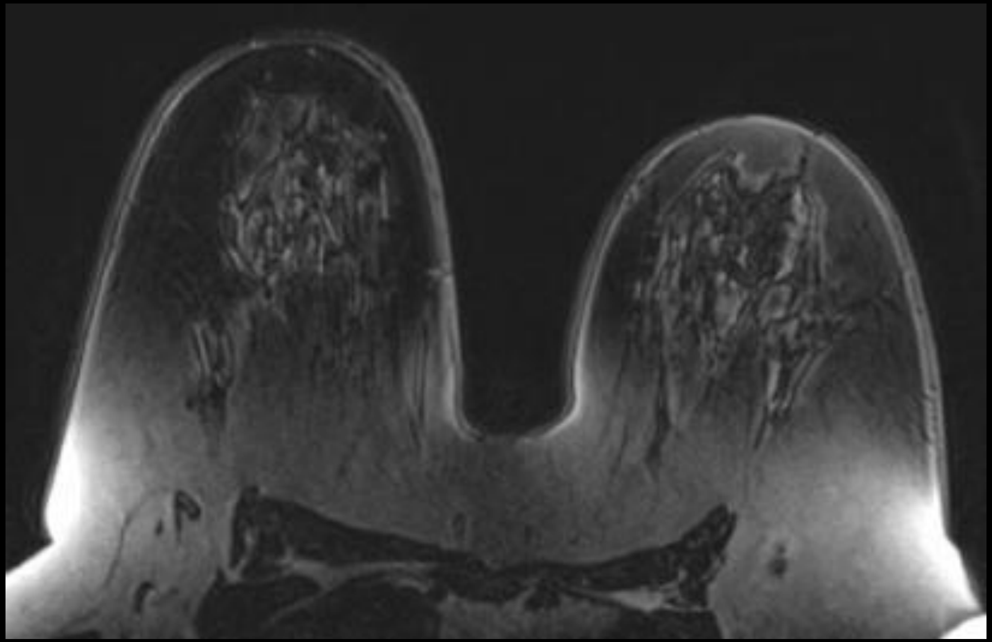


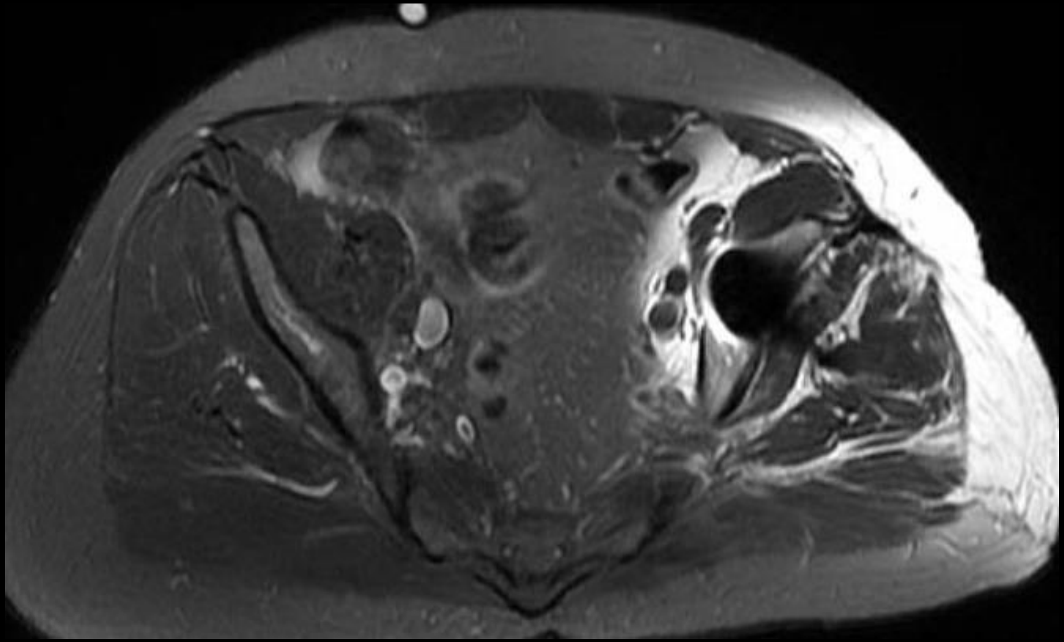




SPIR/FATSAT

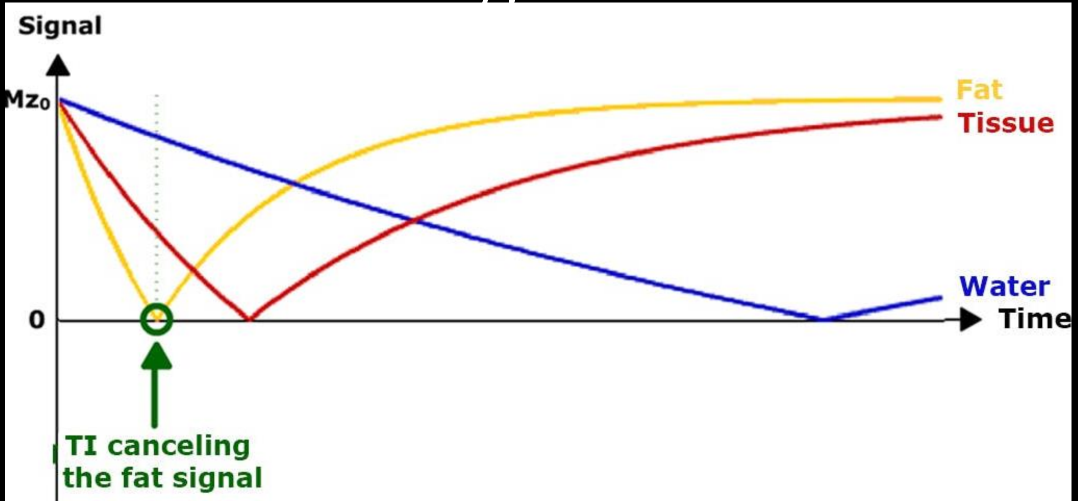


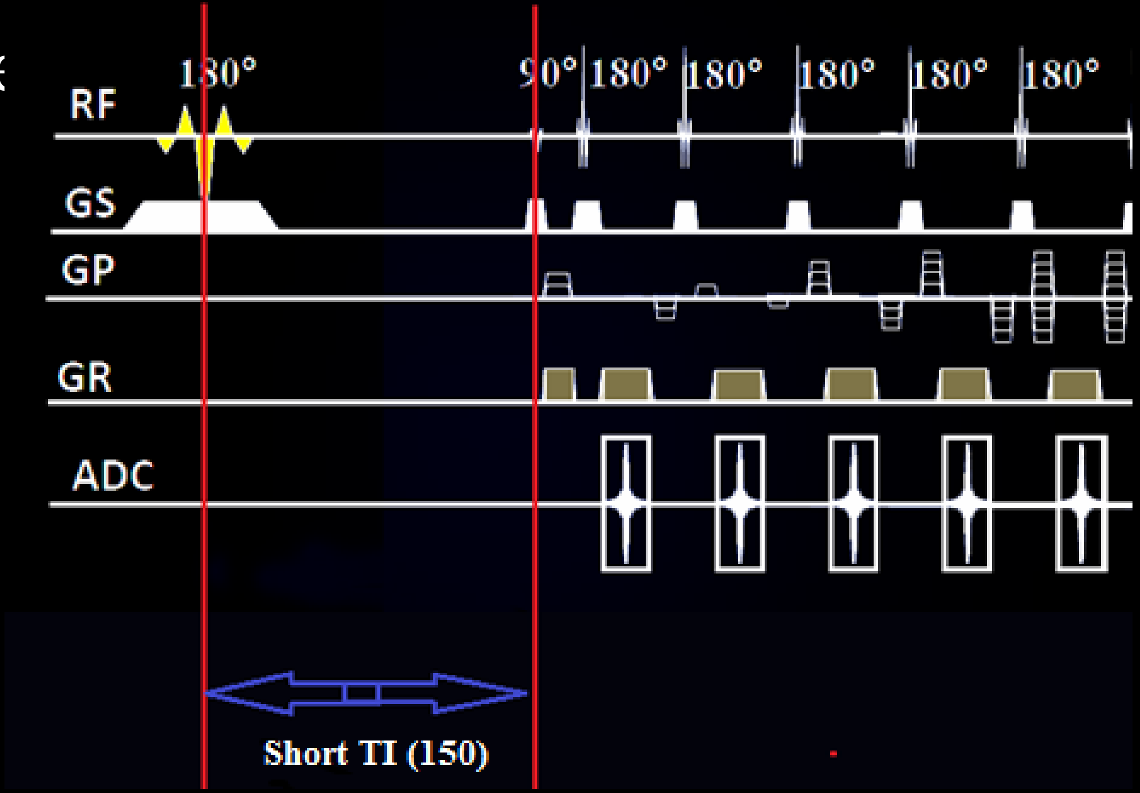


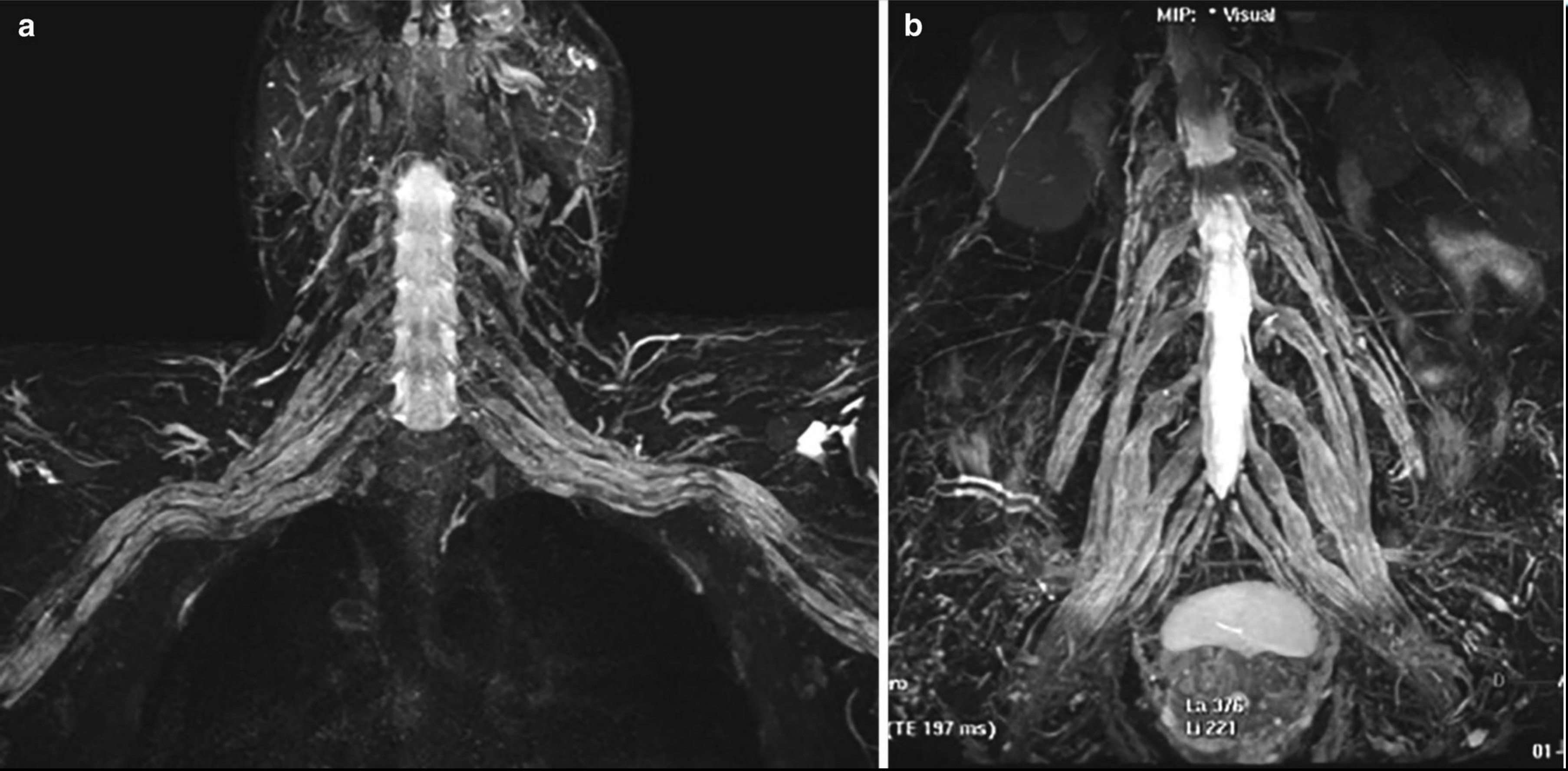


STIR

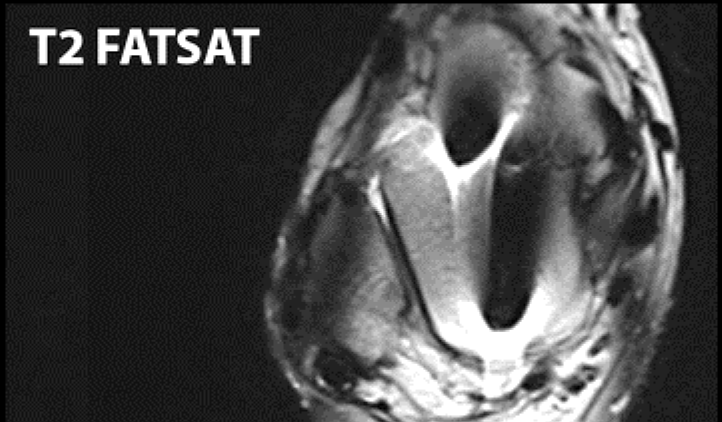
- Fat suppression based on T1 time by inverse pulse
- Not sensitive to field inhomogeneities
- Can be applied even at lower mags. Fie
- DO NOT use with KL
- Choose longer TR





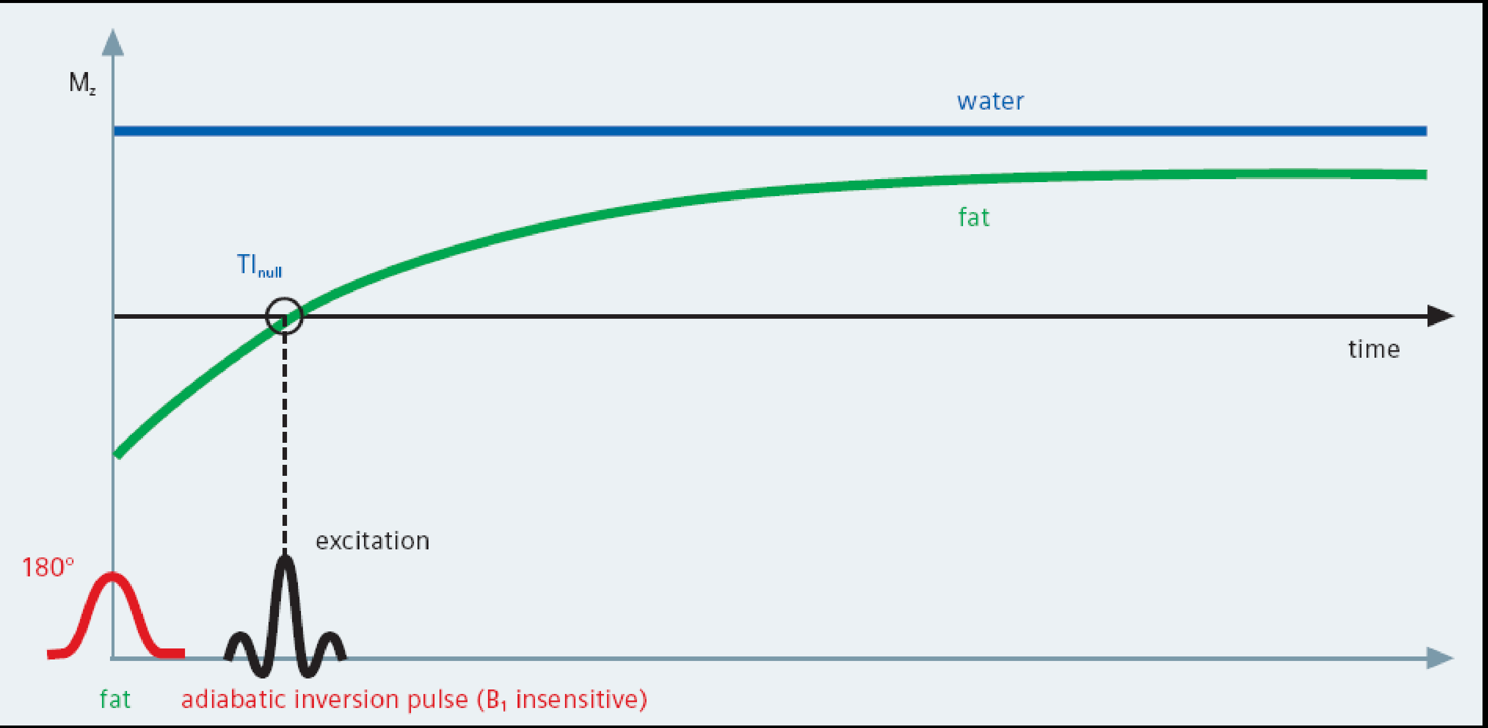


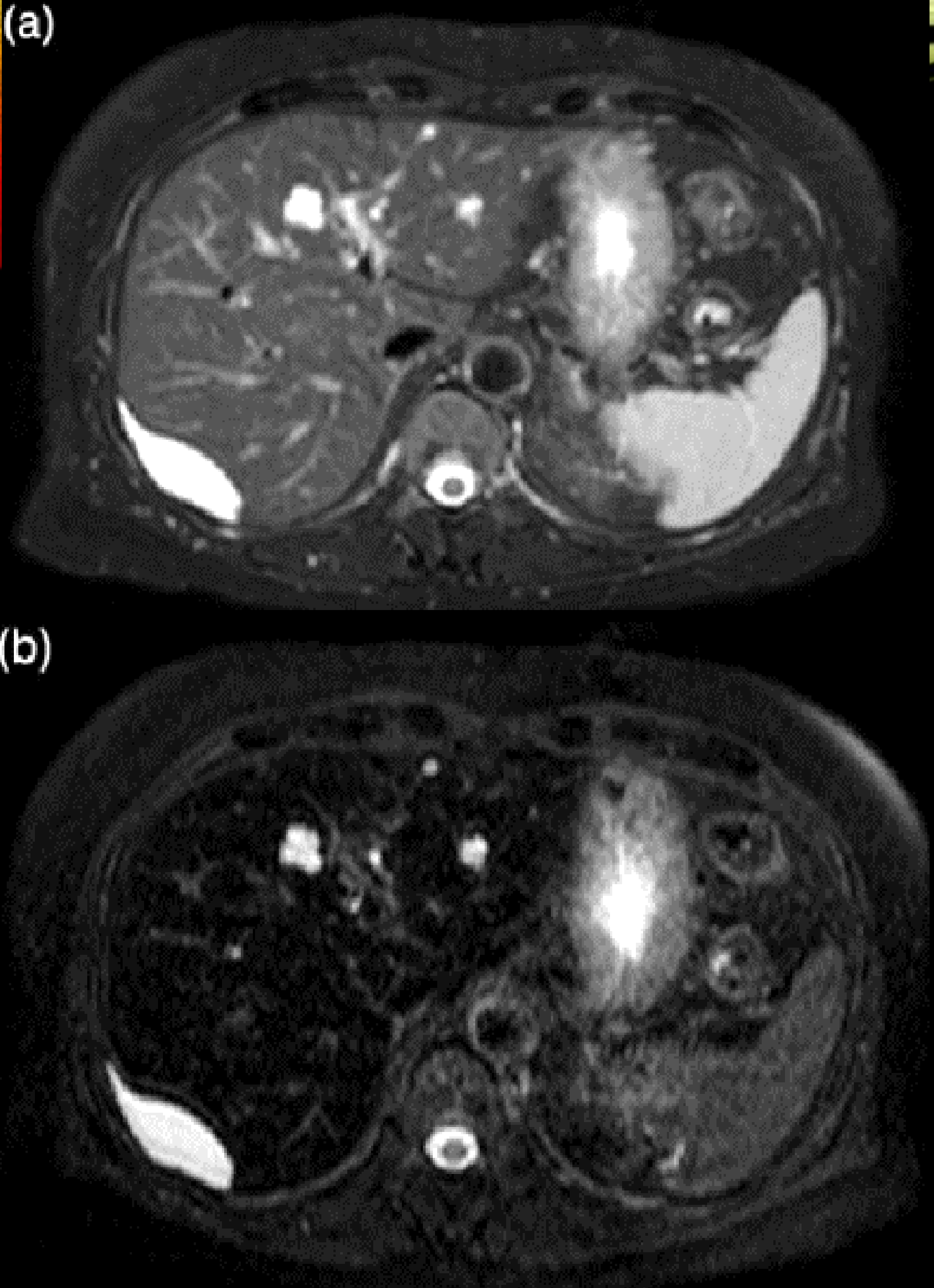
STIR



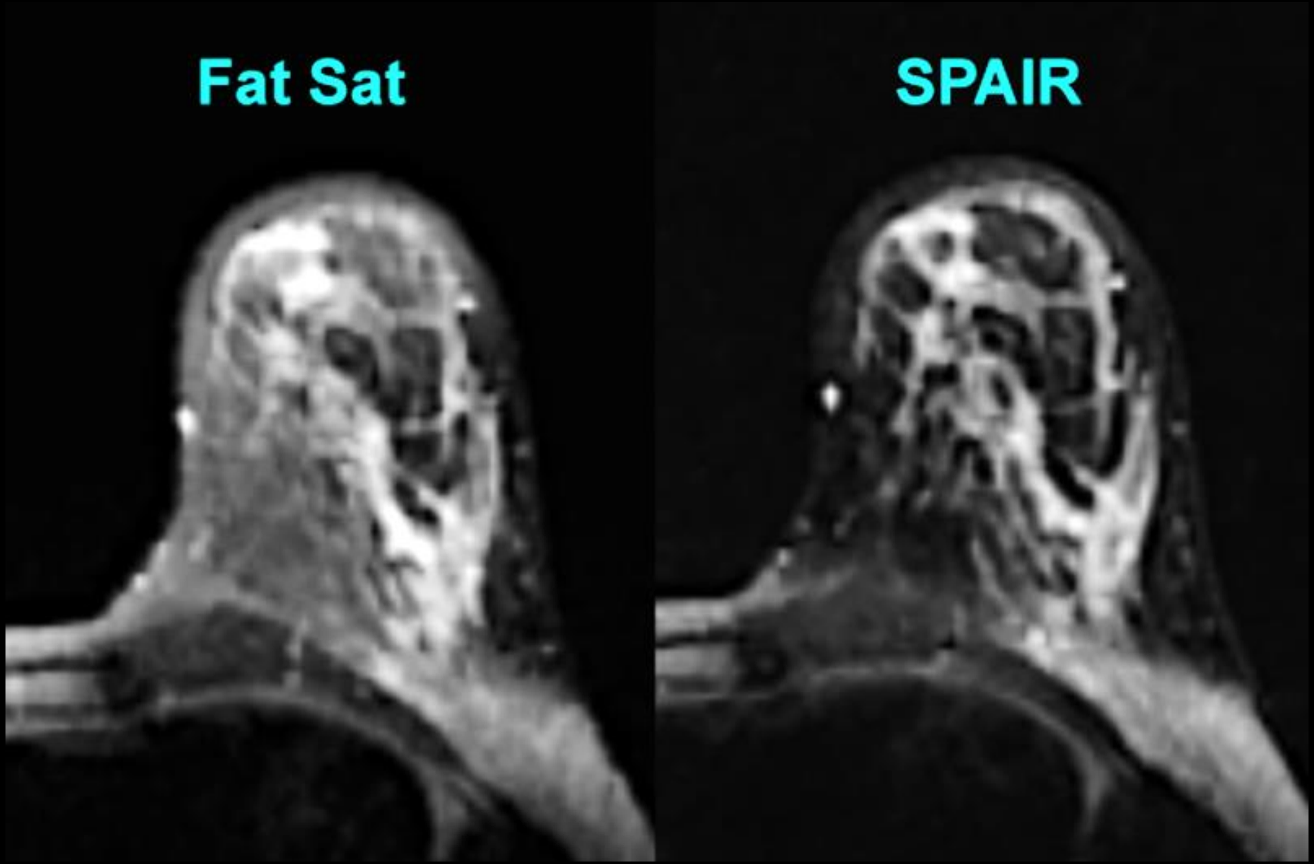
SPAIR/SPECIAL

- Fat suppression based on spectral selection. IR (inverts only fat)
- Less sensitive to field inhomogeneities than FatSat, but more sensitive than STIR
- More signal than STIR
- DO NOT use with KL
-



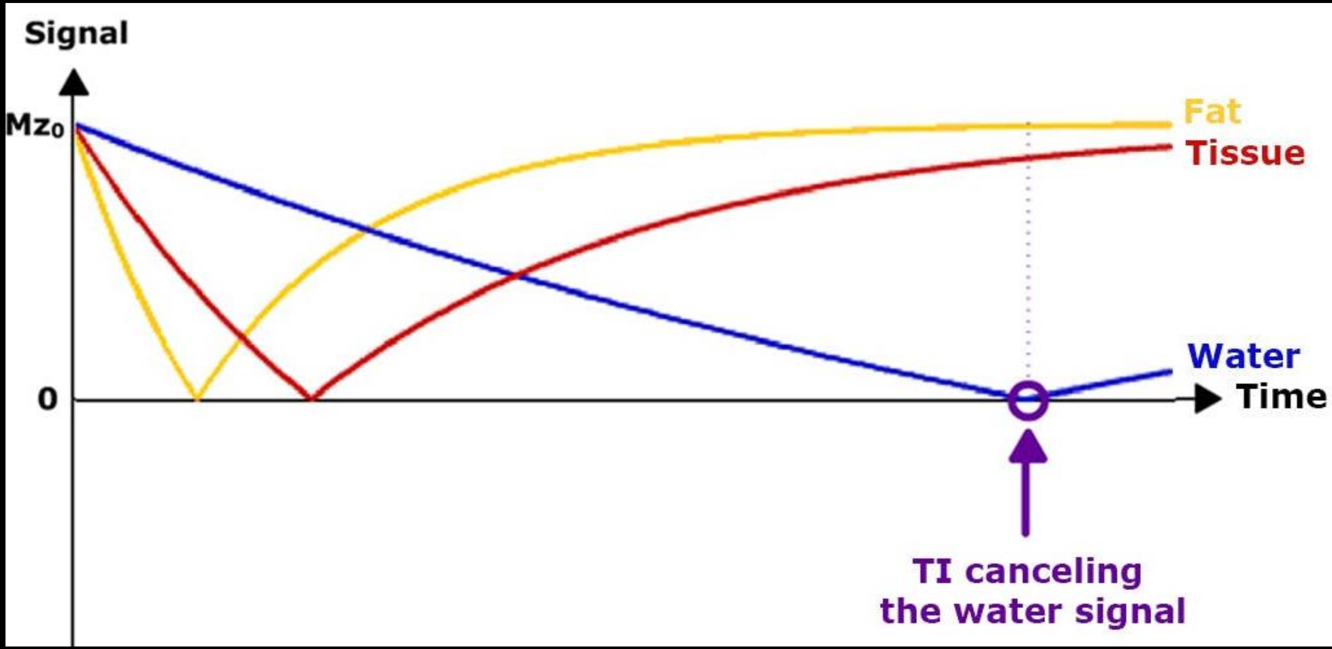


SPAIR/SPECIAL

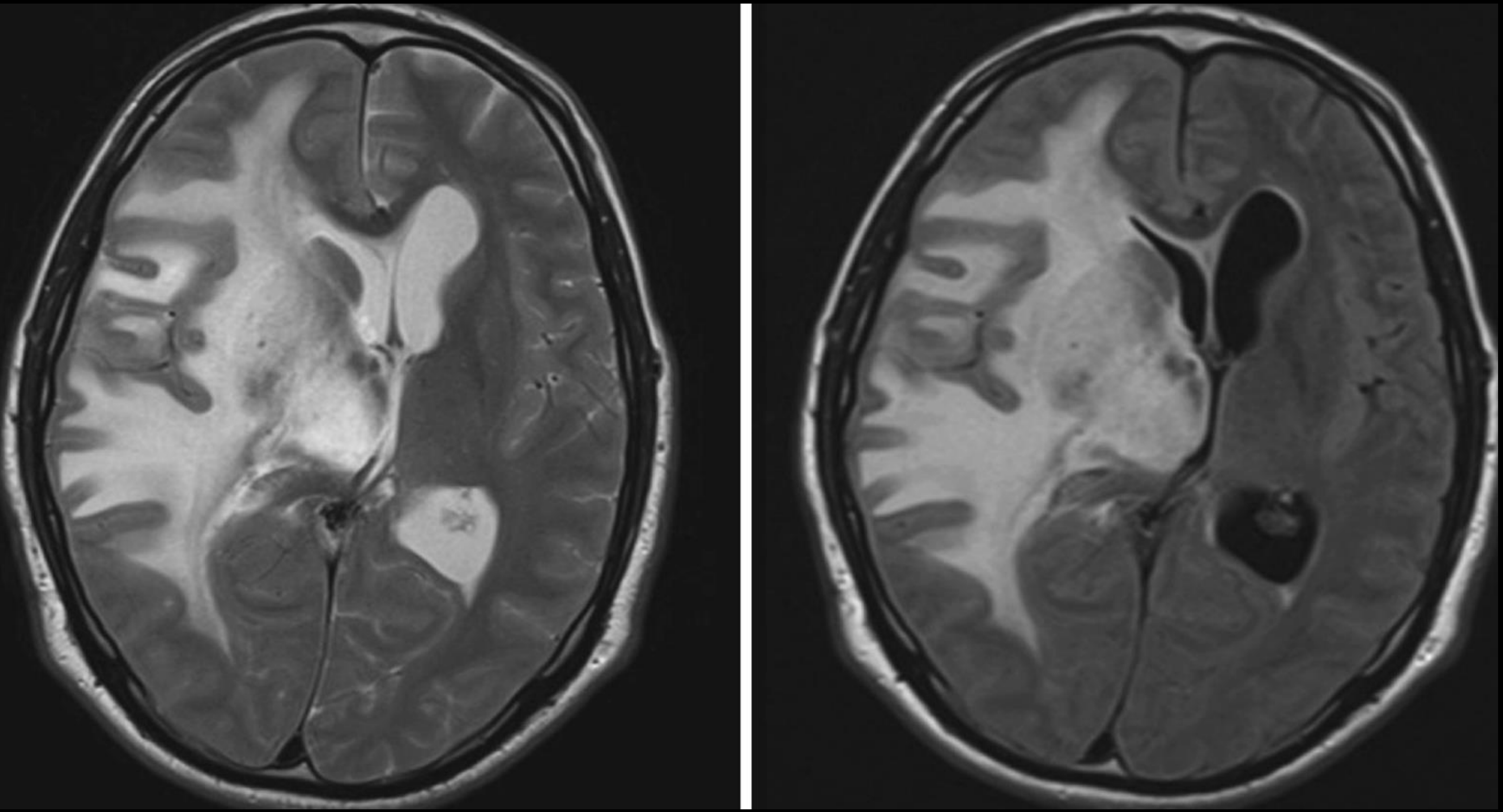


WATER SUPPRESSION (FLAIR)

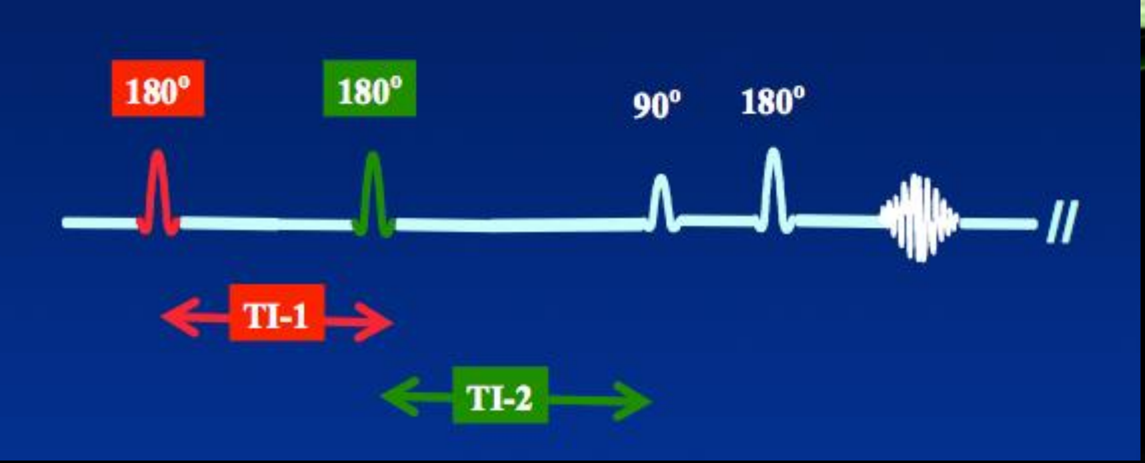
- IR-based fat suppression
- Long TI = long TR
- TI and TR are tied
- Truncation TR = > TI truncation
- T2-w image (long TE)
- Often together with FatSat
-

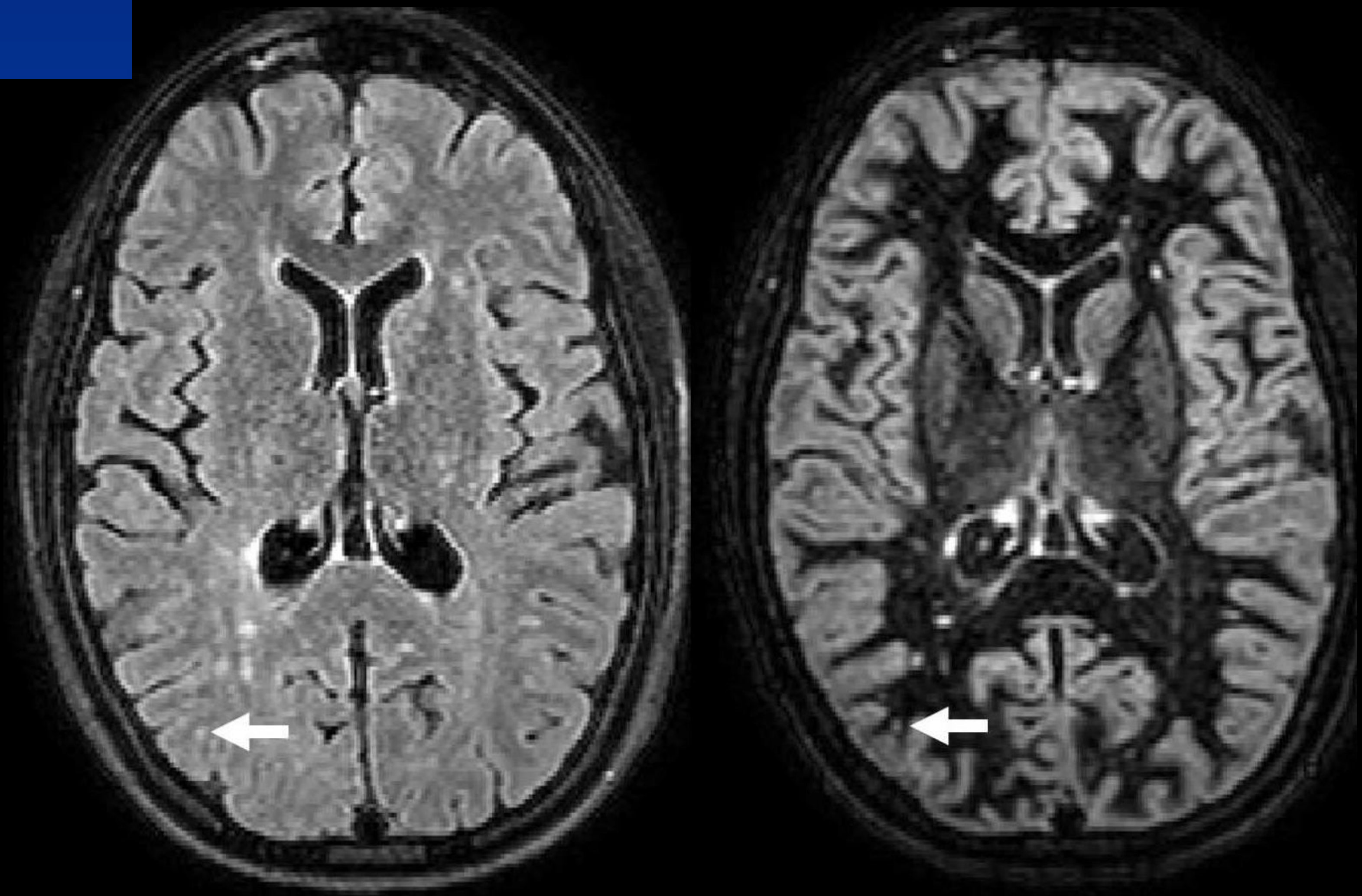


FLAIR



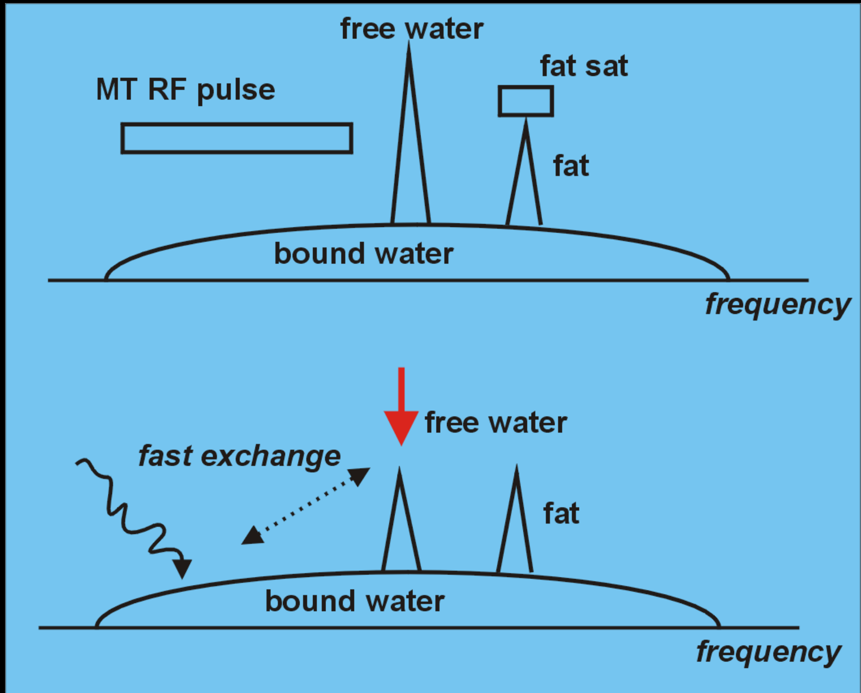
FLAIR/DIR





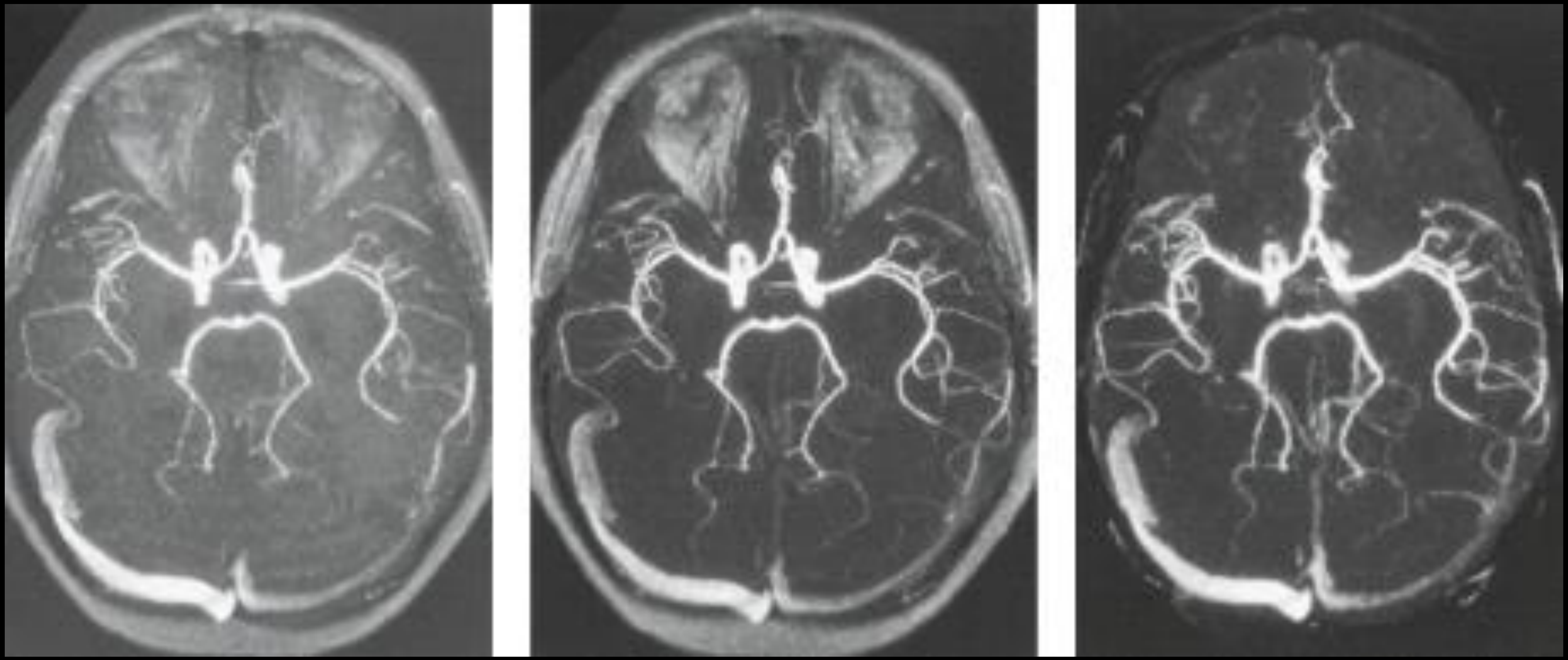
WATER SUPPRESSION (MAG TR)

- Bound water = very short T2 = > does not contribute to the signal
- By saturation of bound water, even free water is saturated
- Exploitation:
- Background signal suppression (KL, TOF MRA)
- Quantification of the free/bound water ratio

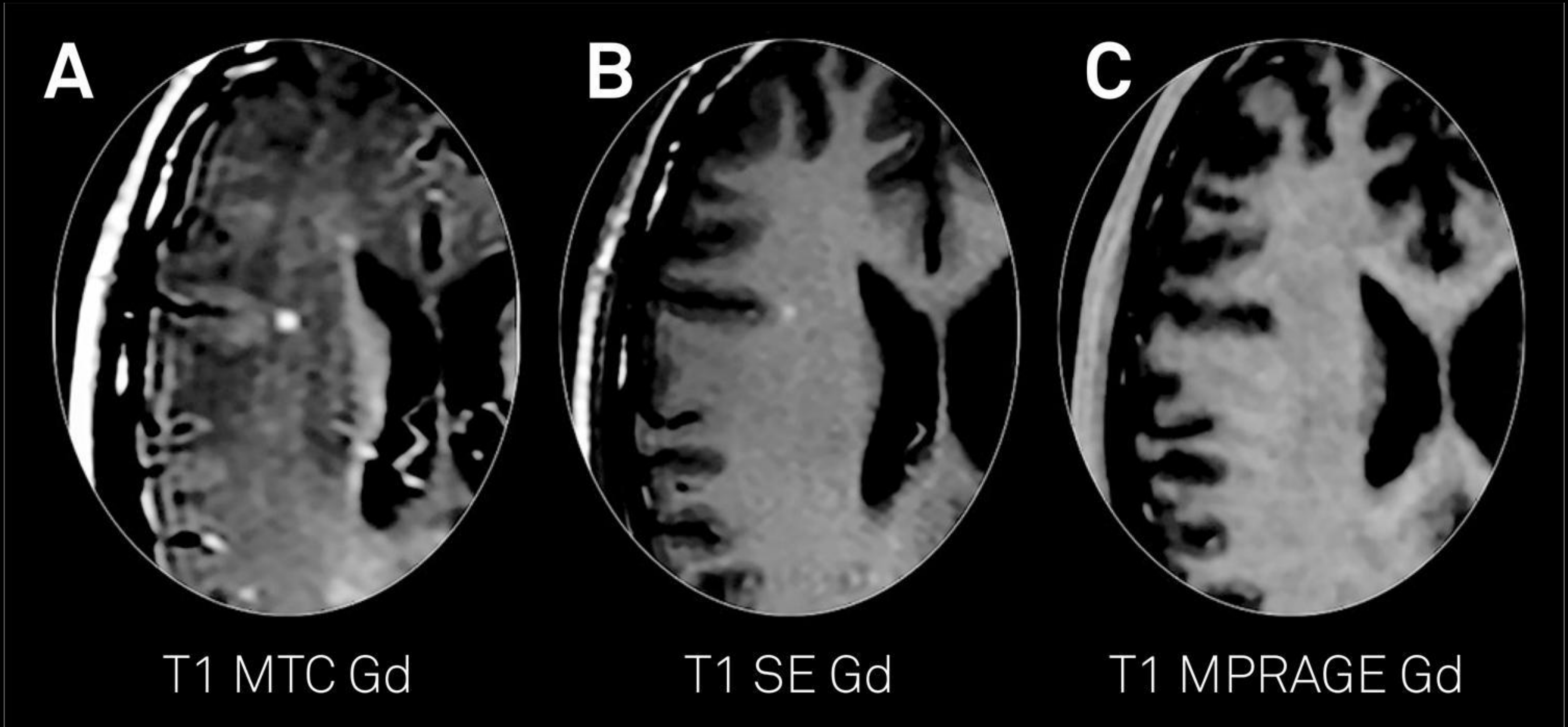


TOF MRA MT

3D TOF　　　3D TOF + MT　　　3D TOF + MT + FatSat

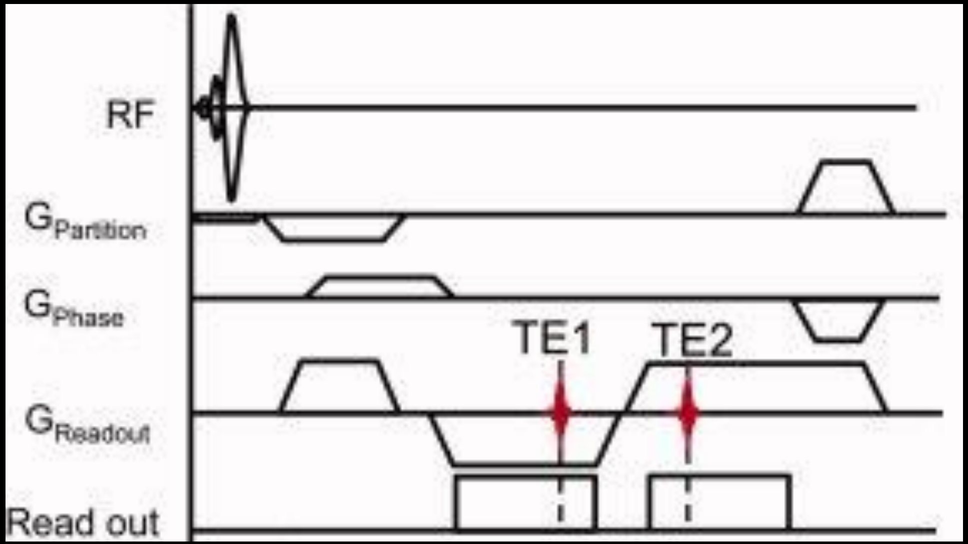


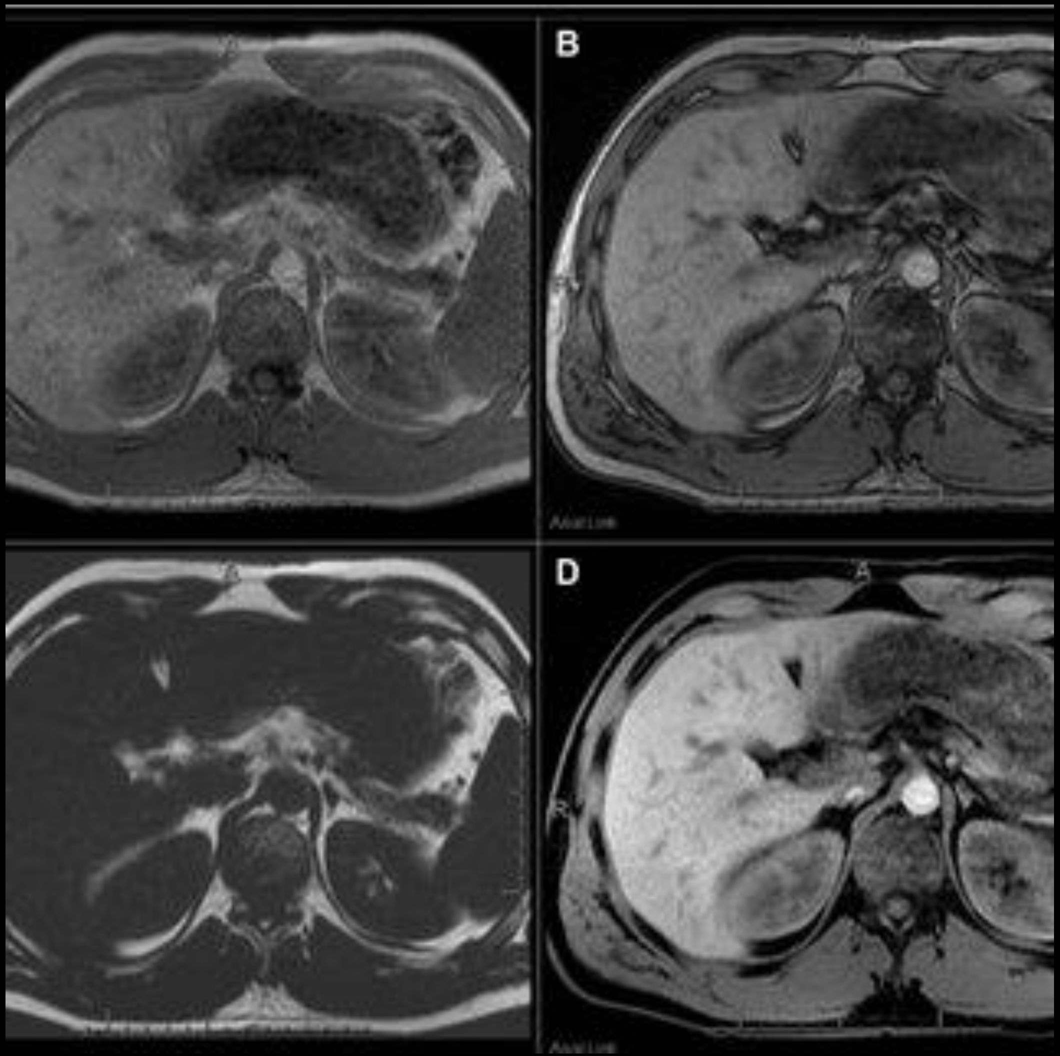
MT + GD KL



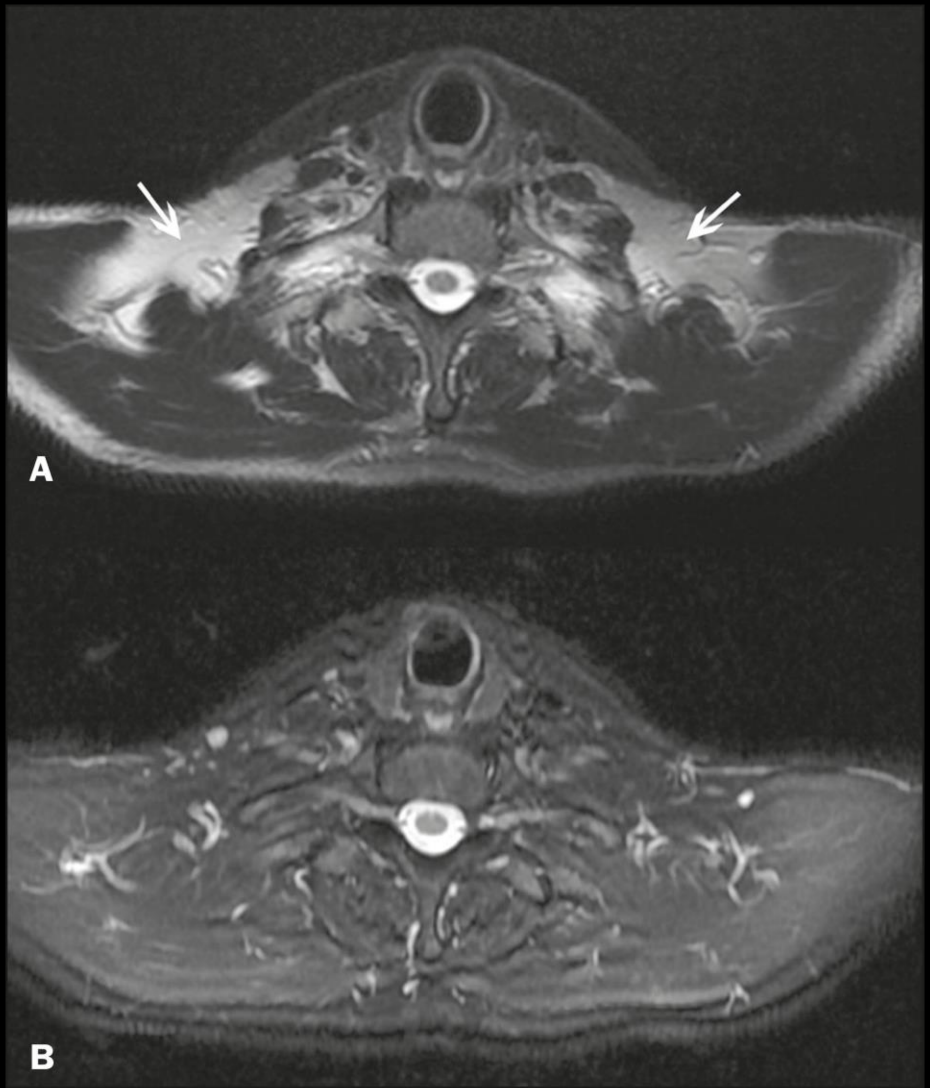
SEPARATION OF WATER AND FAT

- IP = V + T
- OP = V – T
- IP + OP = V + T + V – T = 2V
- IP – OP = V + T – V + T = 2T



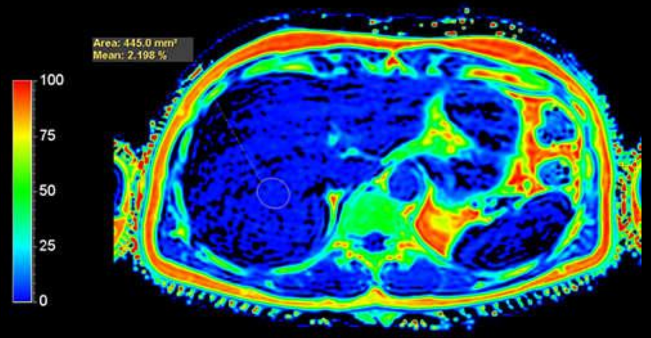


DIXON



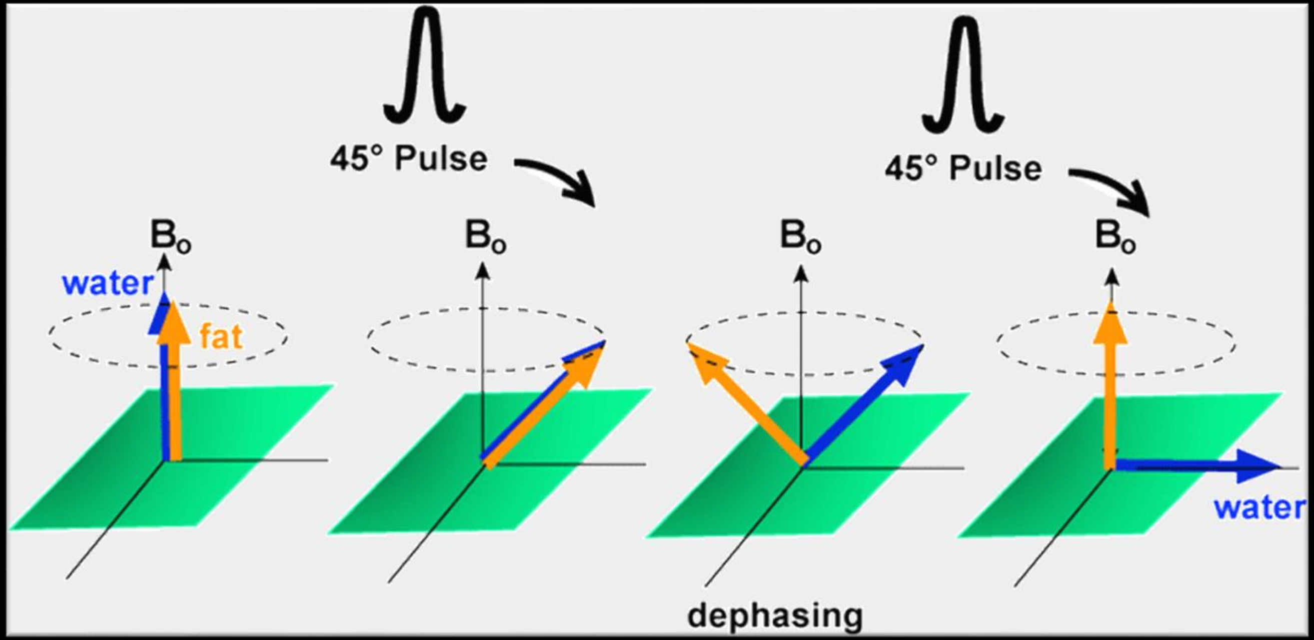
DIXON KVANTIFIKACE

- Multi-echo
- Multi-fat peak correction
- B0 correction
- T2* mapping
- Fat fraction
-

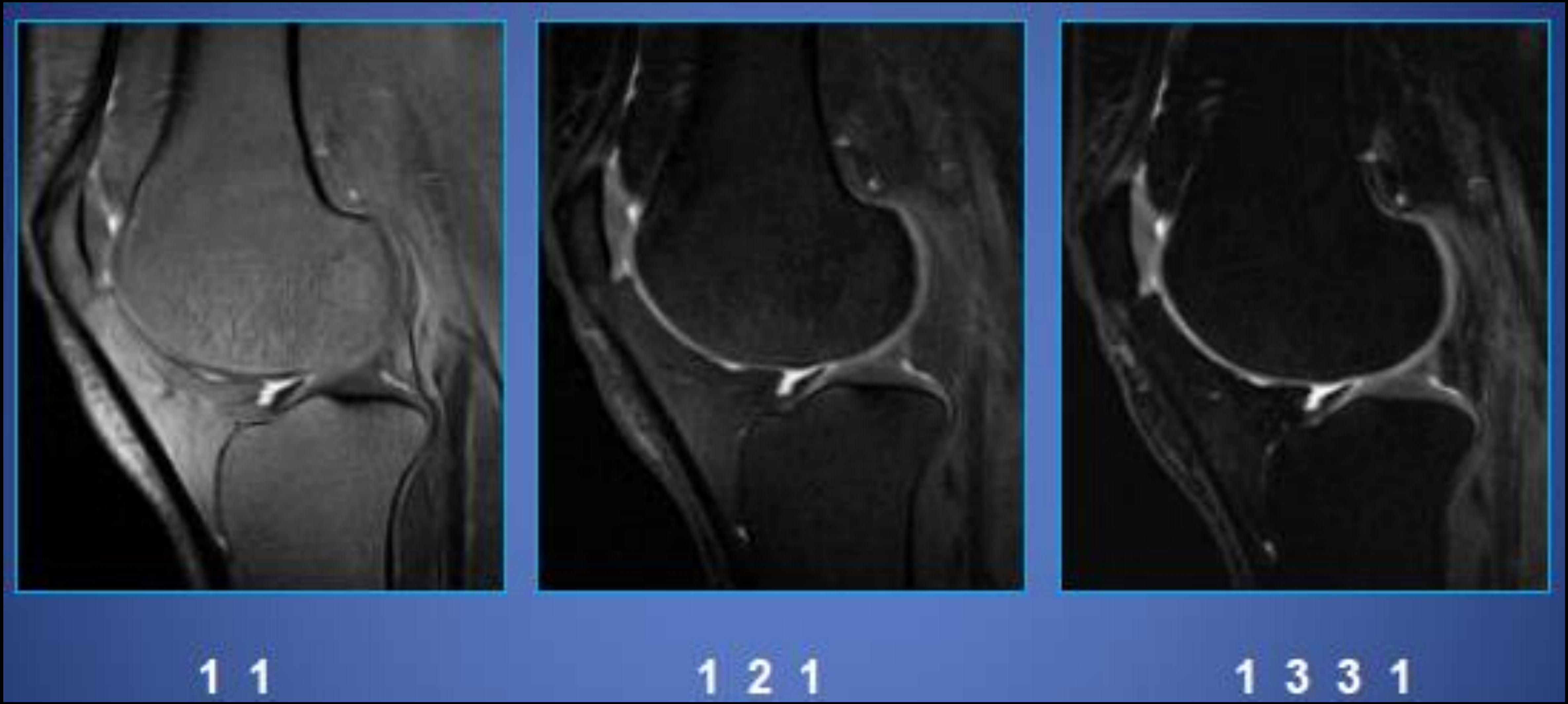


WATER EXCITATION

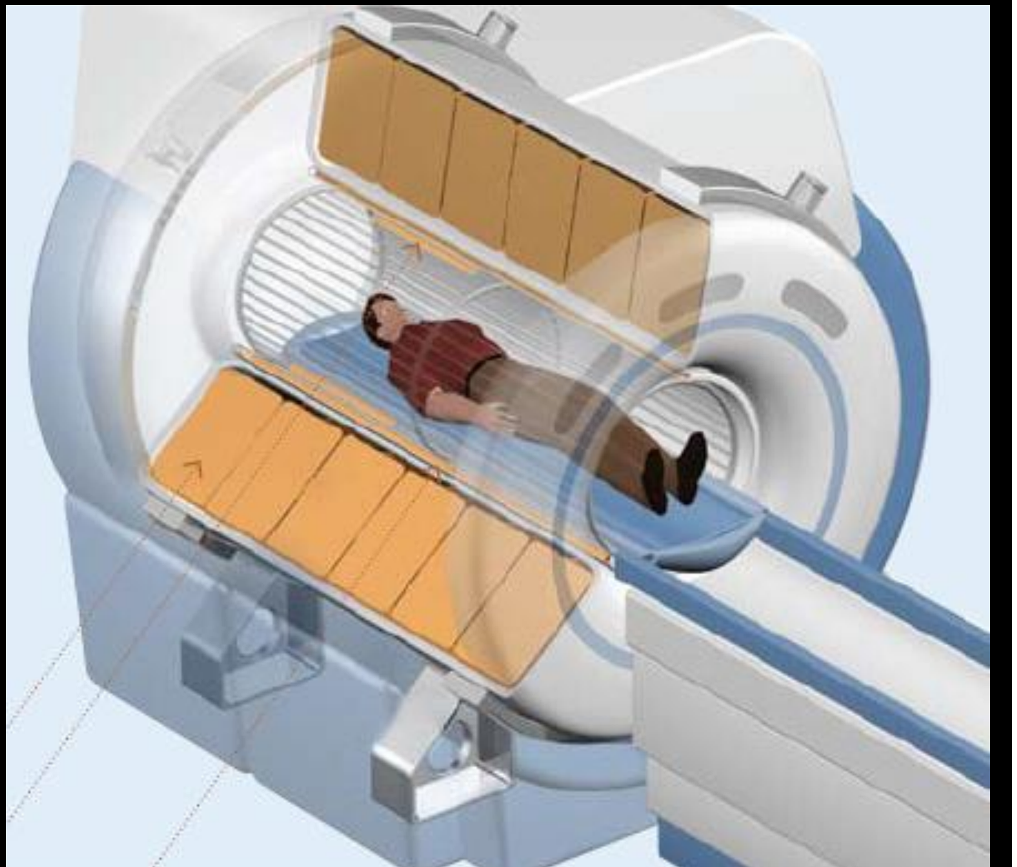
- Using multiple RFs excites only H of water
- Less sensitive to mag inhomogeneities. fields than FatSat
- Models:
- (1 1) = 45° 45°
- (1 2 1) = 22.5° 45° 22.5°
- (1 3 3 1) = 10° 30° 30° 10°
- Higher model of larger exit
- Can change both TE and TR
-

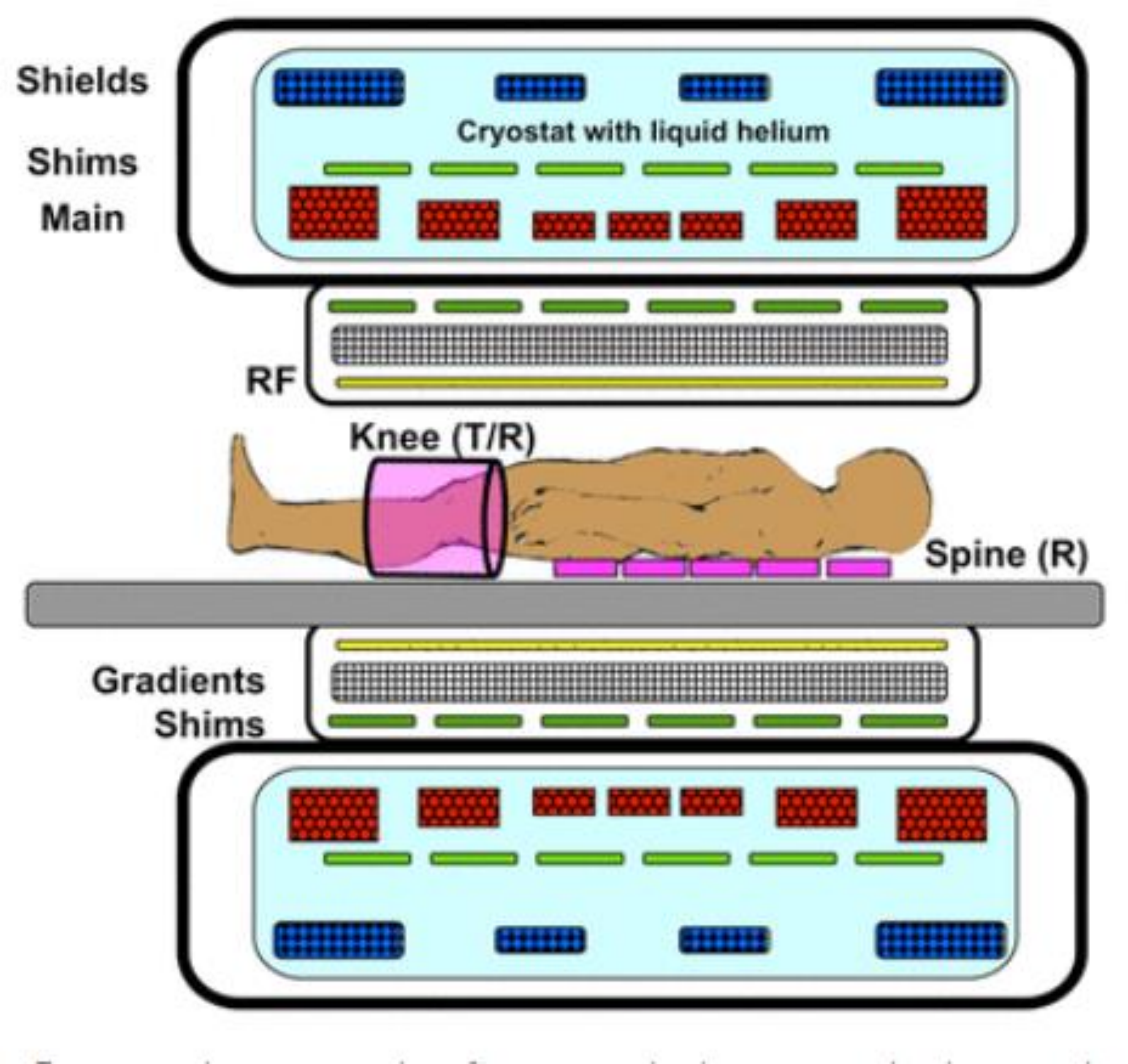


WATER EXCITATION



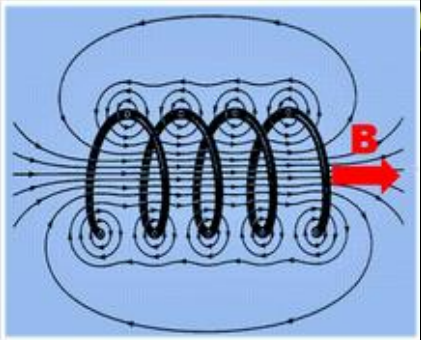
HARDWARE




Shields
Cryostat with liquid helium
Shims
Main
RF
Knee (T/R)
Spine (R)
Gradients
Shims

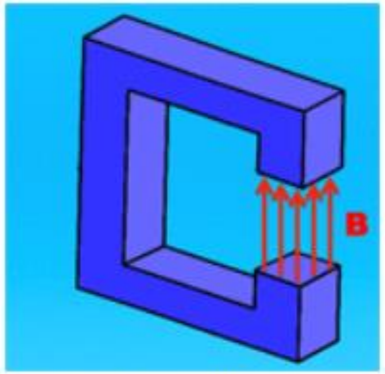
CONSTRUCTION

GE Signa 1.5T superconducting scanner



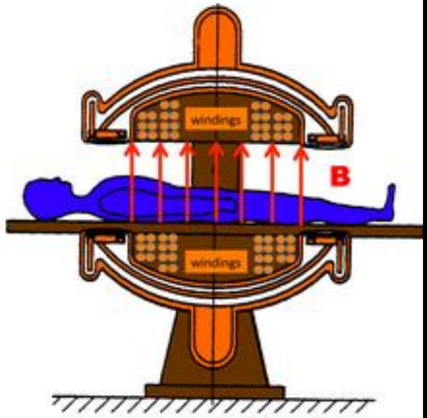
Magnetic field created by solenoid

Hitachi Aperto 0.4T permanent magnet scanner

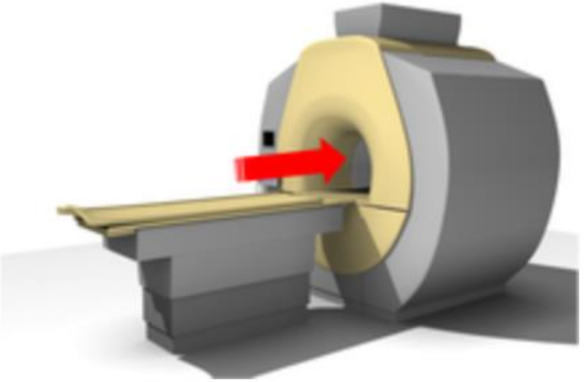


C-shaped permanent magnet

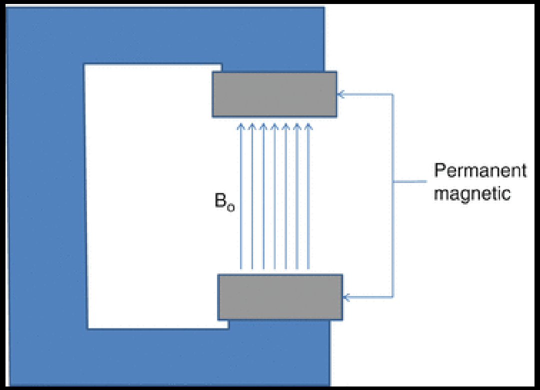
Hitachi Oasis 1.2T HFO superconducting scanner



Dipolar electromagnet design

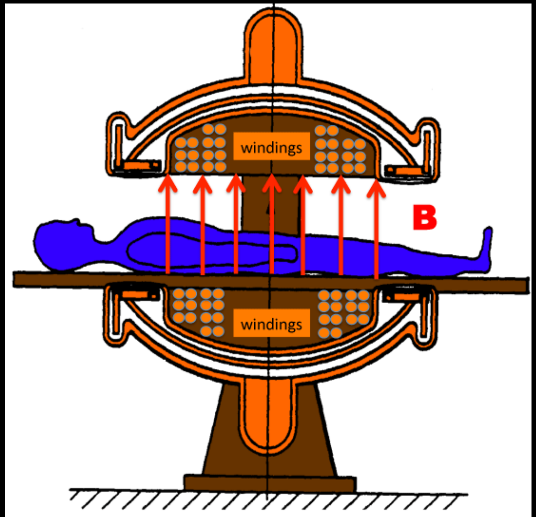


PERMANENT

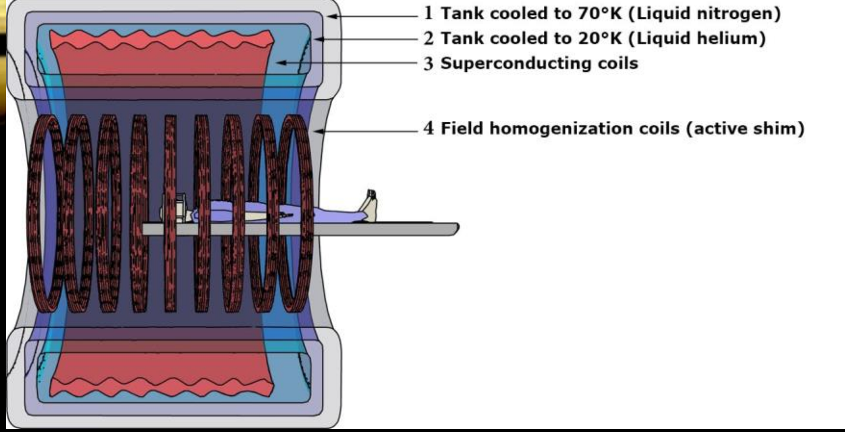


- Metal alloys (Fe77Nd15B8...)
- B0 = 0,1 – 0,3 T
- Advantages:
- Low purchase price
- Low operating costs
- Open
- Disadvantages:
- Weight (15 – 70 tons)
- Field stability very sensitive to temperature

EL.MAG.



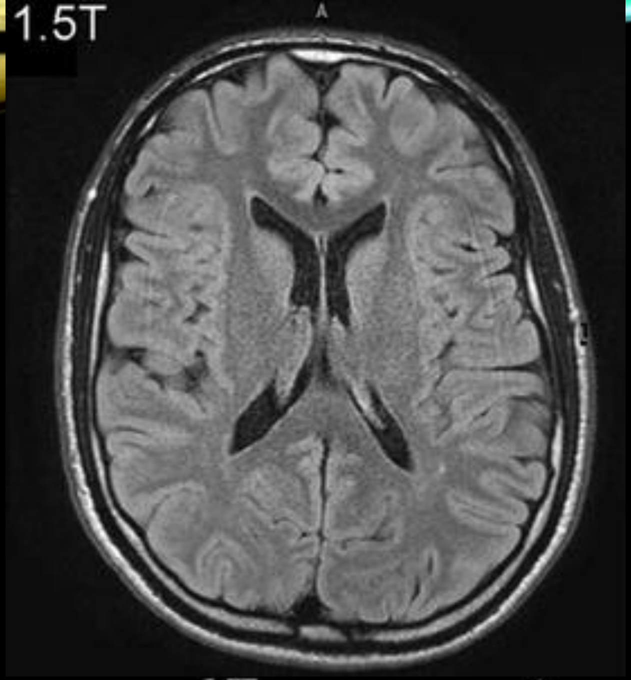
- Elmag induction
- B0 = 0,1 – 0,4 T
- Advantages:
- Low purchase price
- Low weight
- Open and off
- Disadvantages:
- High power consumption (~ 50 kW)
- Field stability very sensitive to temperature



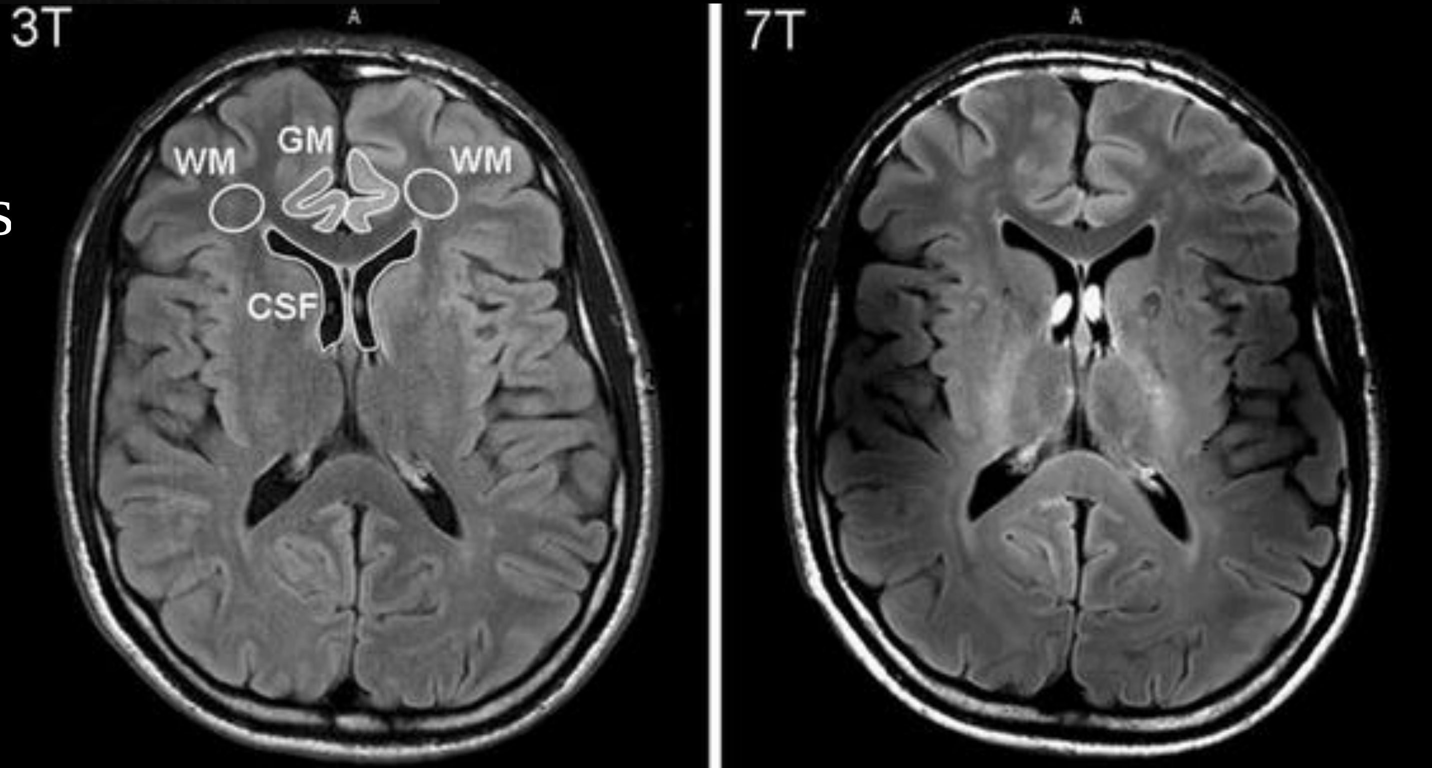
SUPRACOND.

- Elmag induction + liquid he cooling
- B0 = 0,5 – 7 T
- Advantages:
- Image quality
- Stability mag. field
- Disadvantages:
- Acquisition costs
- Can't be turned off
-

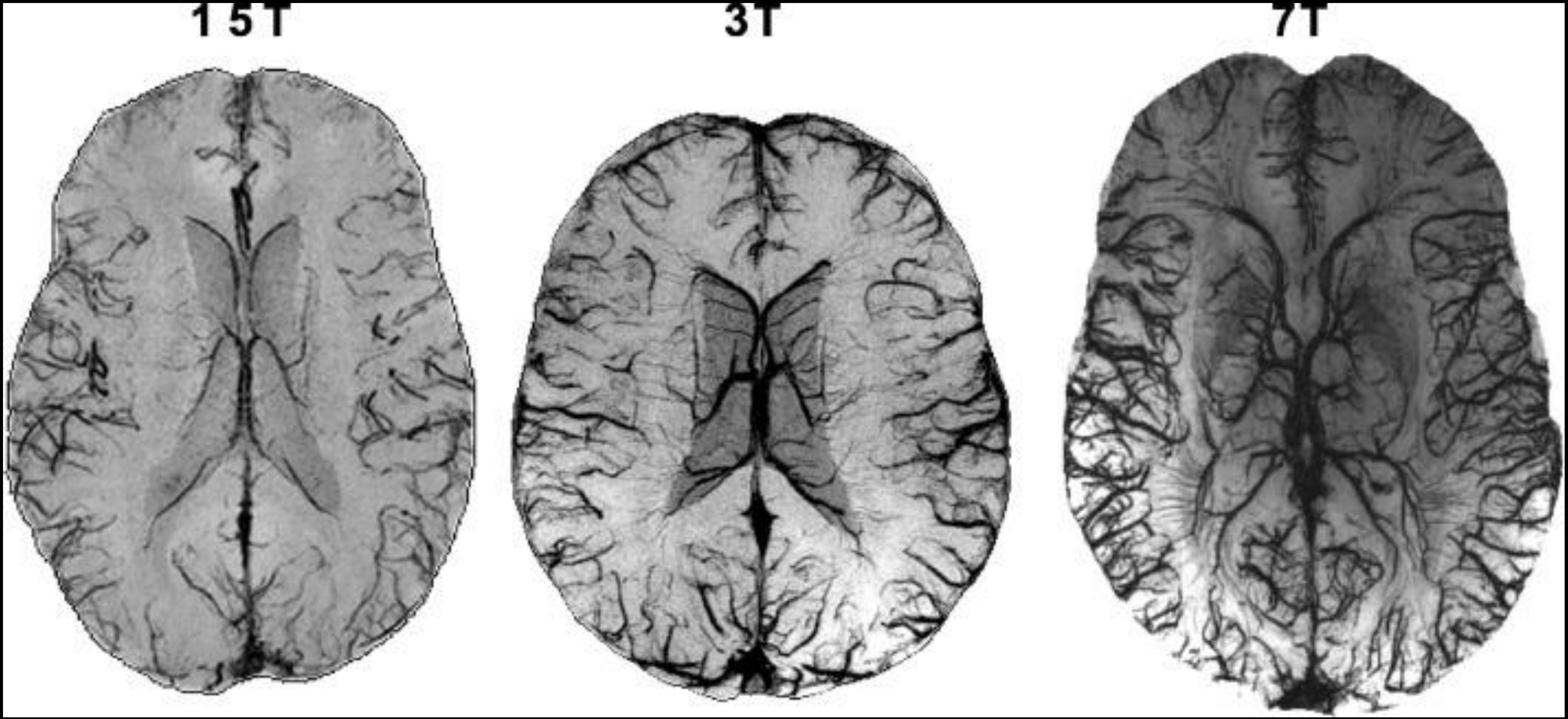
FIELD STRENGTH



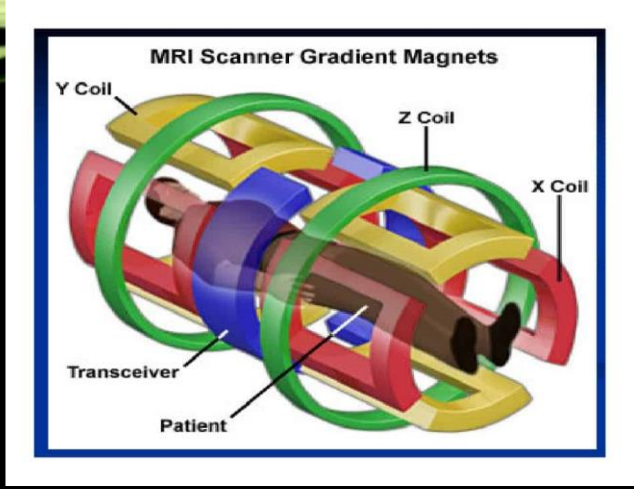
- At a larger B0
- Growing S/W
- Growing T1 time
- Growing SAR (ERF ~ B02!!!)
- The effect of susceptibility grows
- Growing noise
- Rising price
- Image homogeneity decreases
- Decreasing T2* time

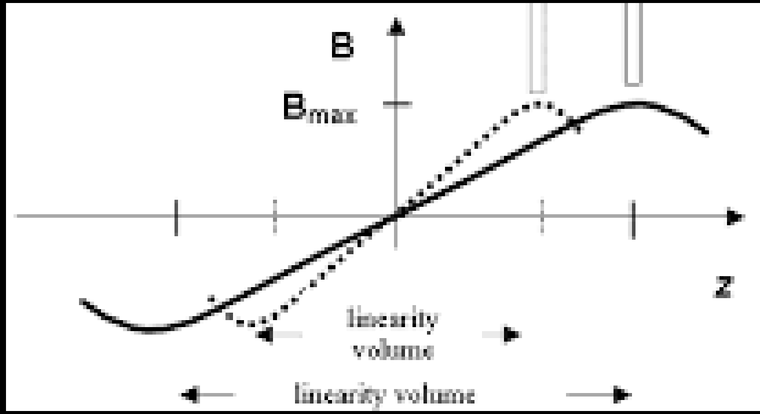


FIELD STRENGTH

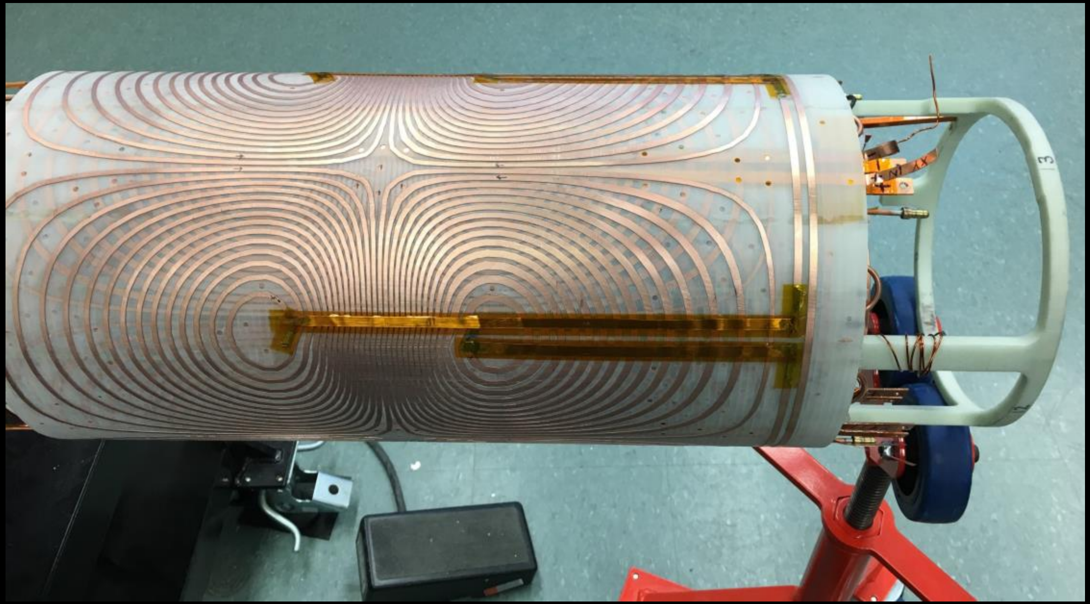


GRADIENTS

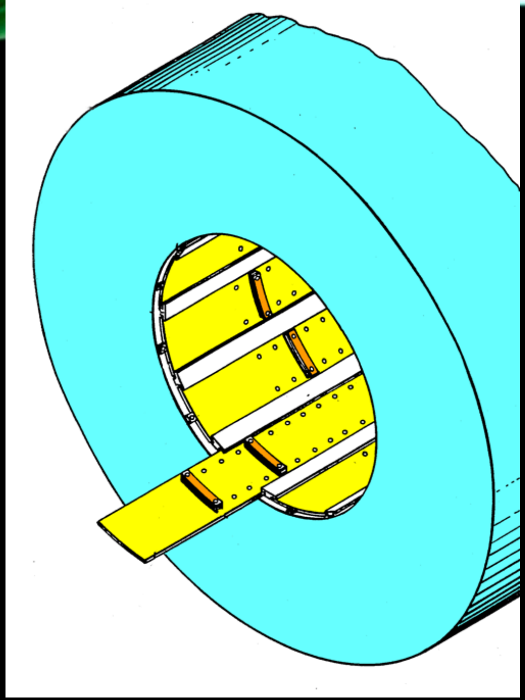




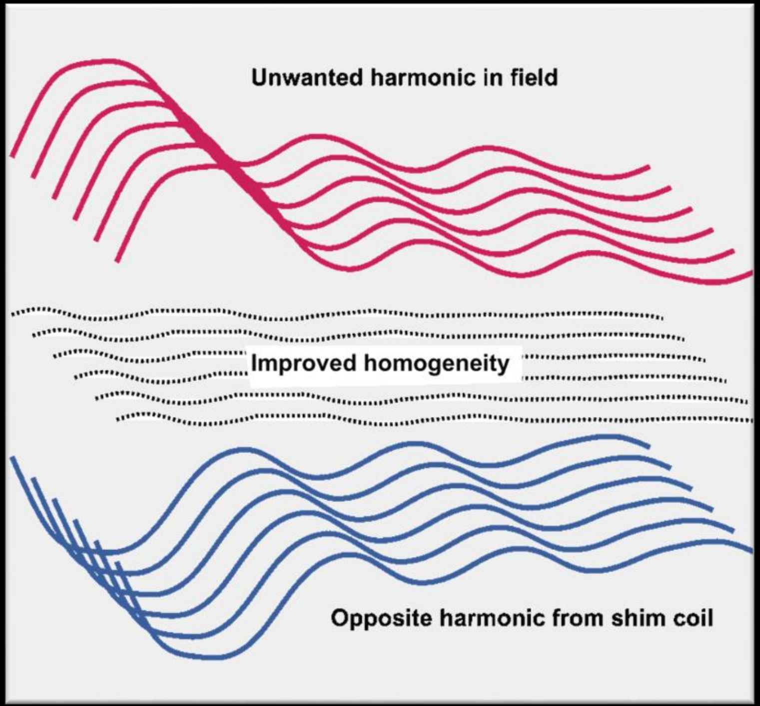
- Spatial information
- Parameters:
- Max. amplitude (20 – 80 mT/m)
- Slew rate (80 – 200 mT/m/ms)
- Linearity
- Amplitude ~ Prost. distinguish
- Slew rate ~ TEmin, TRmin...
-



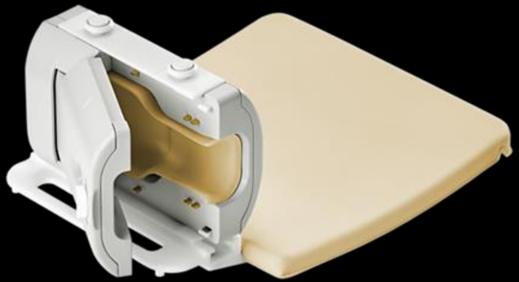
SHIM



- Correction of inhomogeneity mag. field
- Passive/Active
- Minimizing geometric distortion
- Maximizing the signal thanks to the ideal Larmor. frequency
- Better FatSat, MRS, EPI, fMRI...
-

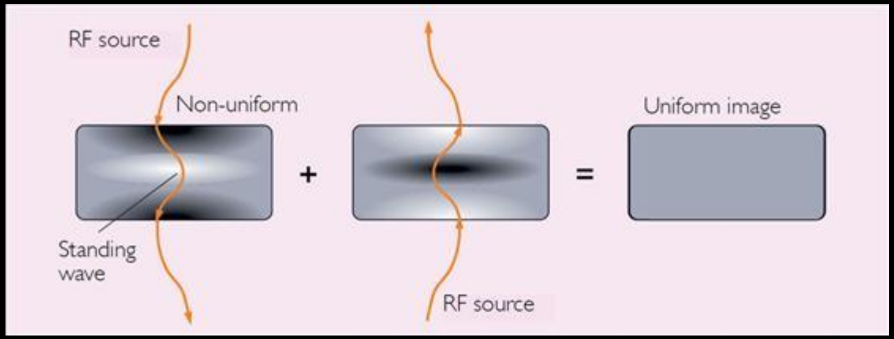


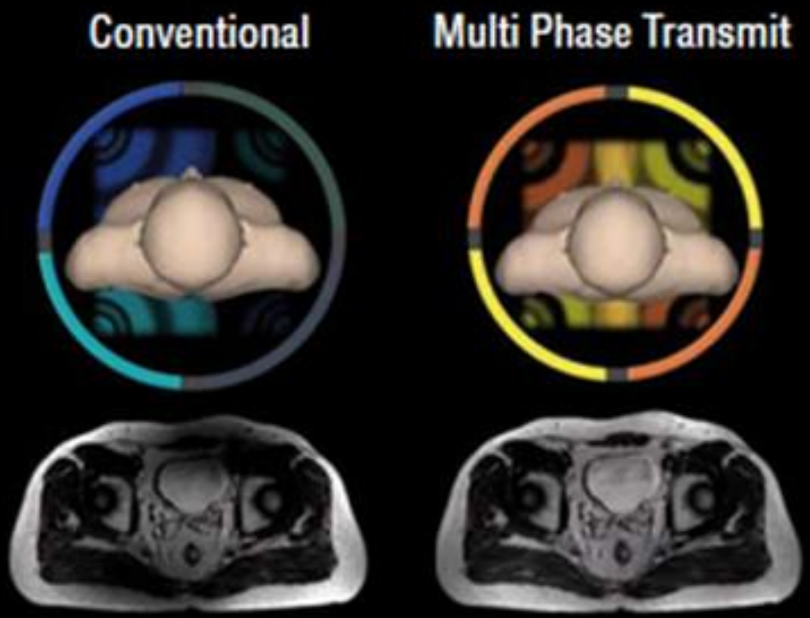
RF COILS



- Broadcast vs Receiving
- Full body
- T/R, worse S/W
- Surface
- Closer to the body = > better S/W
- Dedicated according to ant. areas
- Multi-segment
- Multiple coils in one block
- Coverage of larger areas
- Enable advanced techniques
- Greater signal inhomogeneity

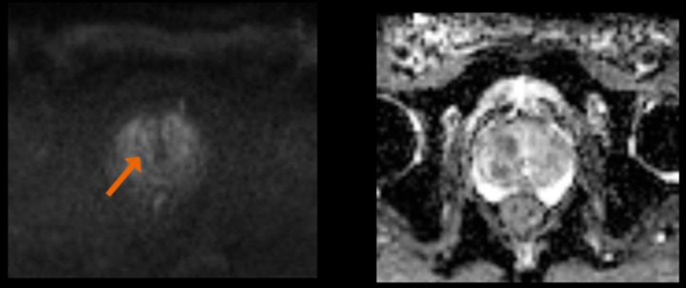
MULTI TRANSMIT

- Larger B0 = > shorter waves. Length = > greater signal inhomogeneity
- 

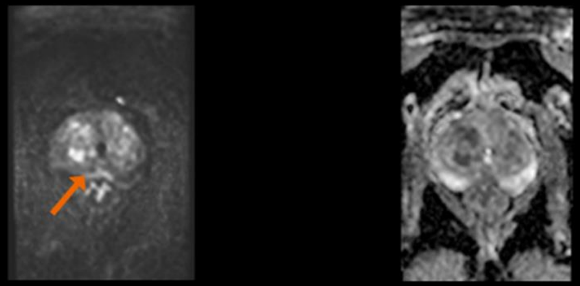


2D EXCITATION

- 2D spatially selective RF
- Display of small/"rectangular" organs

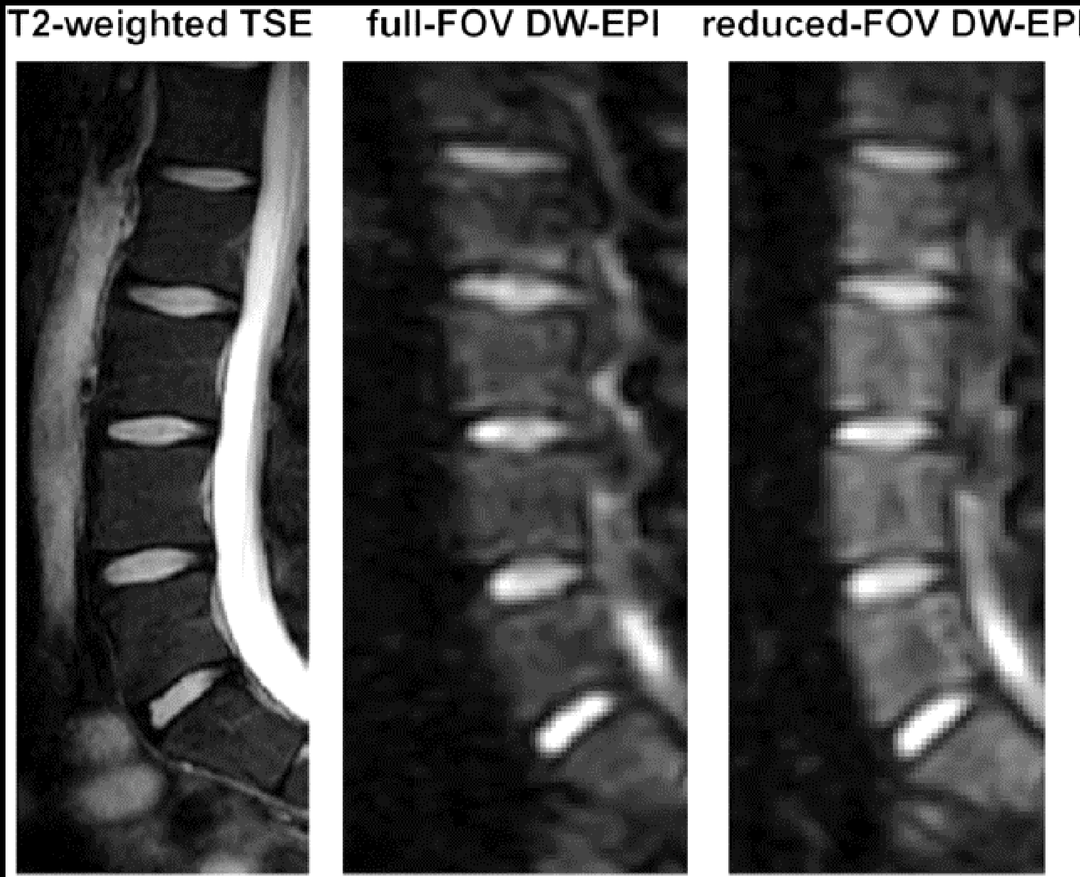


Conventional DWI
b 50, 1000, *1500, ADC*
2.1 x 2.1 x 3 mm^3
TR/TE 4600 / 79 ms
TA 3:23 min



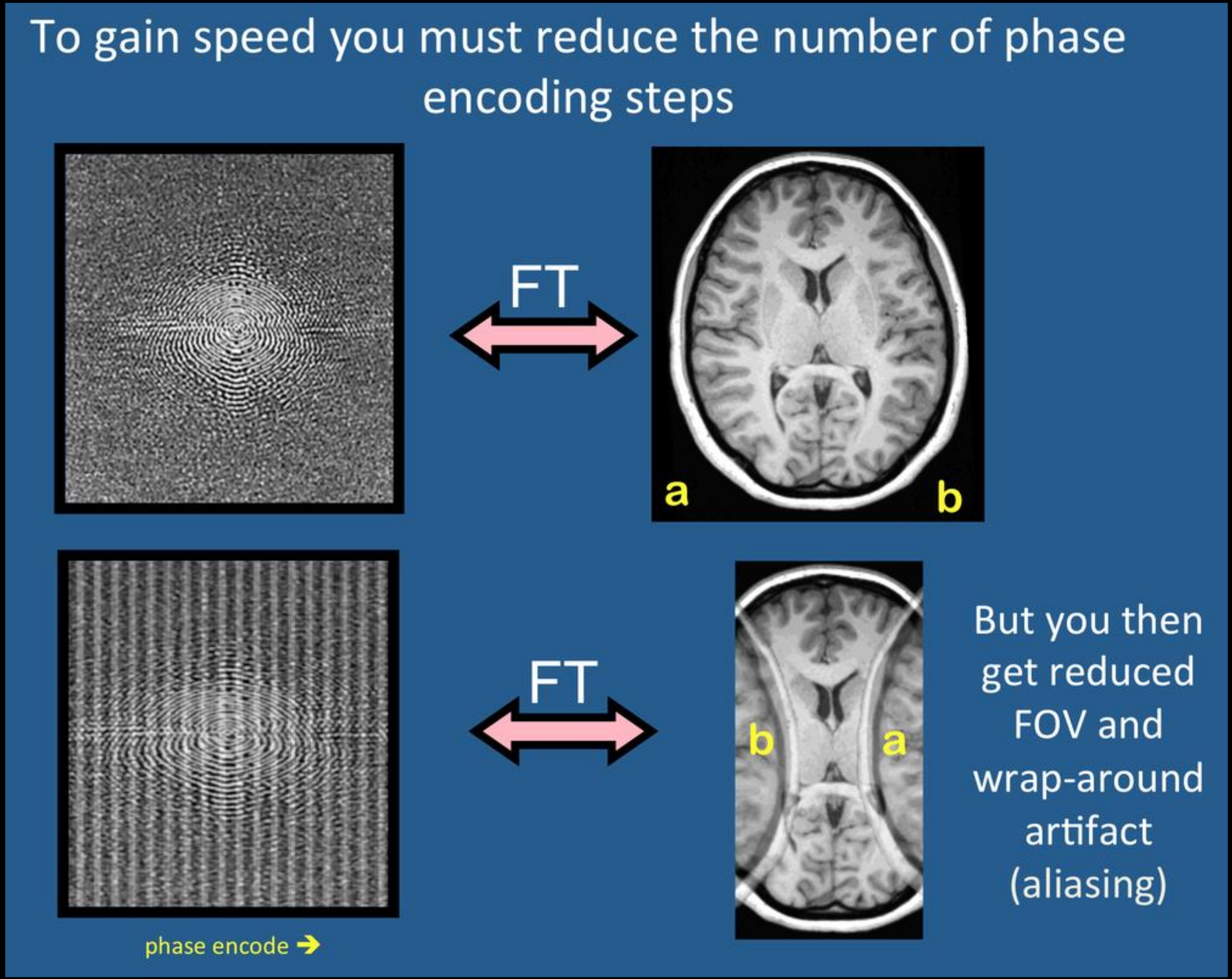
ZOOMit^{PRO1}
b 50, 1000, *1500, ADC*
0.95 x 0.95 x 3 mm^3
TR/TE 4600 / 79 ms
TA 3:29 min

Shanghai 6th People Hospital, Shanghai, China



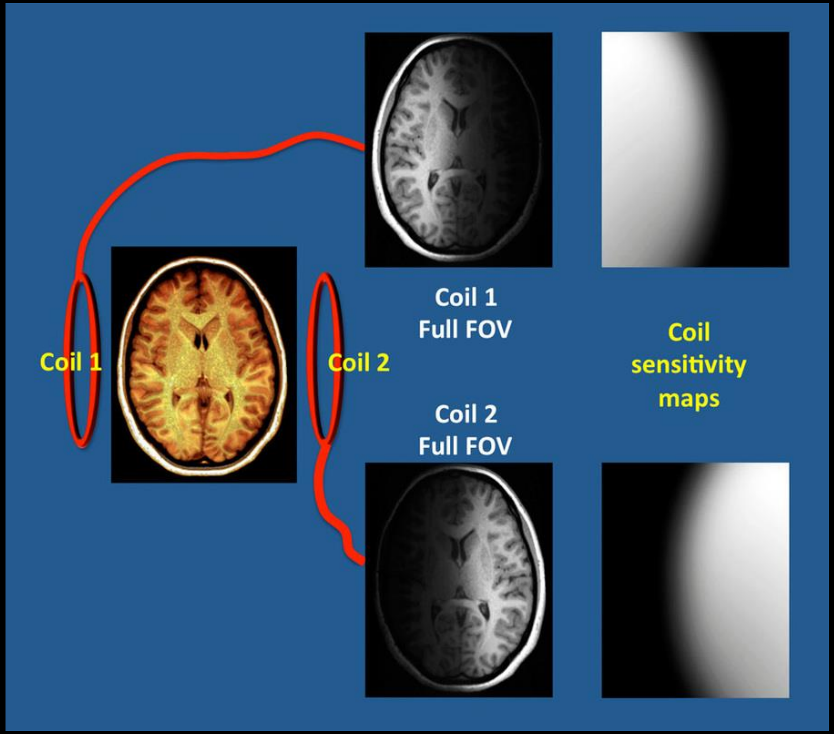
PARALLEL TECHNIQUES

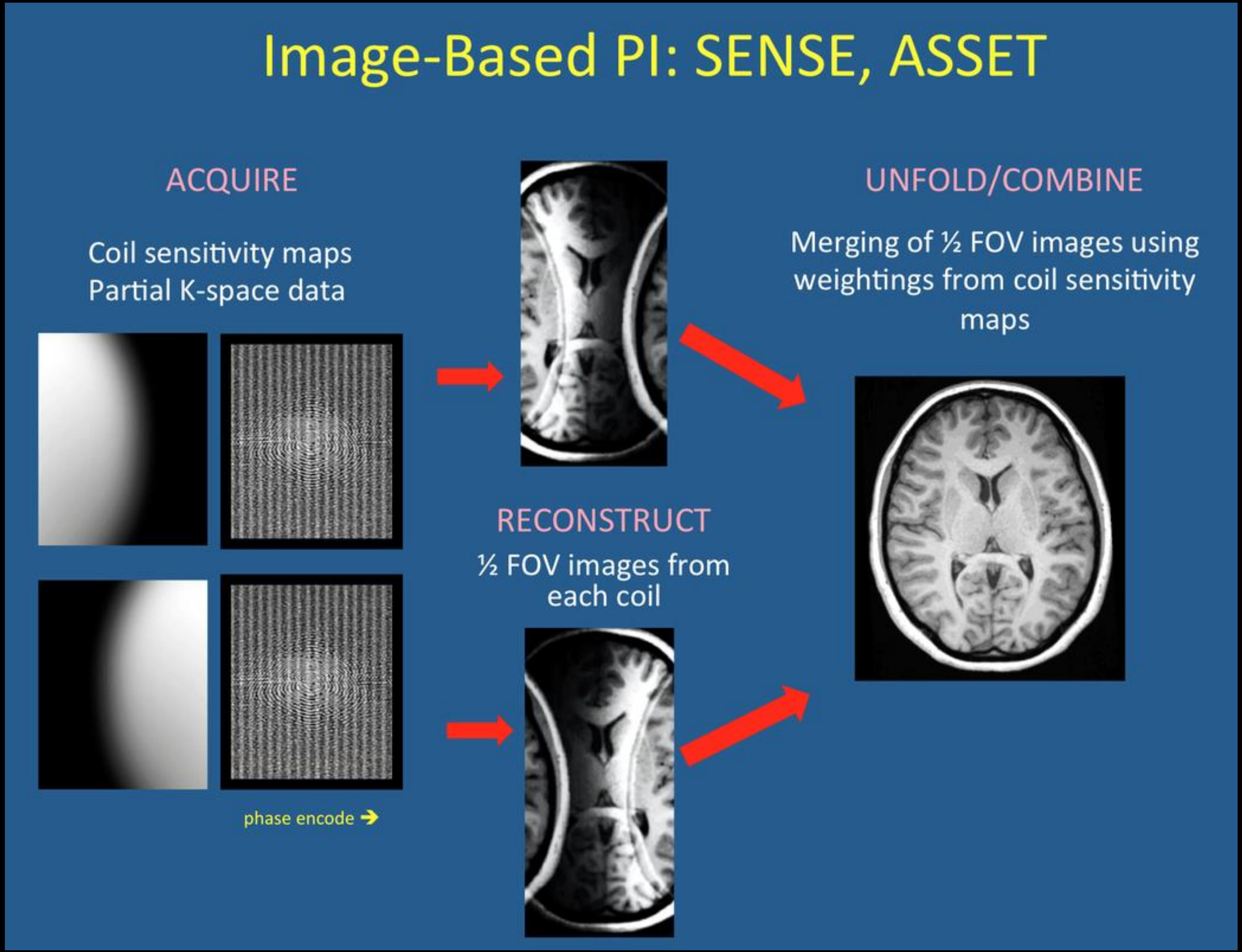
- Discarding k-space rows
-



SENSE/ASSET

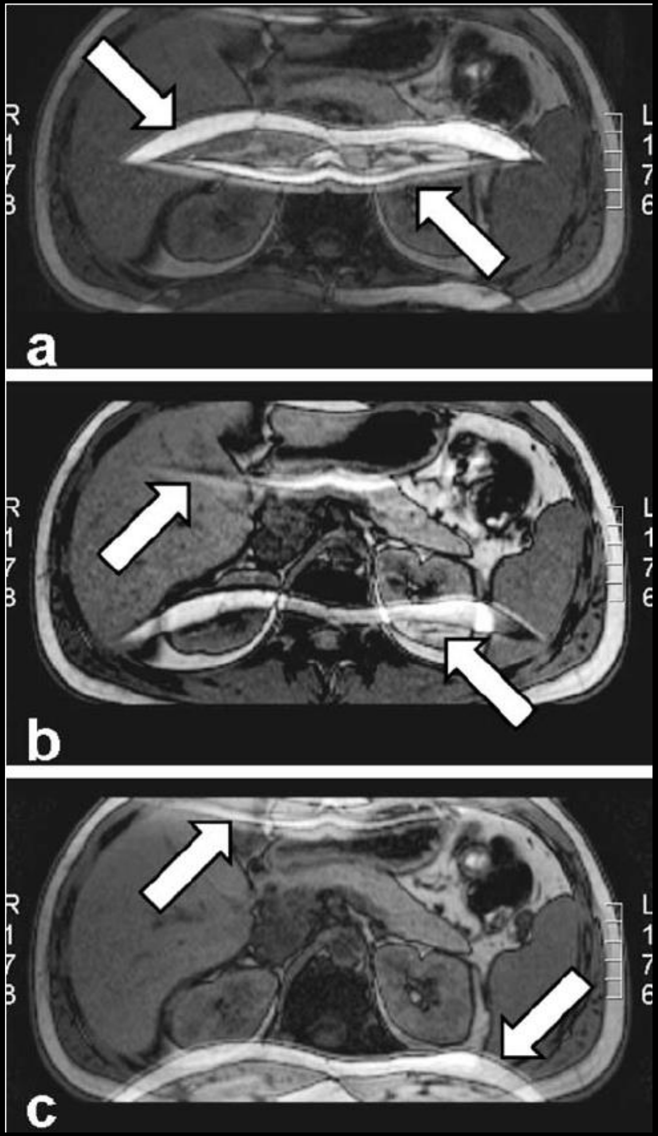
- Requires calibration
- 1. Reconstruction, then correction

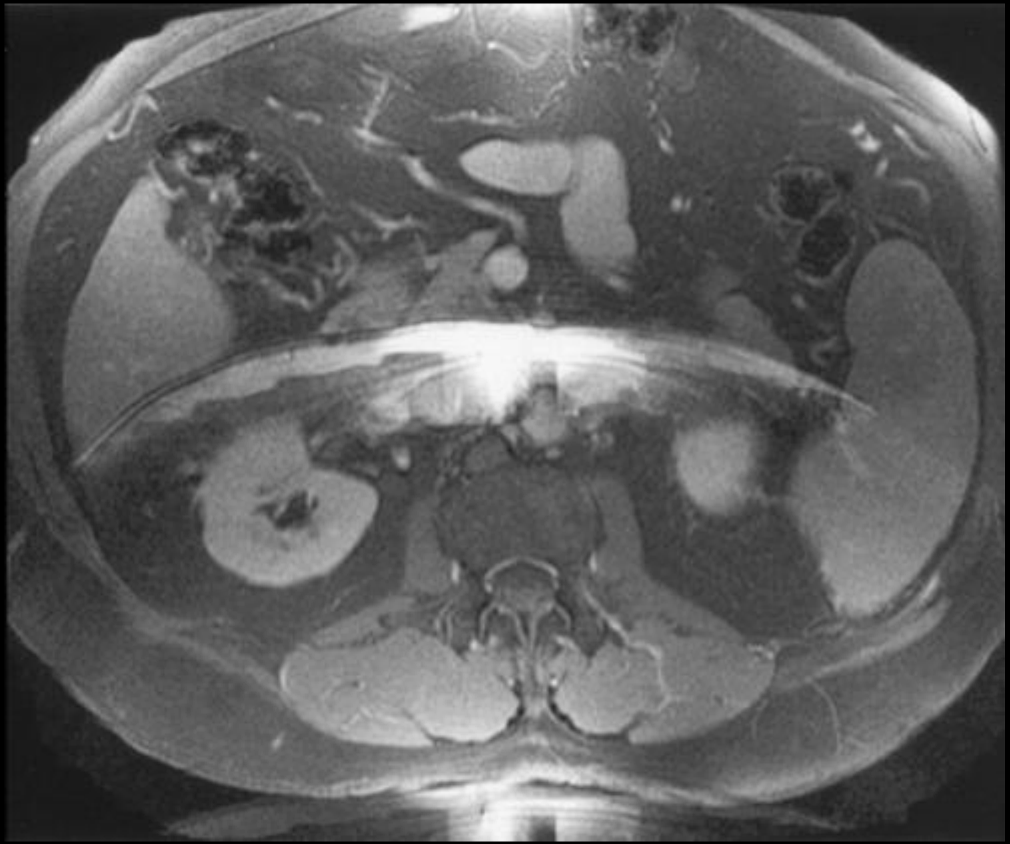




SENSE/ASSET

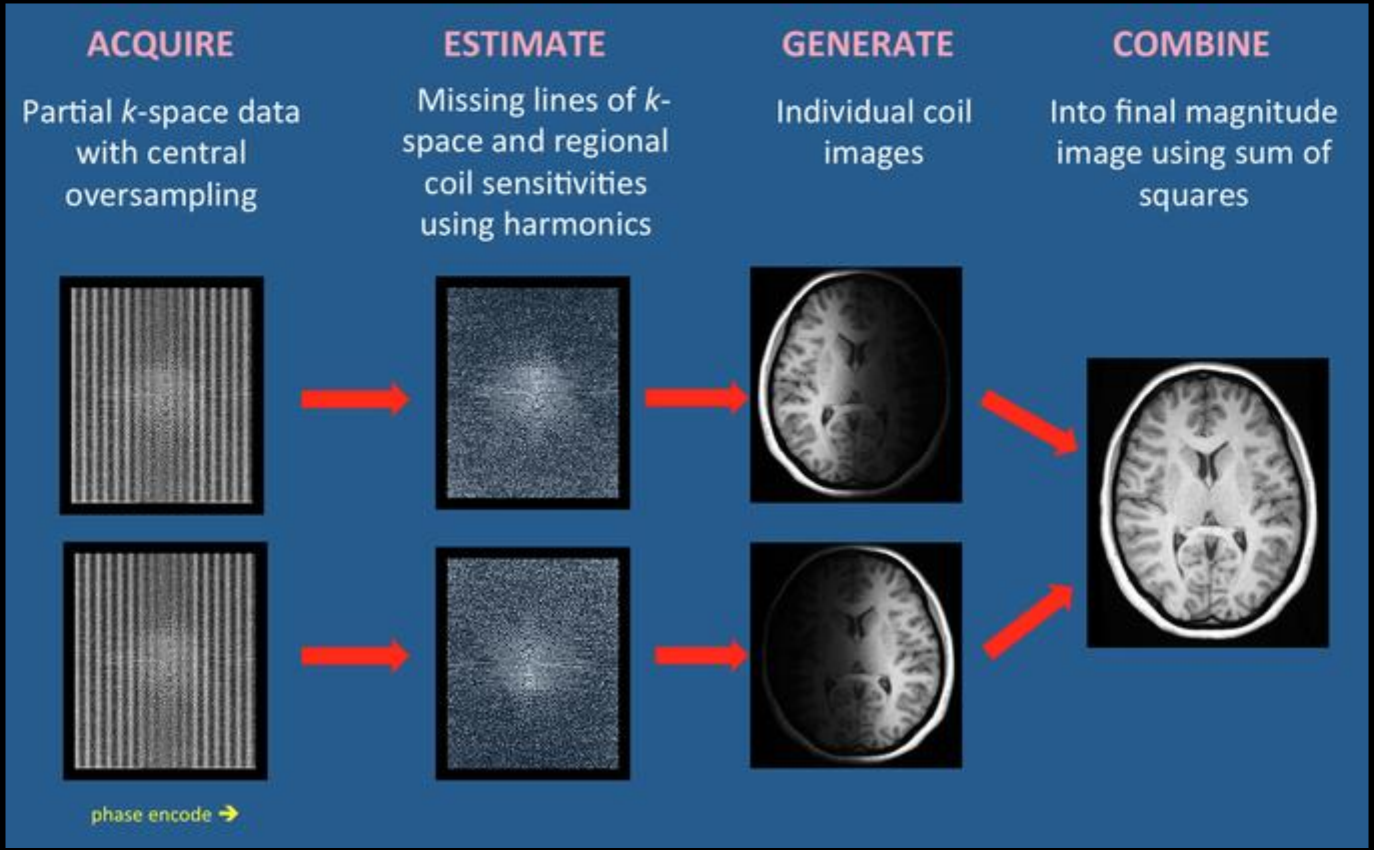
- Artifact
-





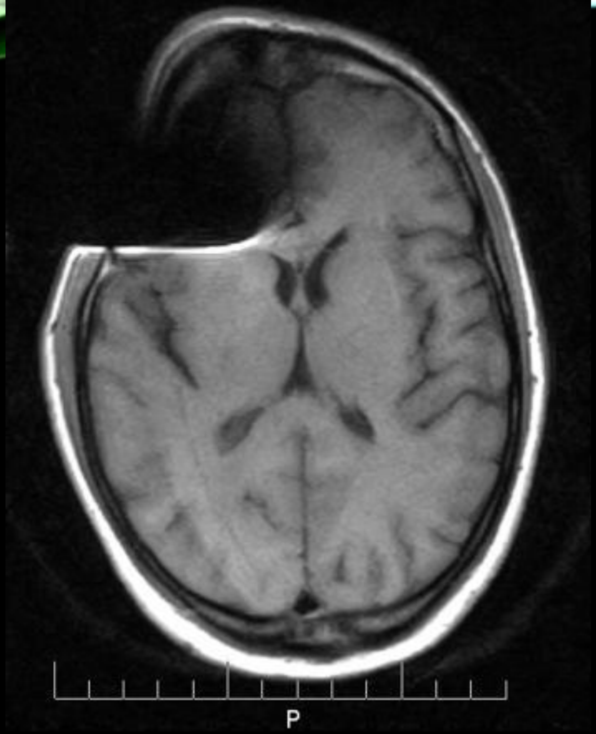
ARC/GRAPPA

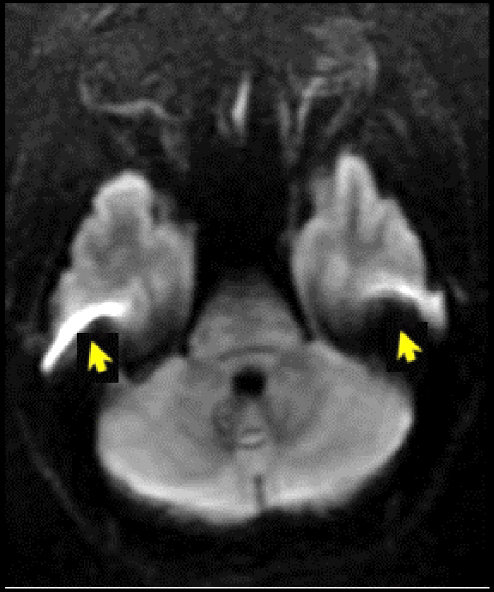
- No need for calibration
- 1. Correction, then reconstruction
- Center without deleting columns
-



ARTEFACTS

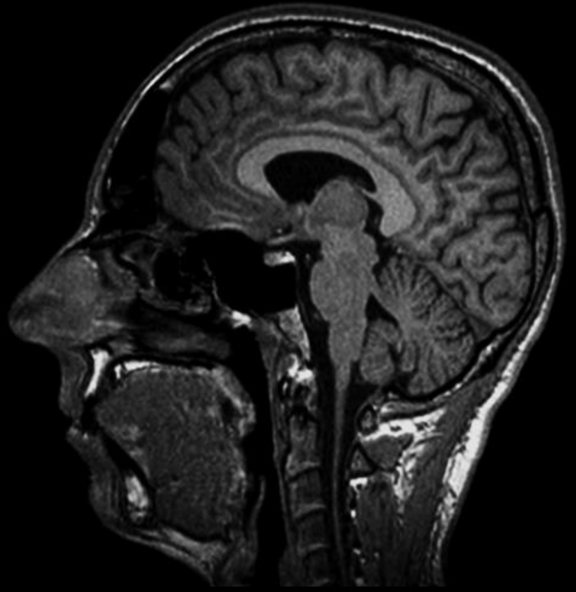
- Inhomogeneity B0
- Misaligned machine
- Metal object
- Difference of susceptibilit
-



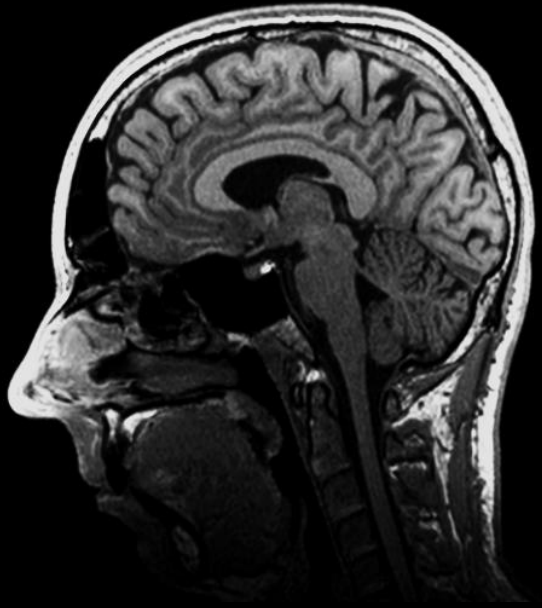


ARTEFACTS

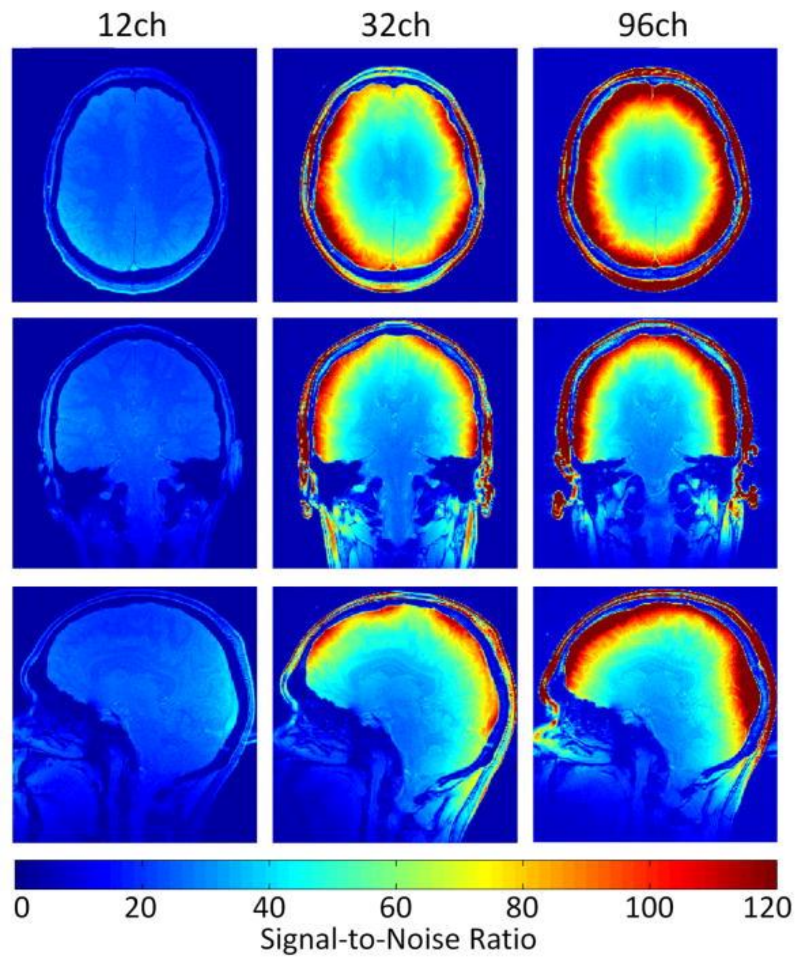
- Inhomogeneity B1
- Local inaccuracy of the RF pulse angle
- Inhomogeneity of the received signal (coil surface)



1 kanálová

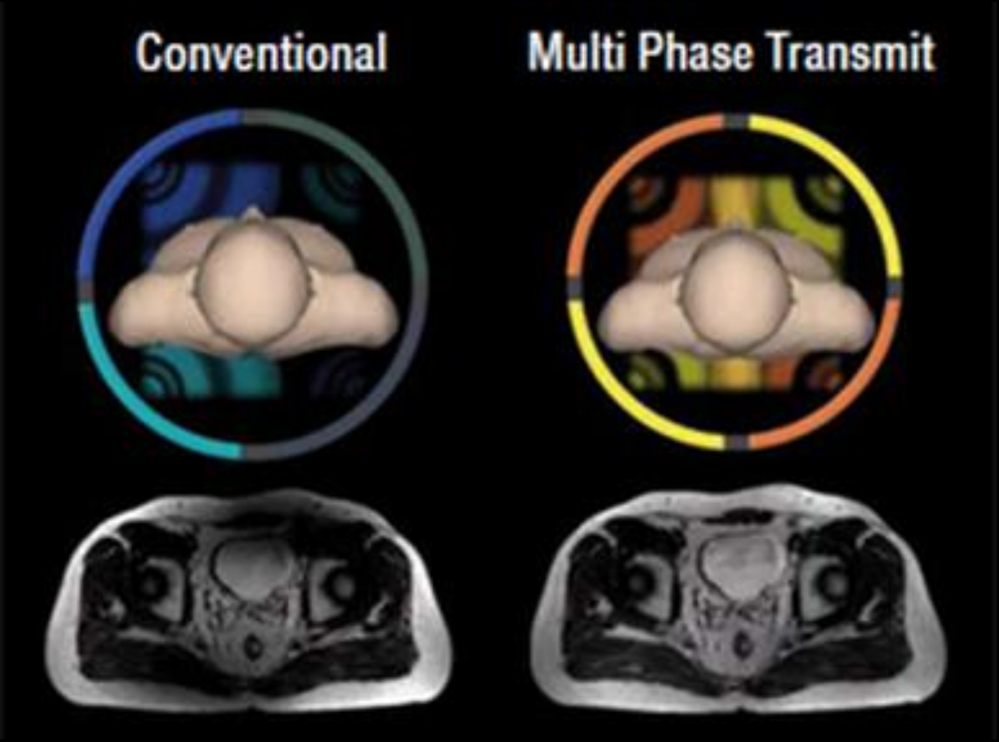


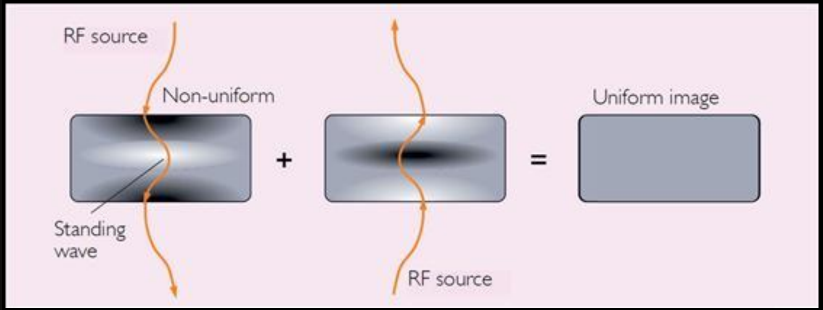
Multi-kanálová



ARTEFACTS

- Inhomogeneity B1
- Dielectric effect
- Wavelength in body ~ 25cm (3T)

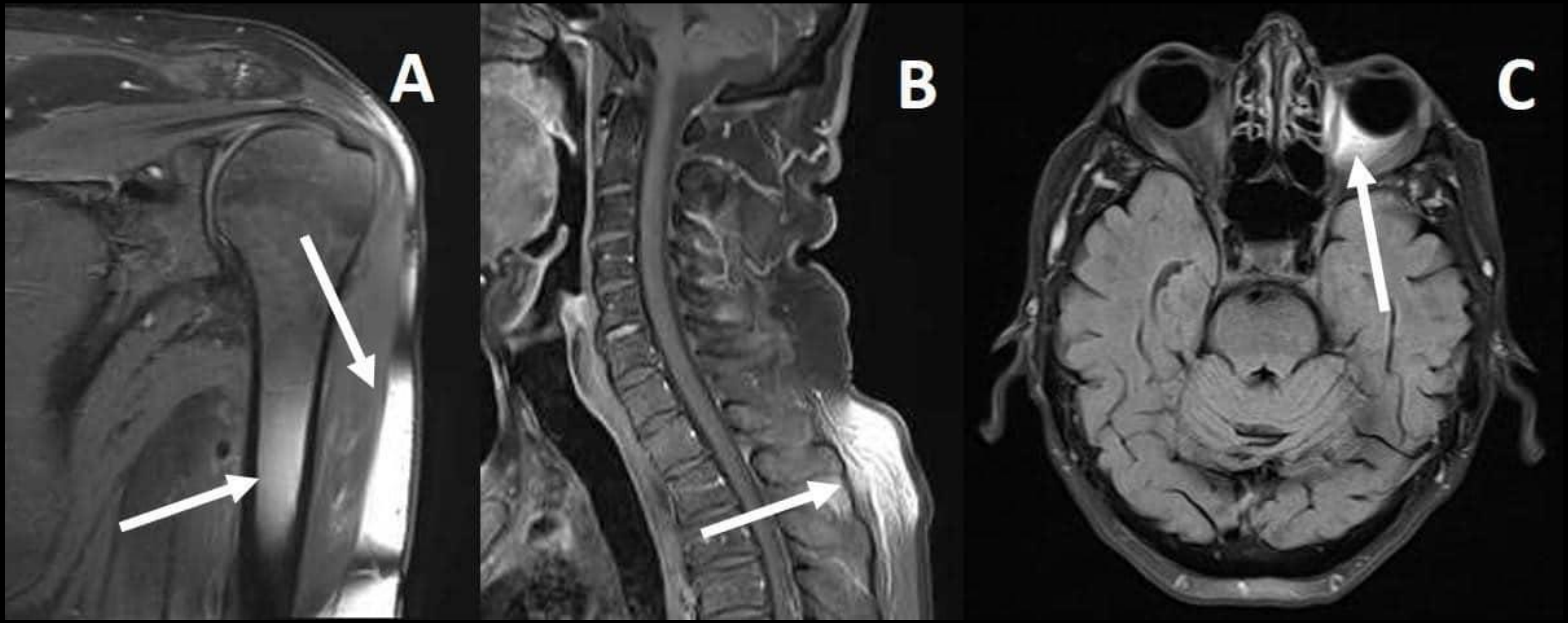


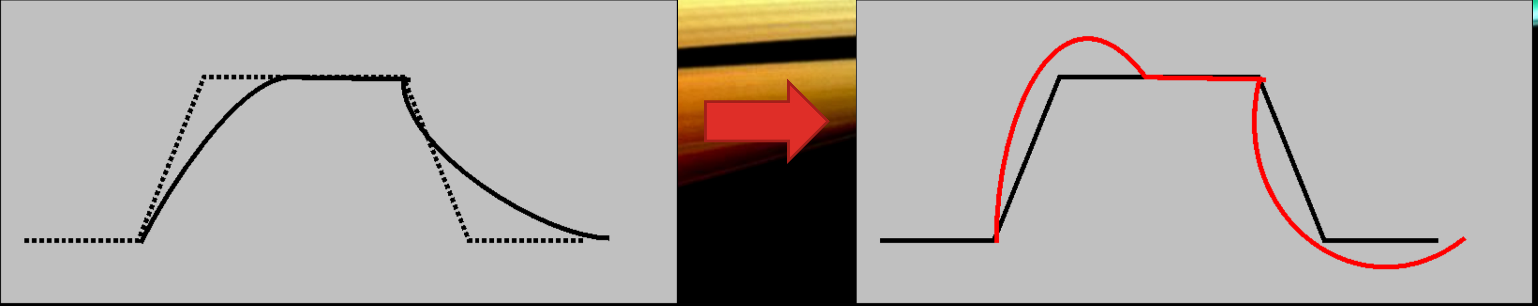


FLAIR 7T

ARTEFACTS

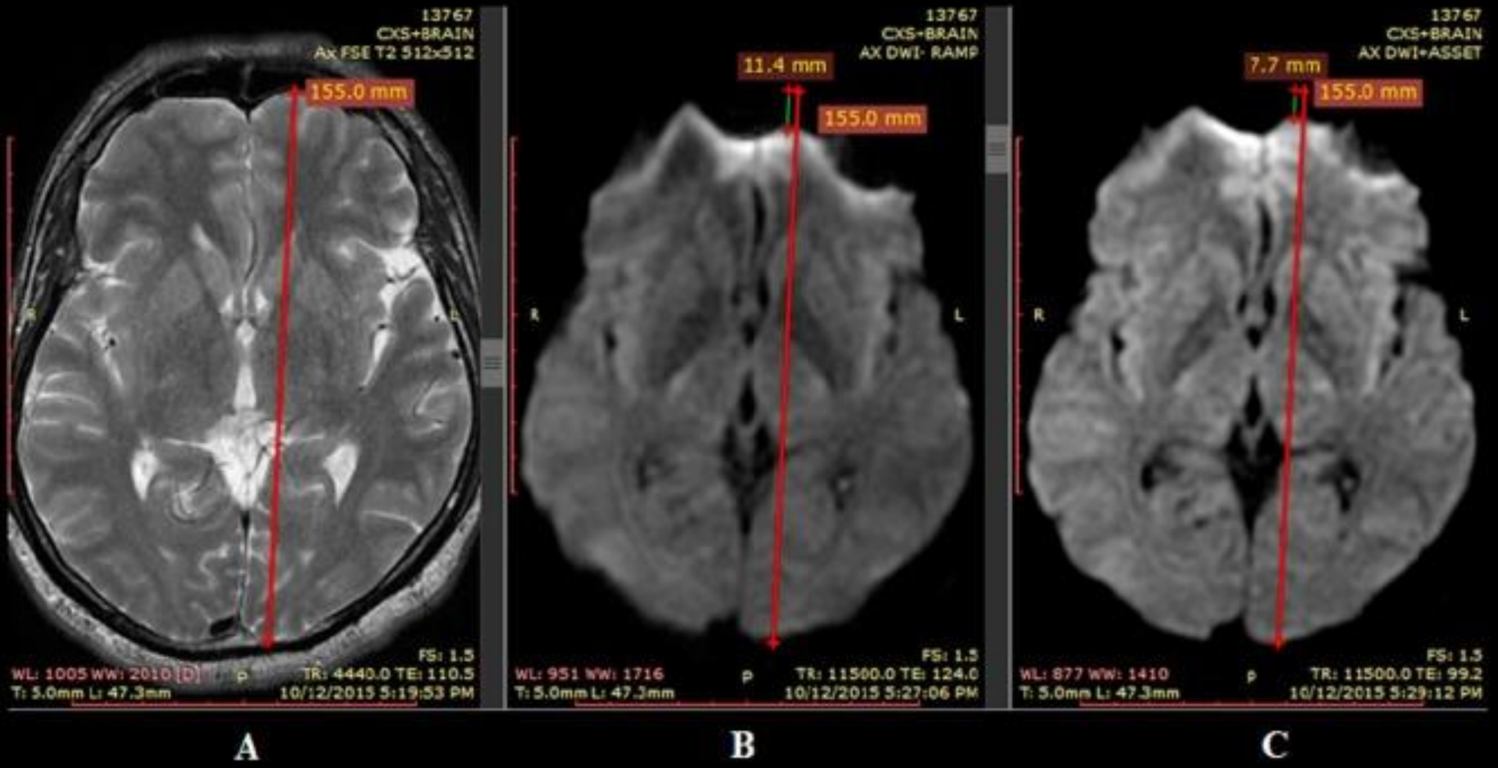
- Inhomogeneity B1
- Poor fat saturation
-





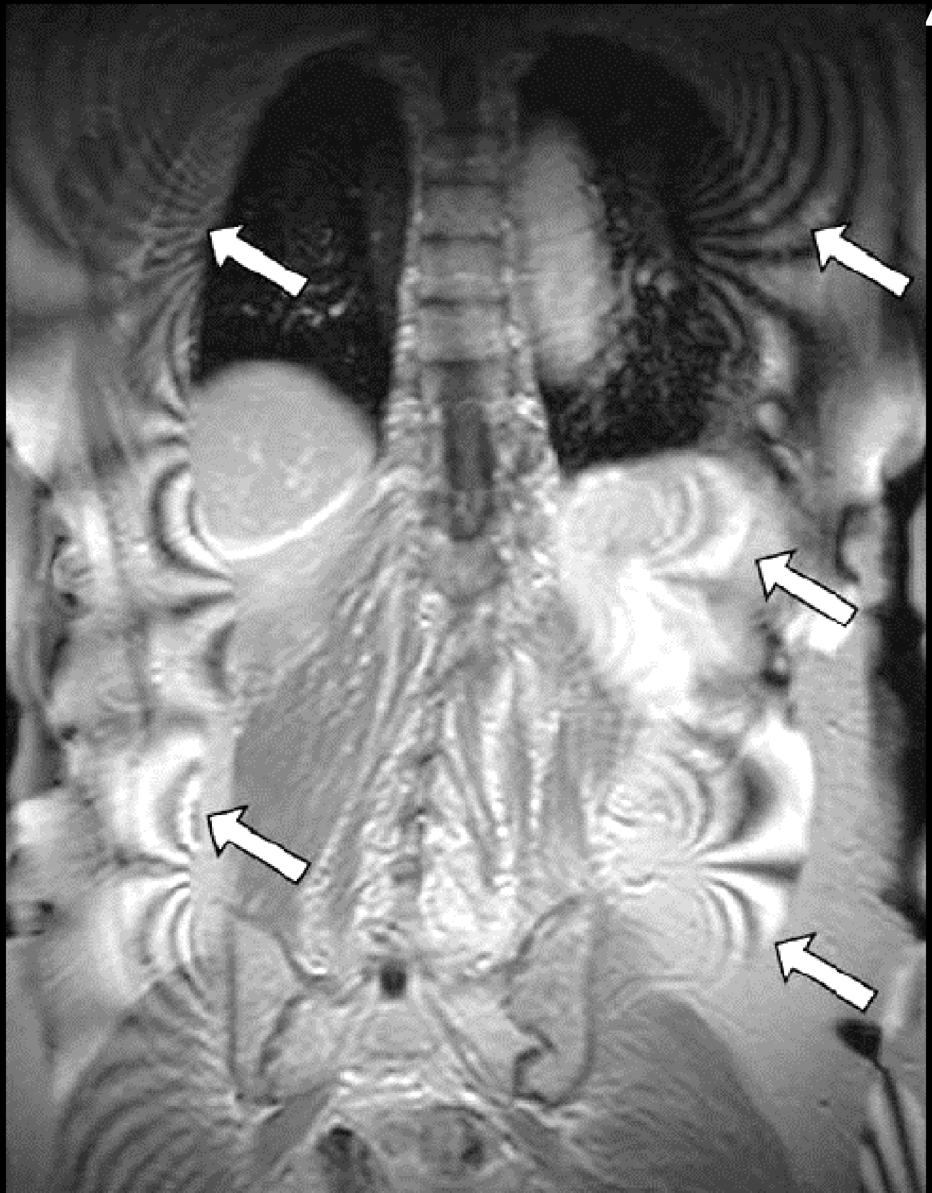
ARTEFACTS

- Imperfection of gradients
- Geometric distortion

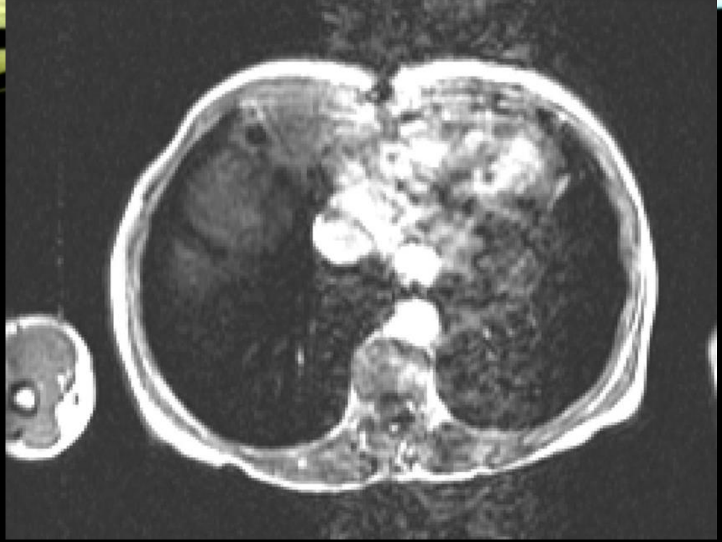


ARTEFACTS

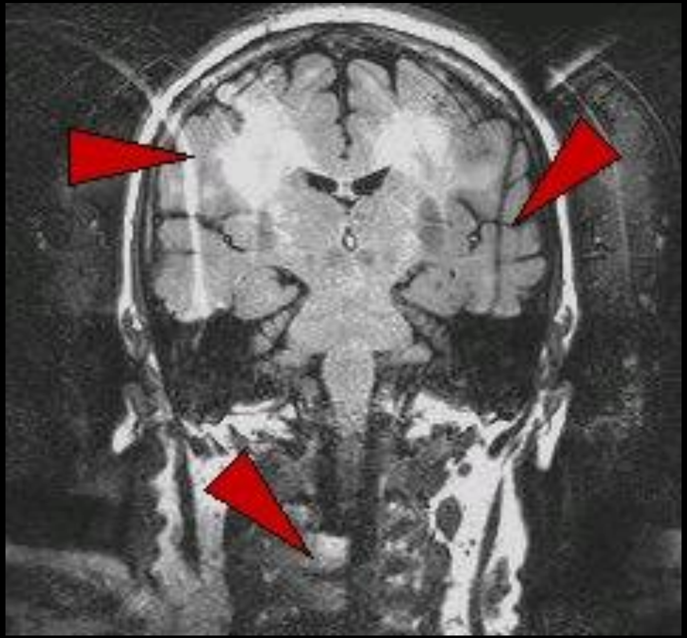
- Imperfection of gradients
- Circular artifacts

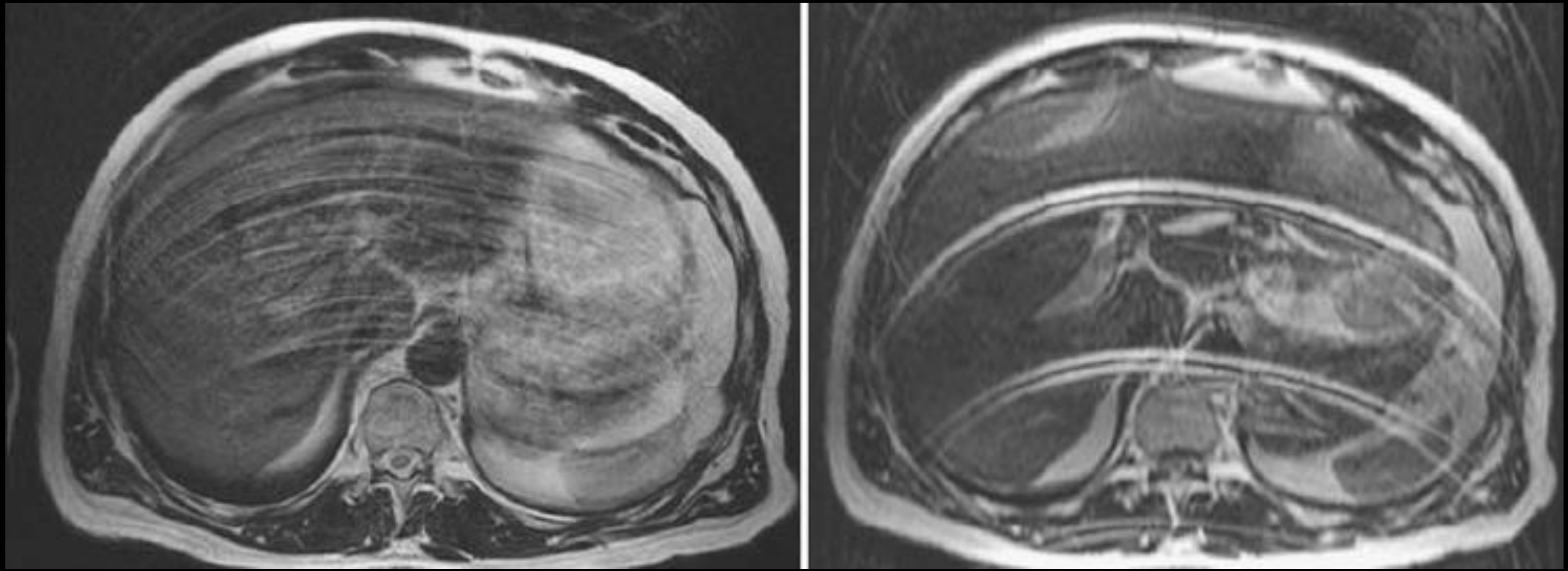


ARTEFACTS



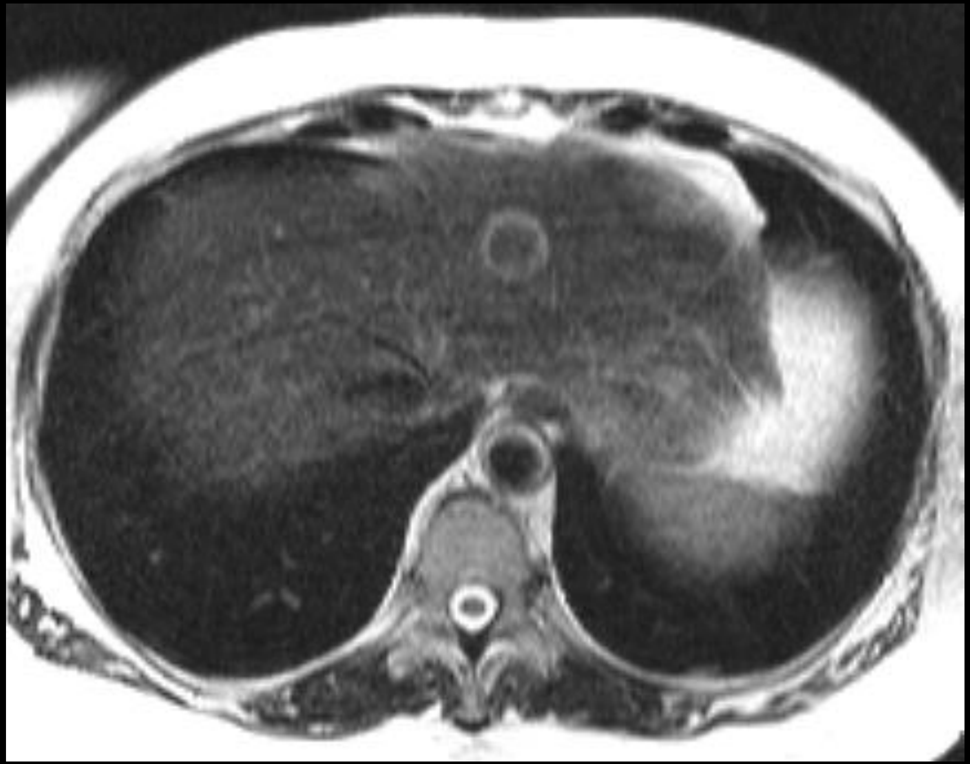
- Movement, flow
- Poor localization of signal phases
-





ARTEFACTS

- Movement, flow
- Poor localization of signal phases



ARTEFACTS

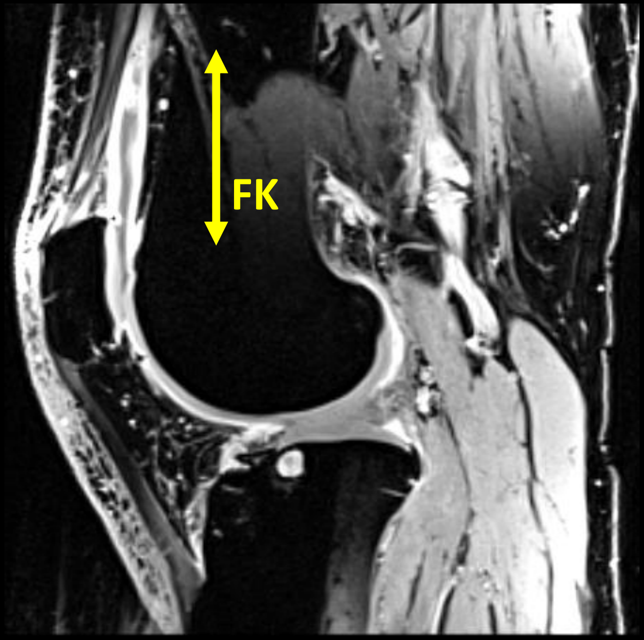
- Motion suppression options
- Breath-hold scoop
- Pickup synchronized with the breathing curve
- Pickup synchronized with diaphragm movement
- Pickup synchronized with ECG
- Change the data pickup type (Propeller/MultiVane)

ARTEFACTS

- Flow suppression options
- Suitable direction of phase coding
-

NPW = off

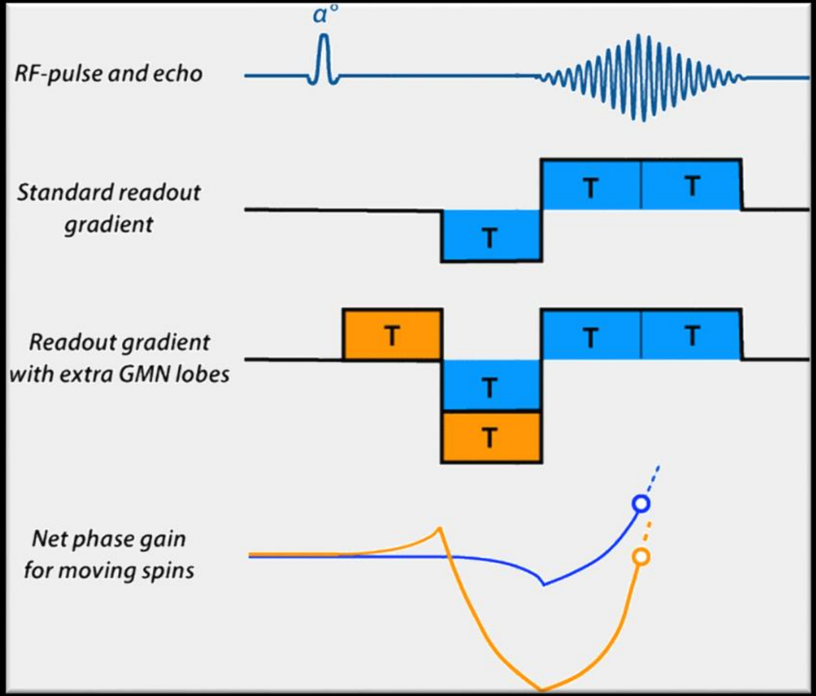
NPW = off

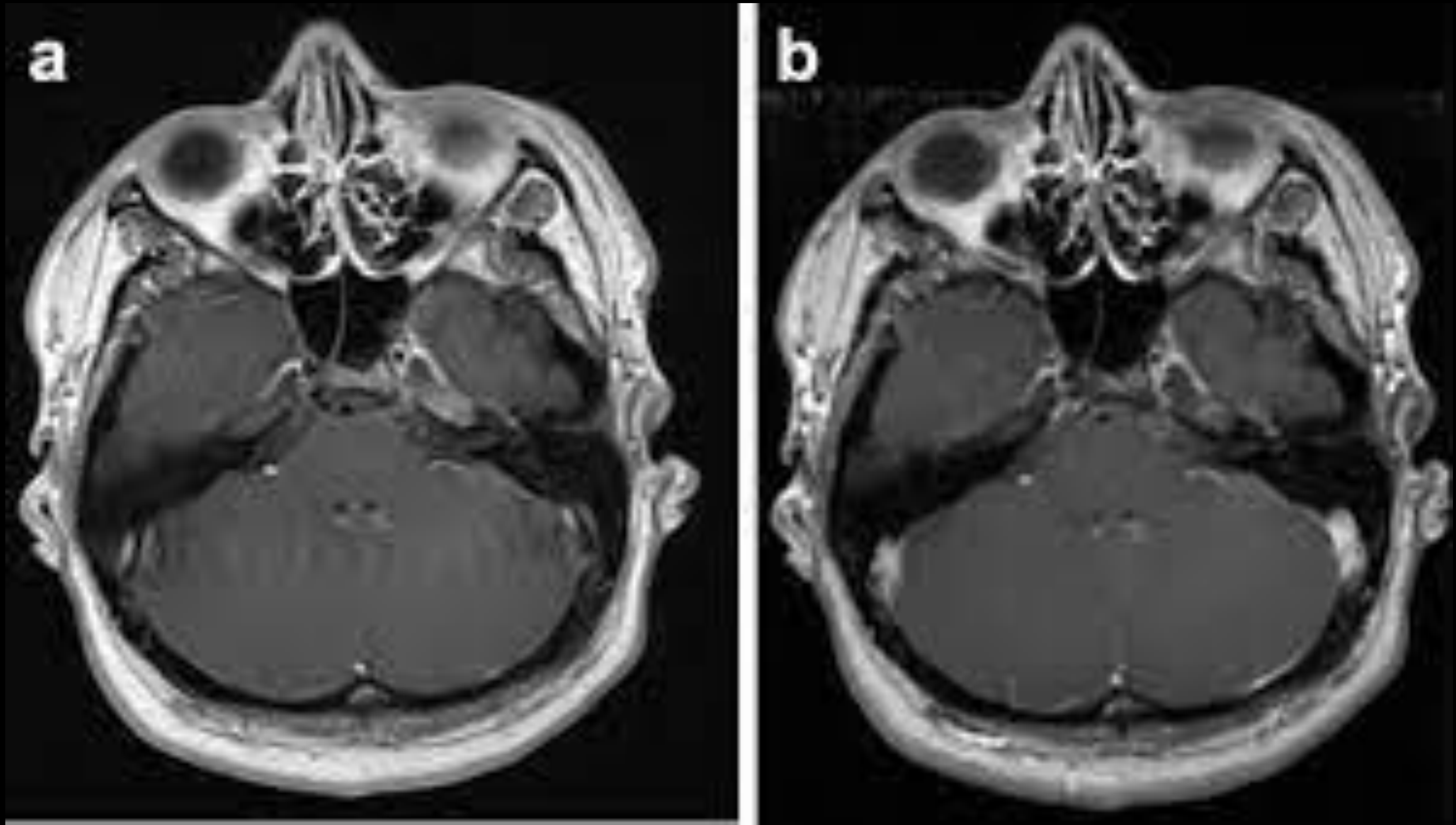


NPW = on

ARTEFACTS

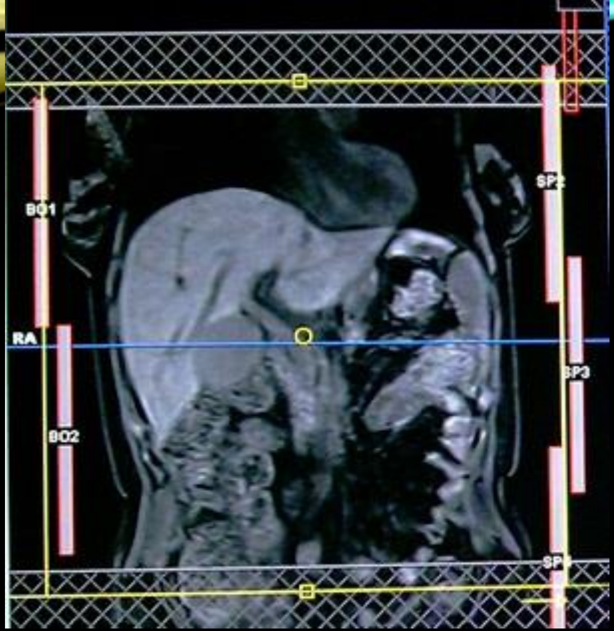
- Flow suppression options
- Add a gradient pulse
-





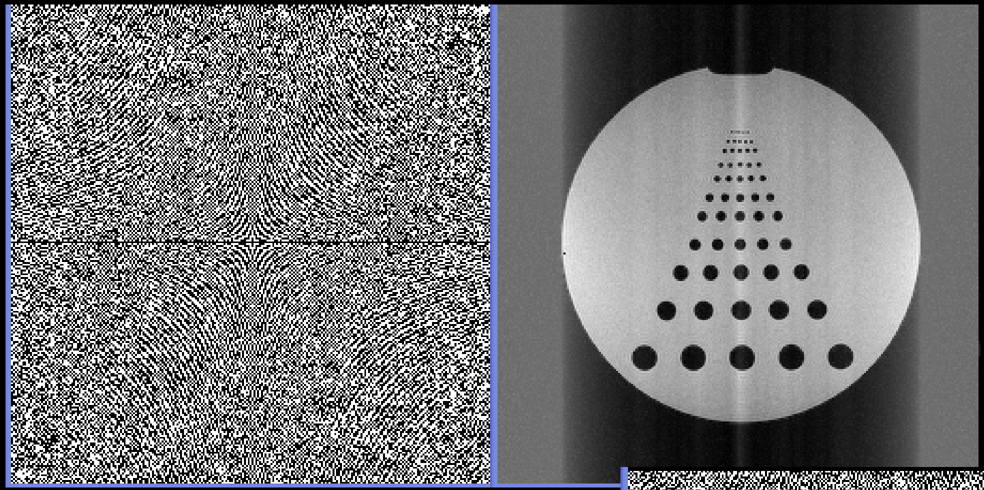
ARTEFACTS

- Flow suppression options
- Spatial saturation

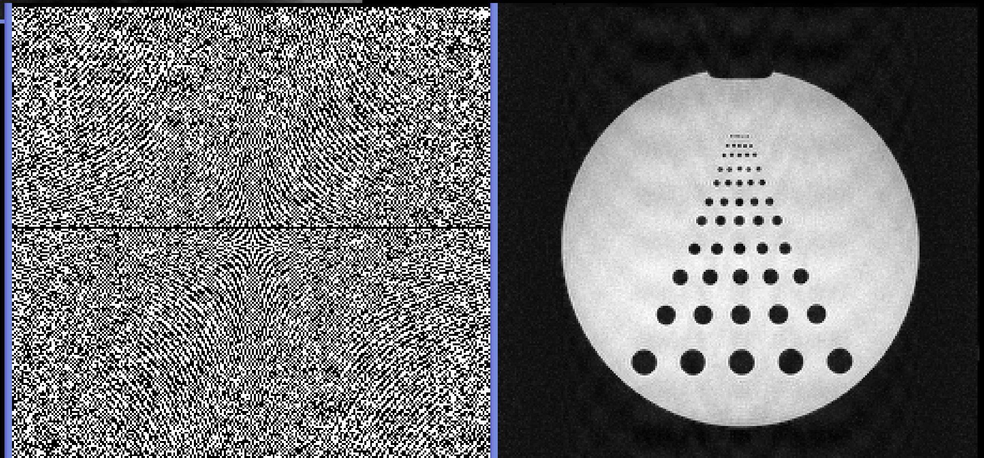


ARTEFACTS

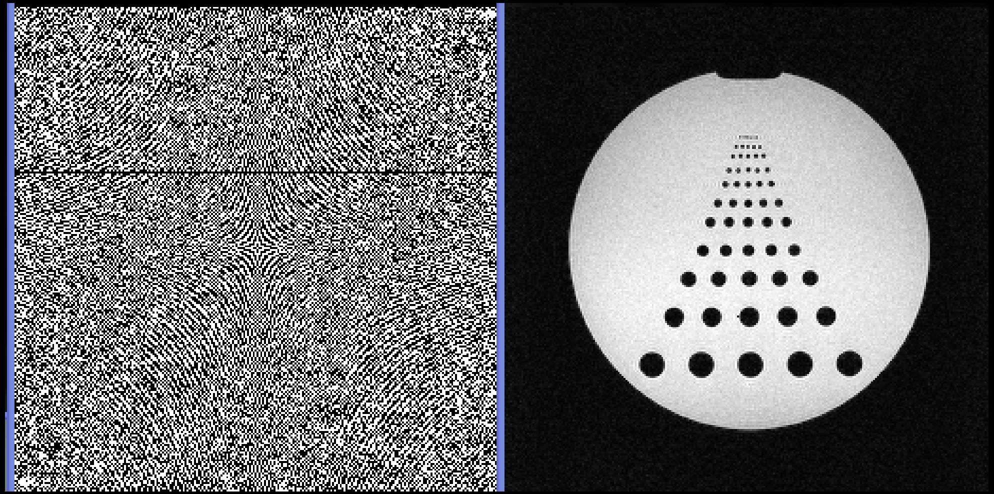
- Signal line failure



Řádek 0



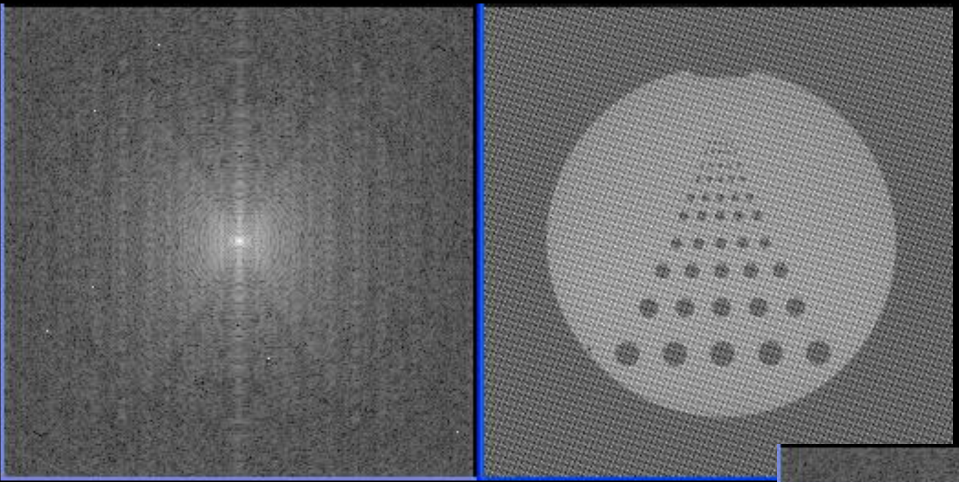
Řádek 10



Řádek 40

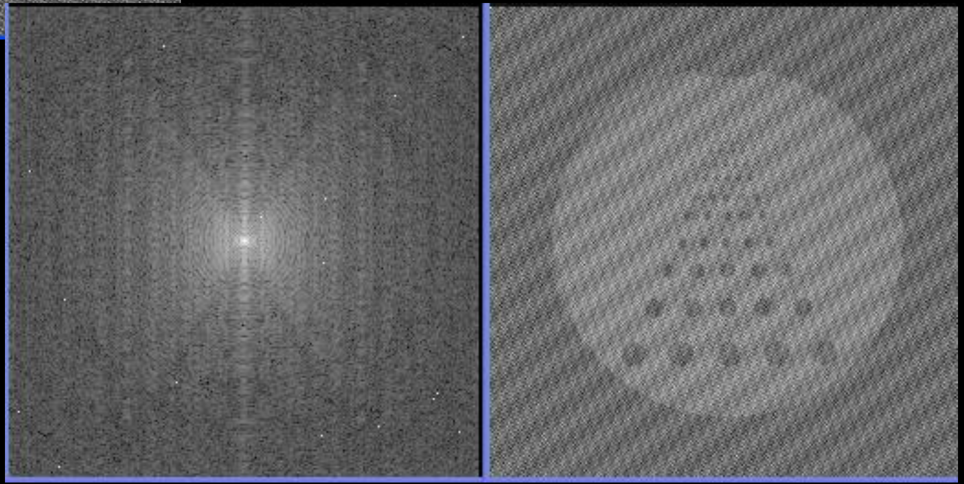
ARTEFACTS

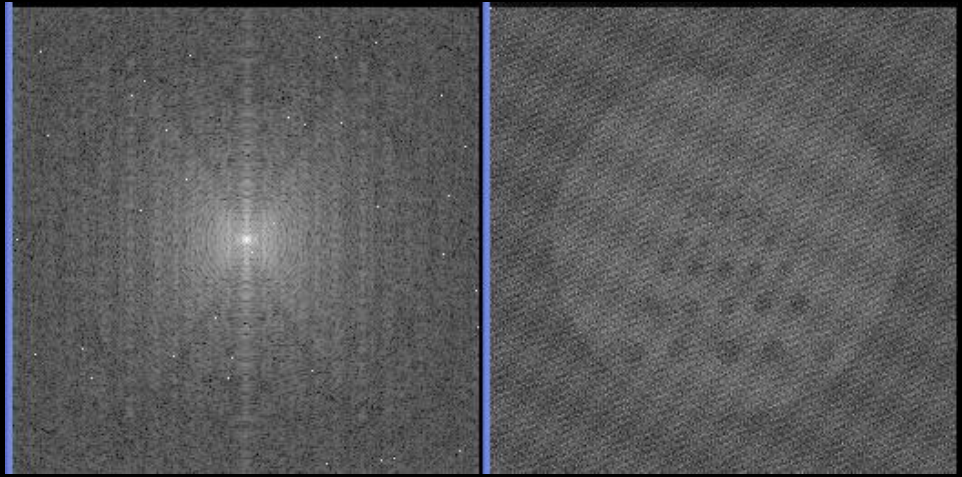
- Failure of multiple signal points (sparking)



5 jisker

15 jisker

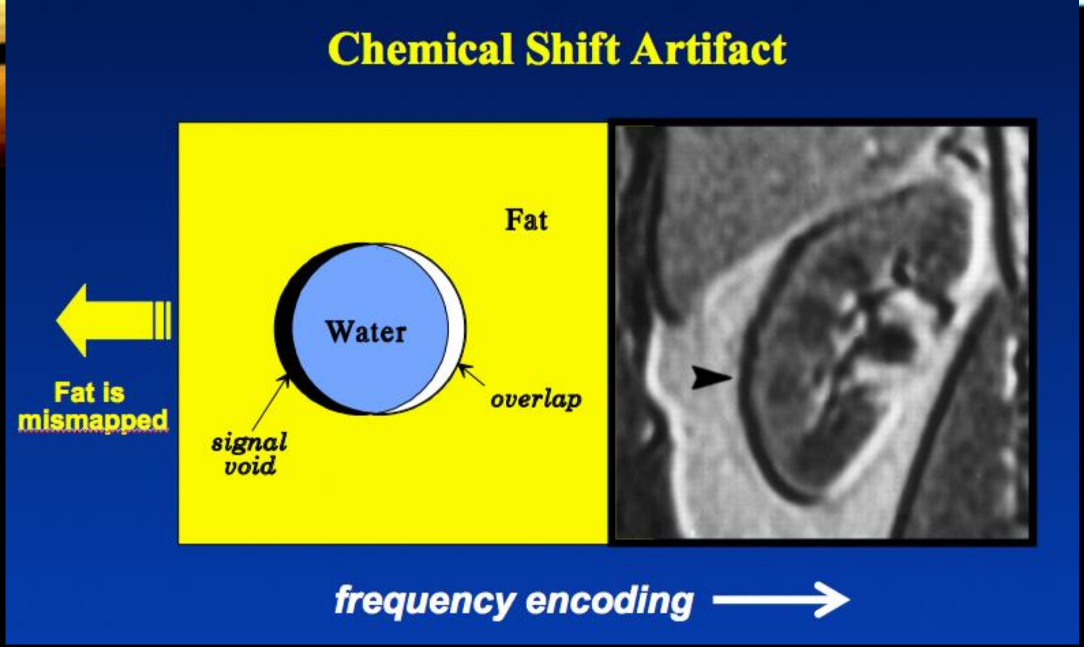




35 jisker

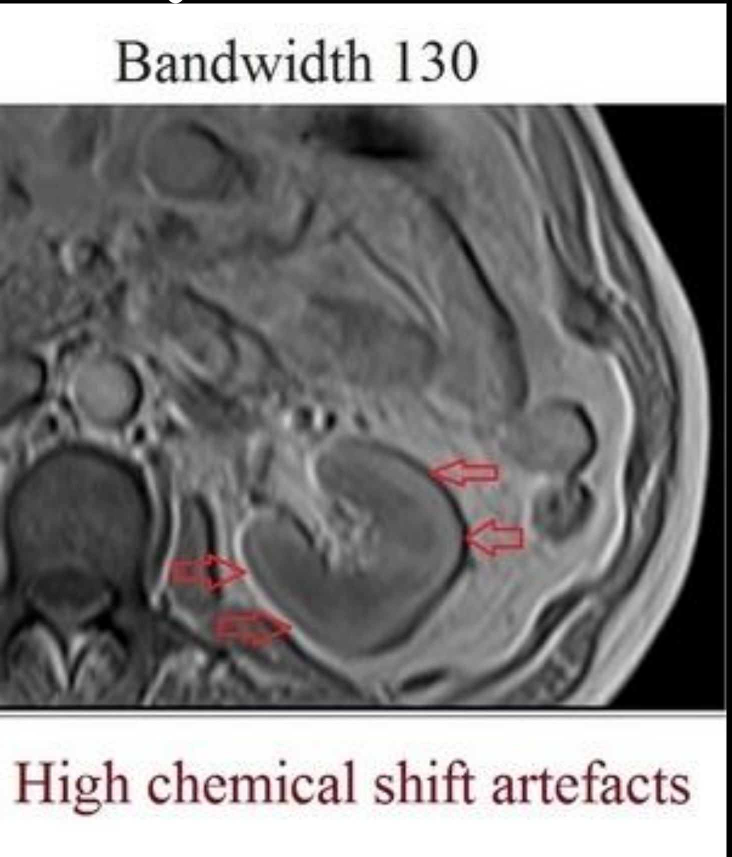
ARTEFACTS

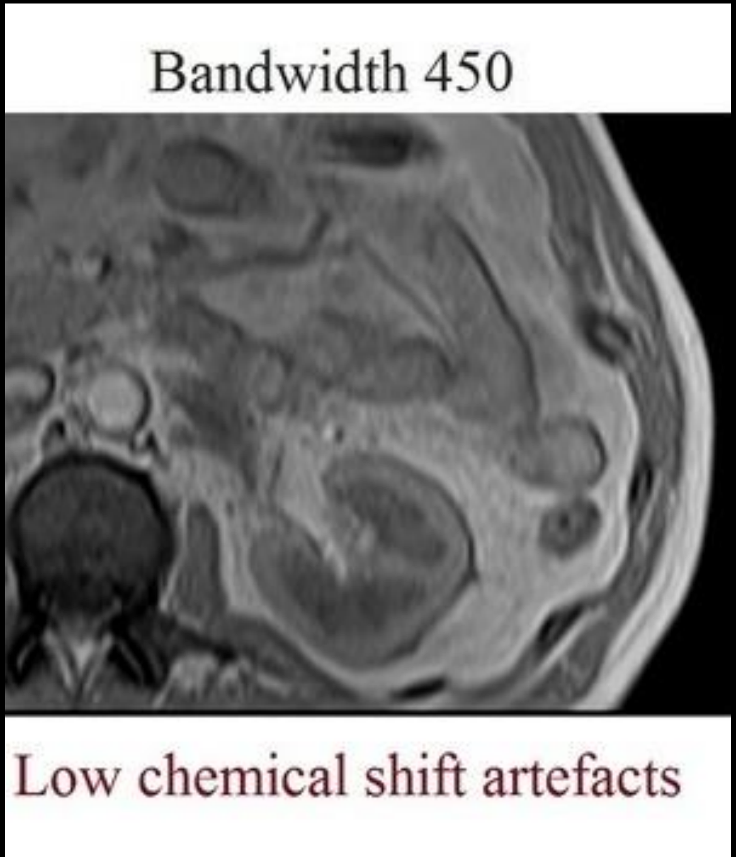
- Chemical shift
-

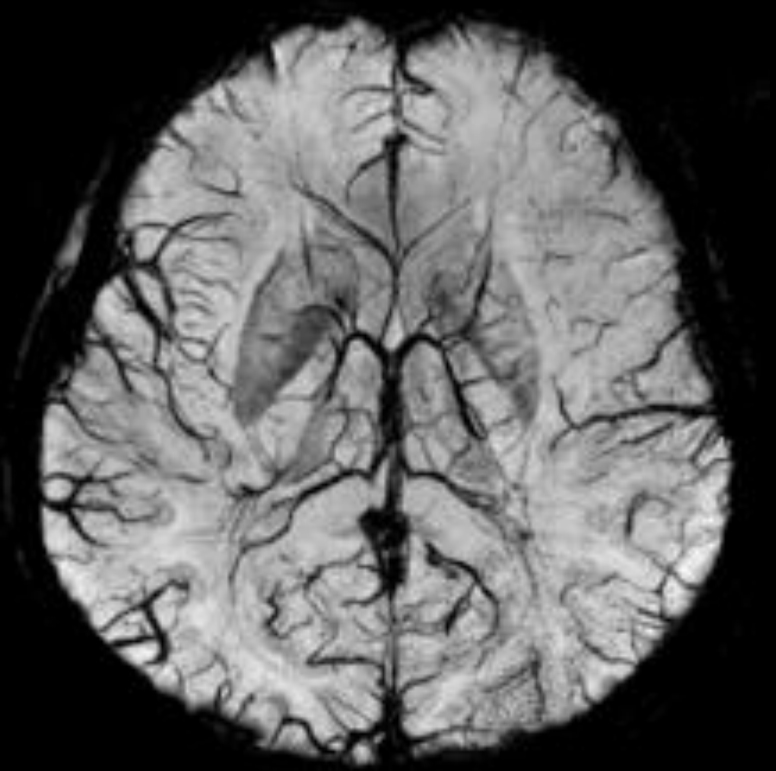


ARTEFACTS

- Chemical shift – increase in BW = decrease in displacement
-

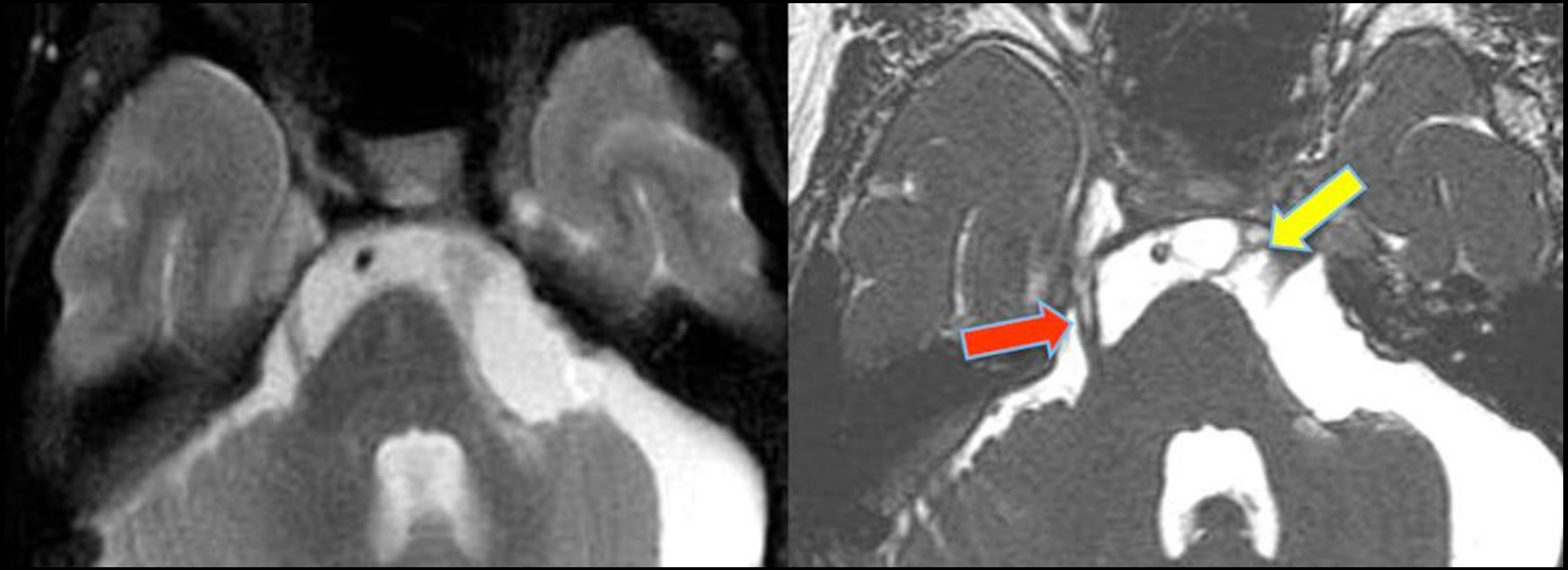






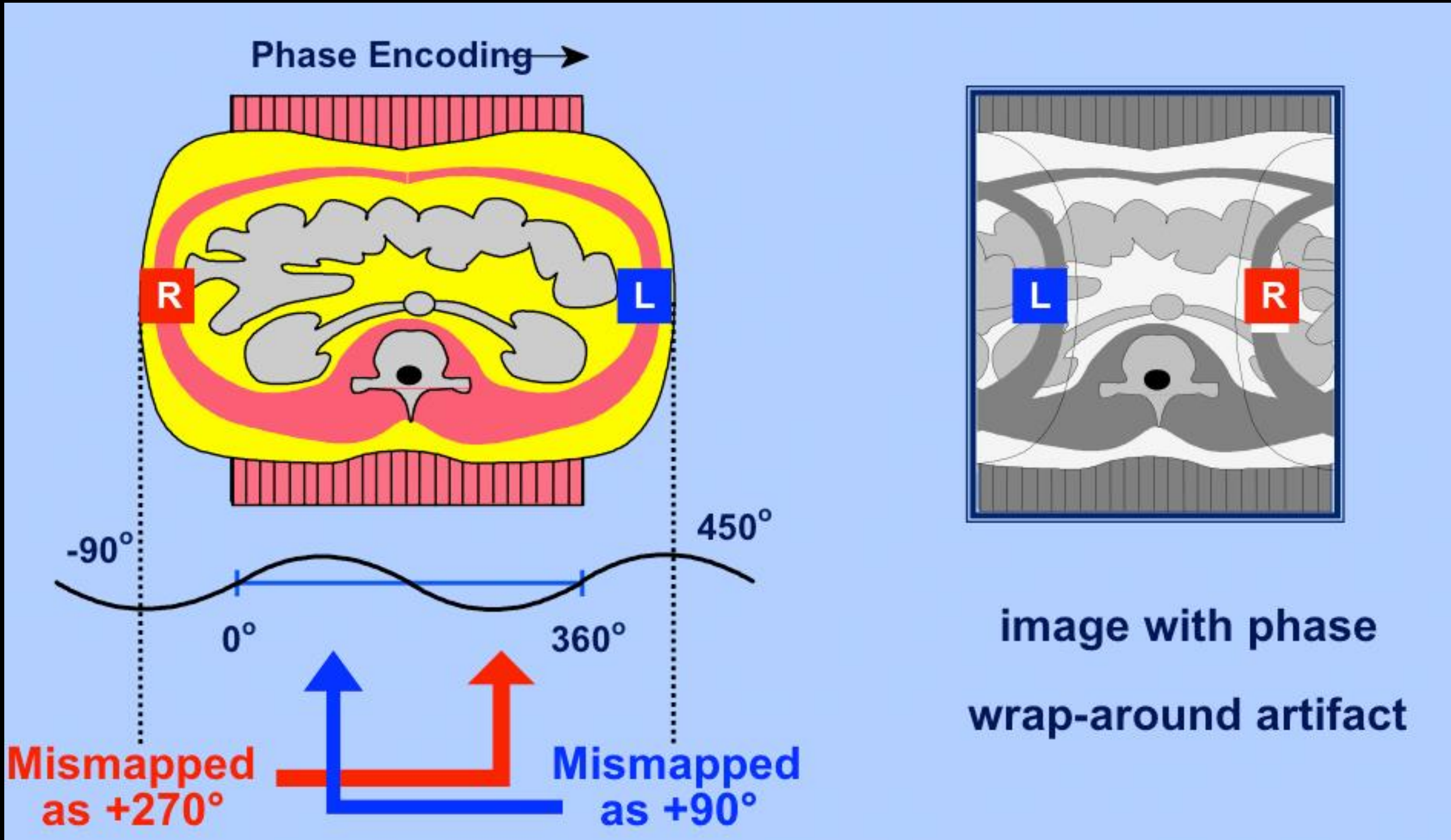
ARTEFACTS

- Partial volume = > reduce voxel
-



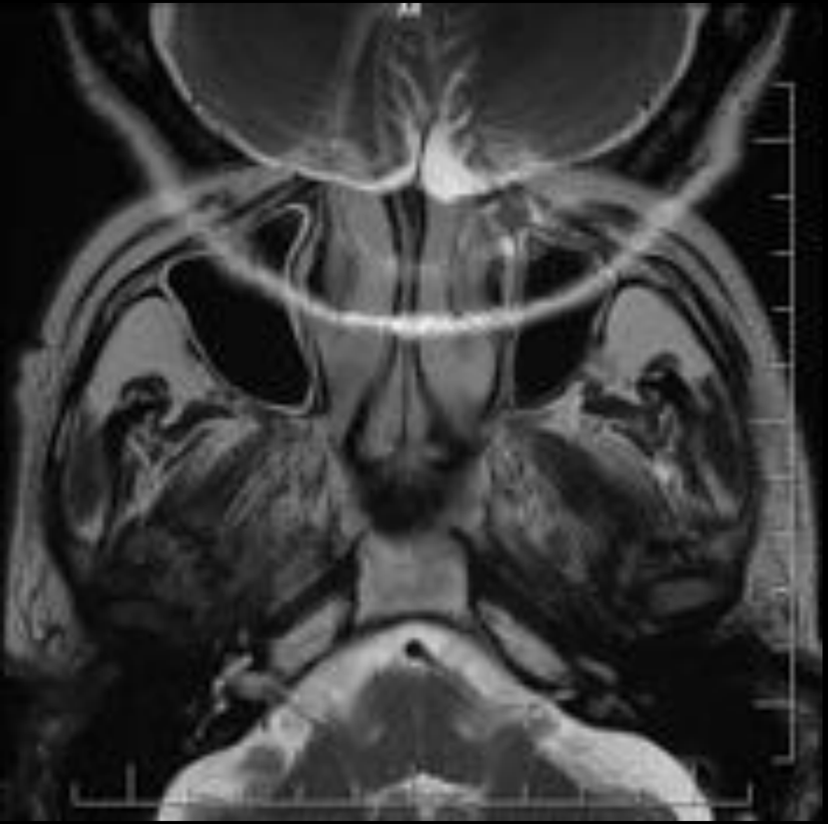
ARTEFACTS

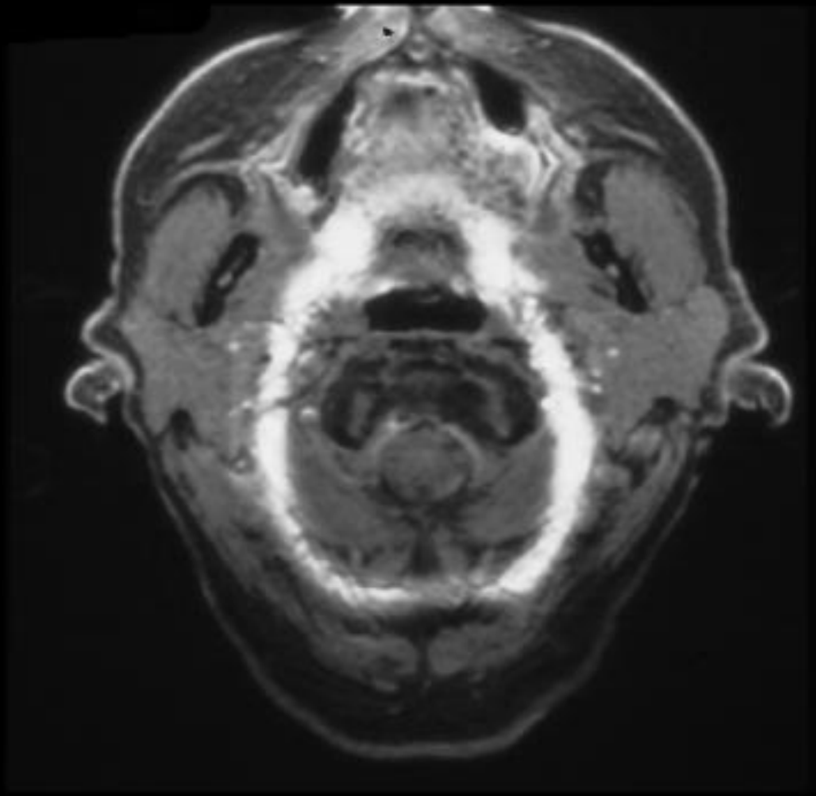
- Flip
- Larger FOV
- Change of FK
- NPW
-



ARTEFACTS

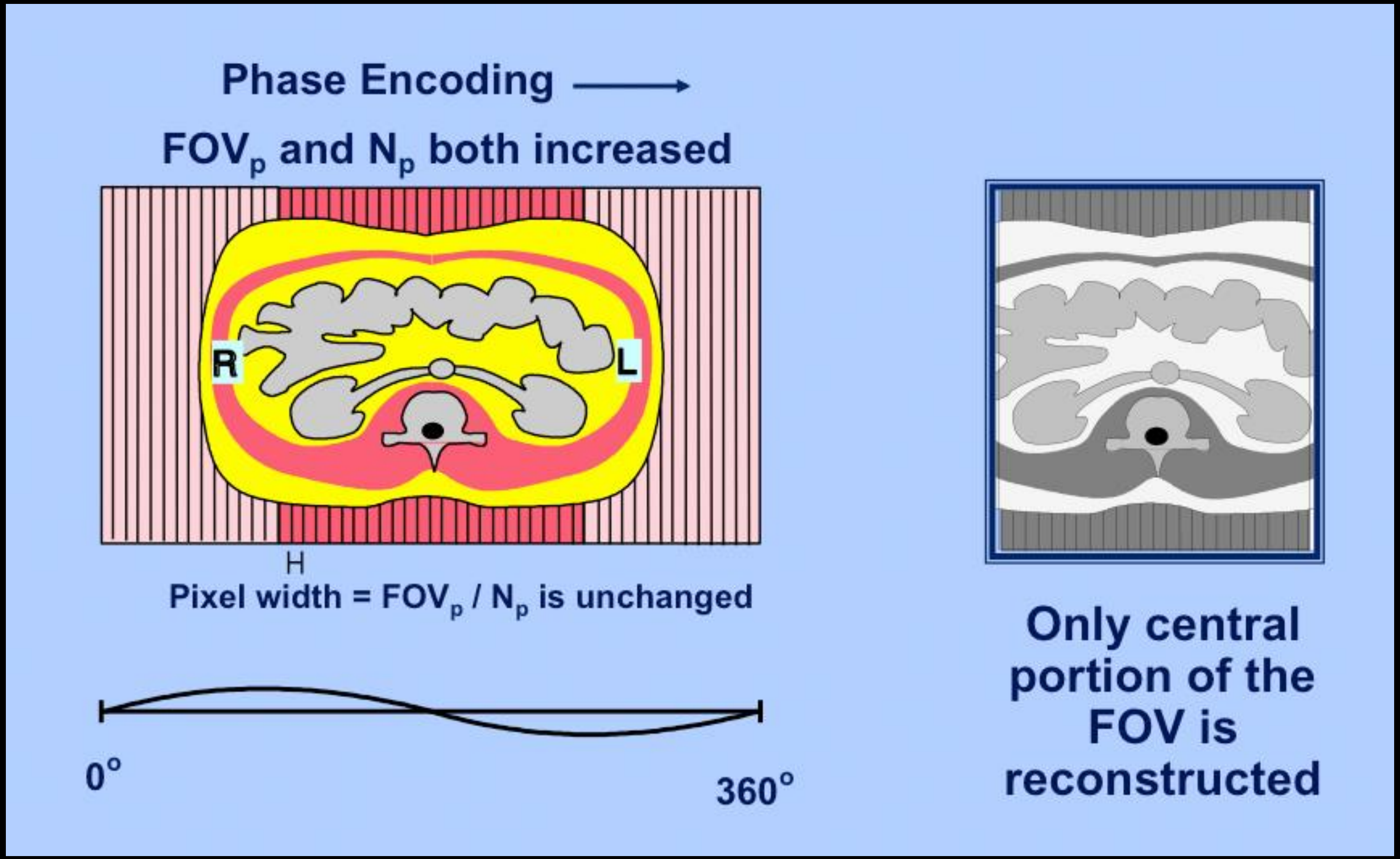
- Flip
-

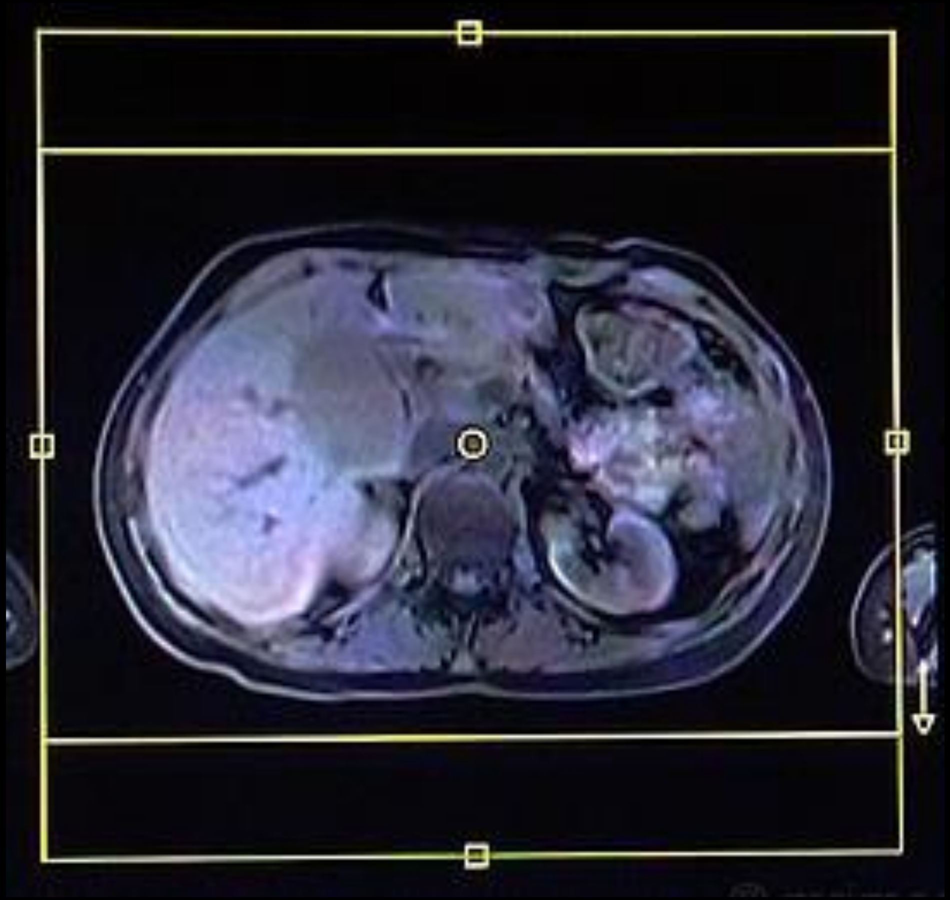




ARTEFACTS

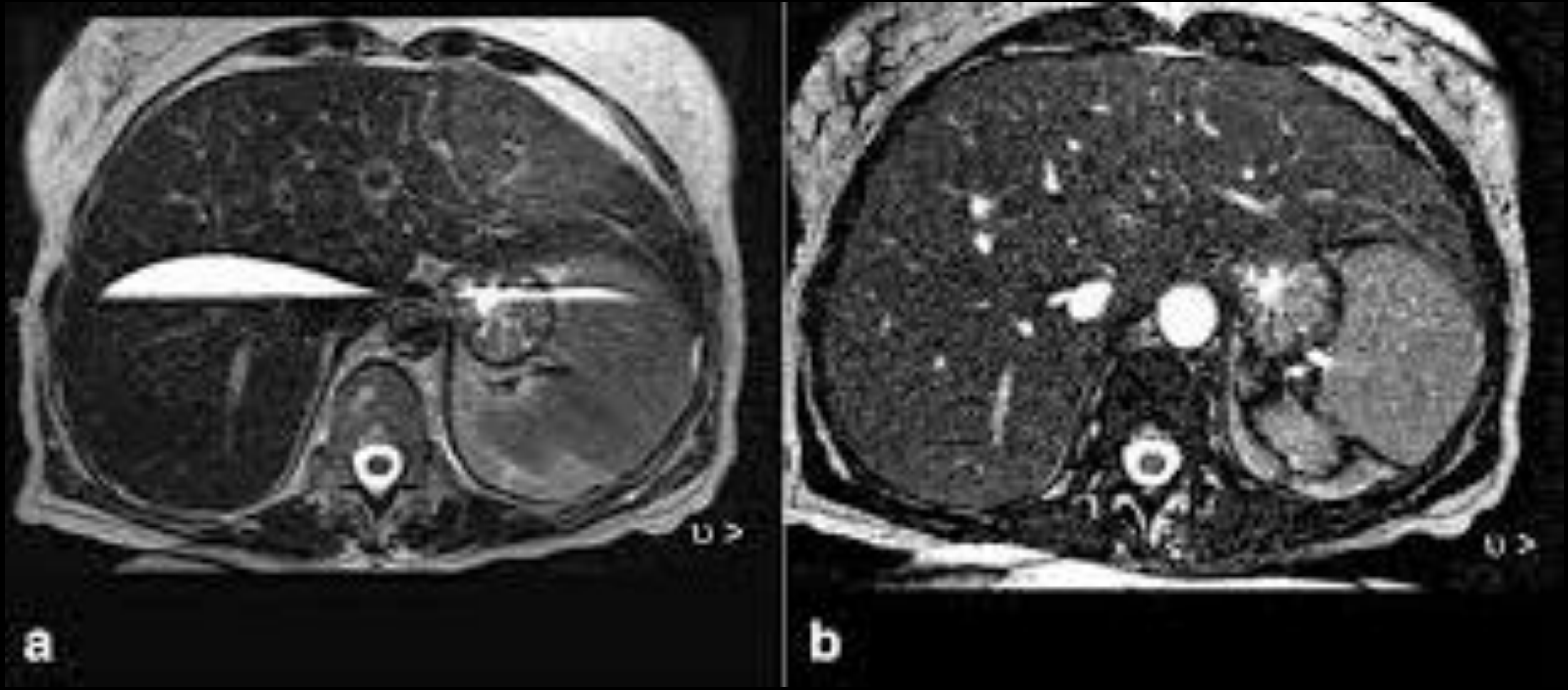
- Flip





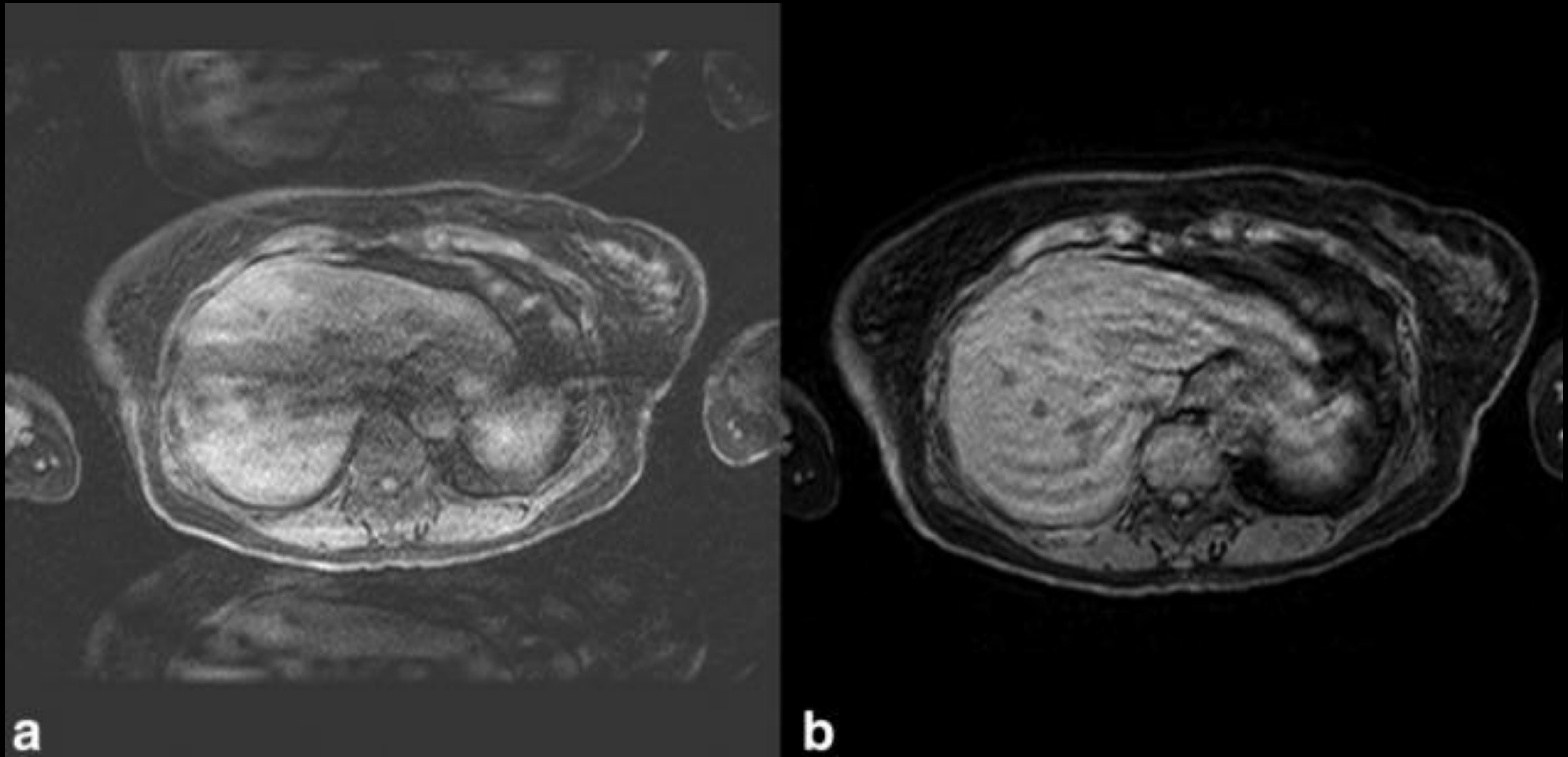
ARTEFACTS

- Flip vs SENSE
-



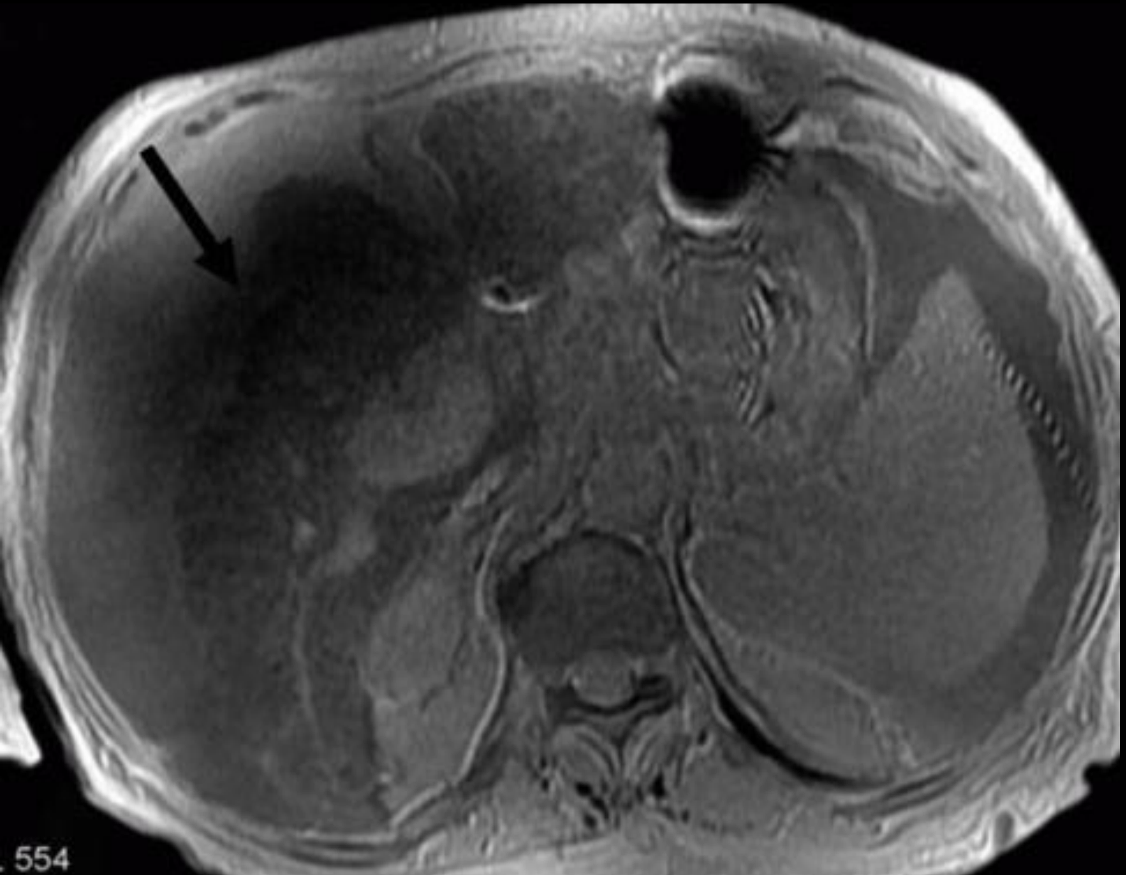
ARTEFACTS

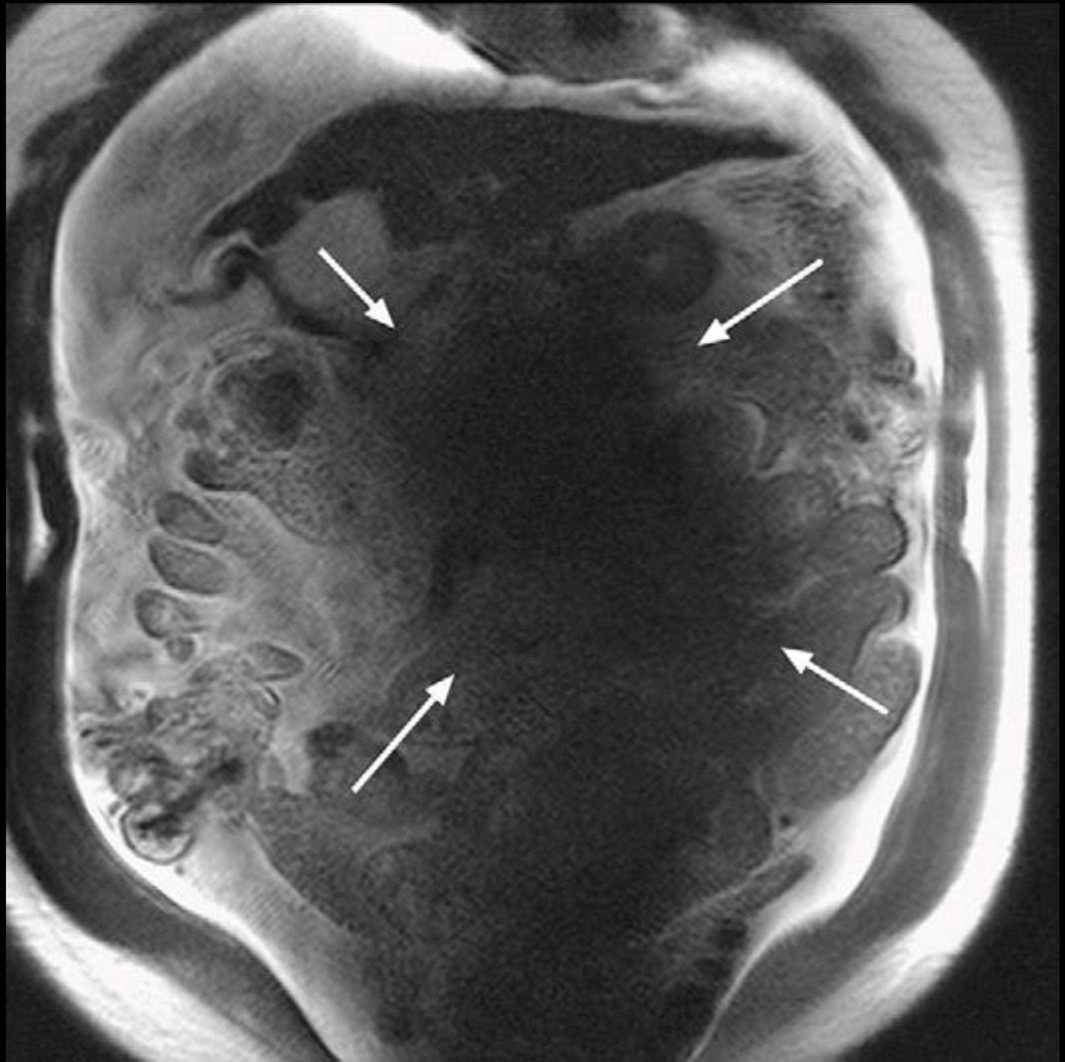
- Poor SENSE calibration
-



ARTEFACTS

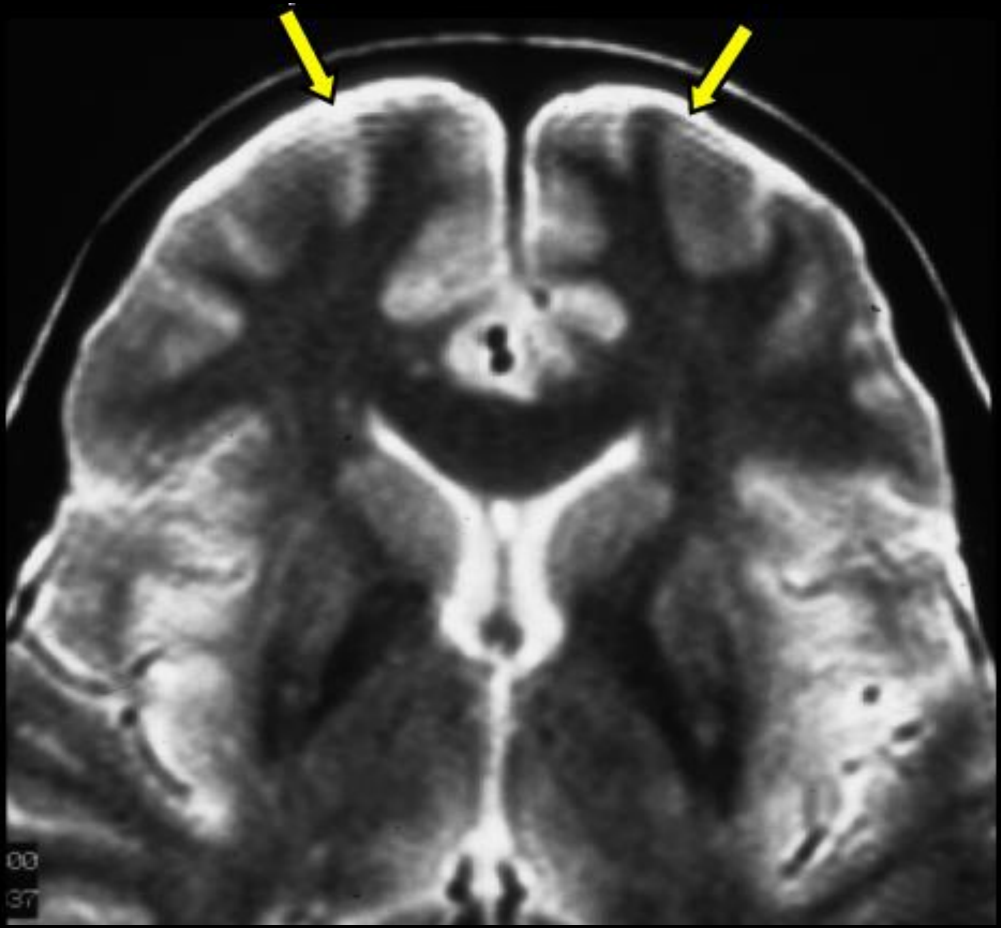
- Dielectric effect

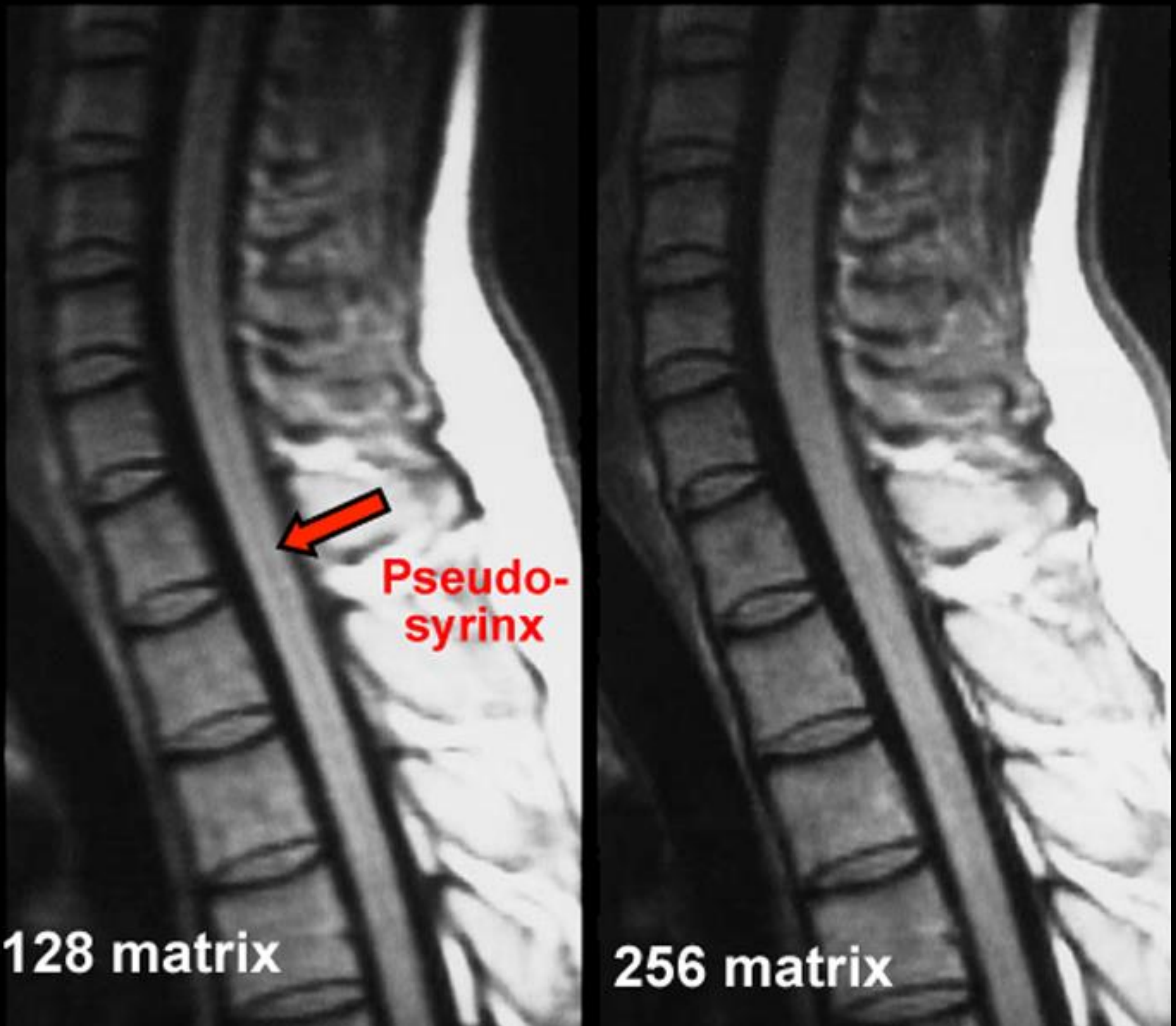




ARTEFACTS

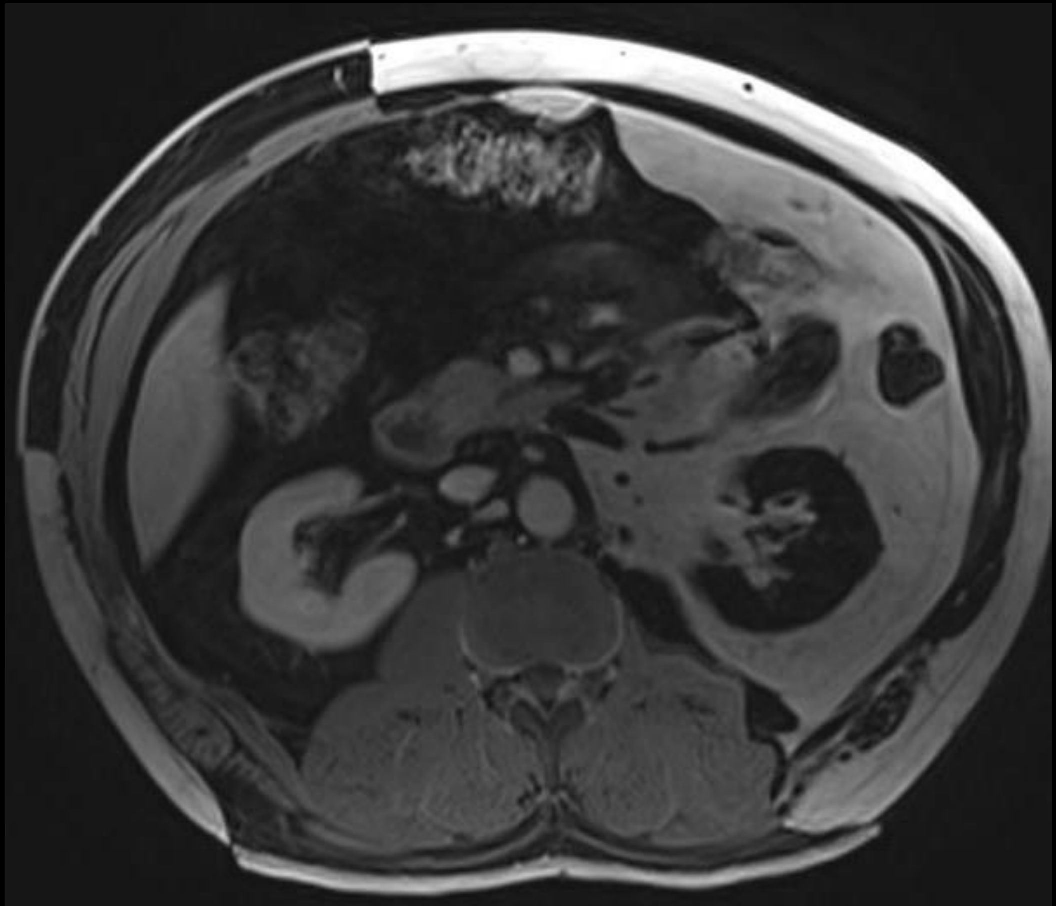
- Gibbs'

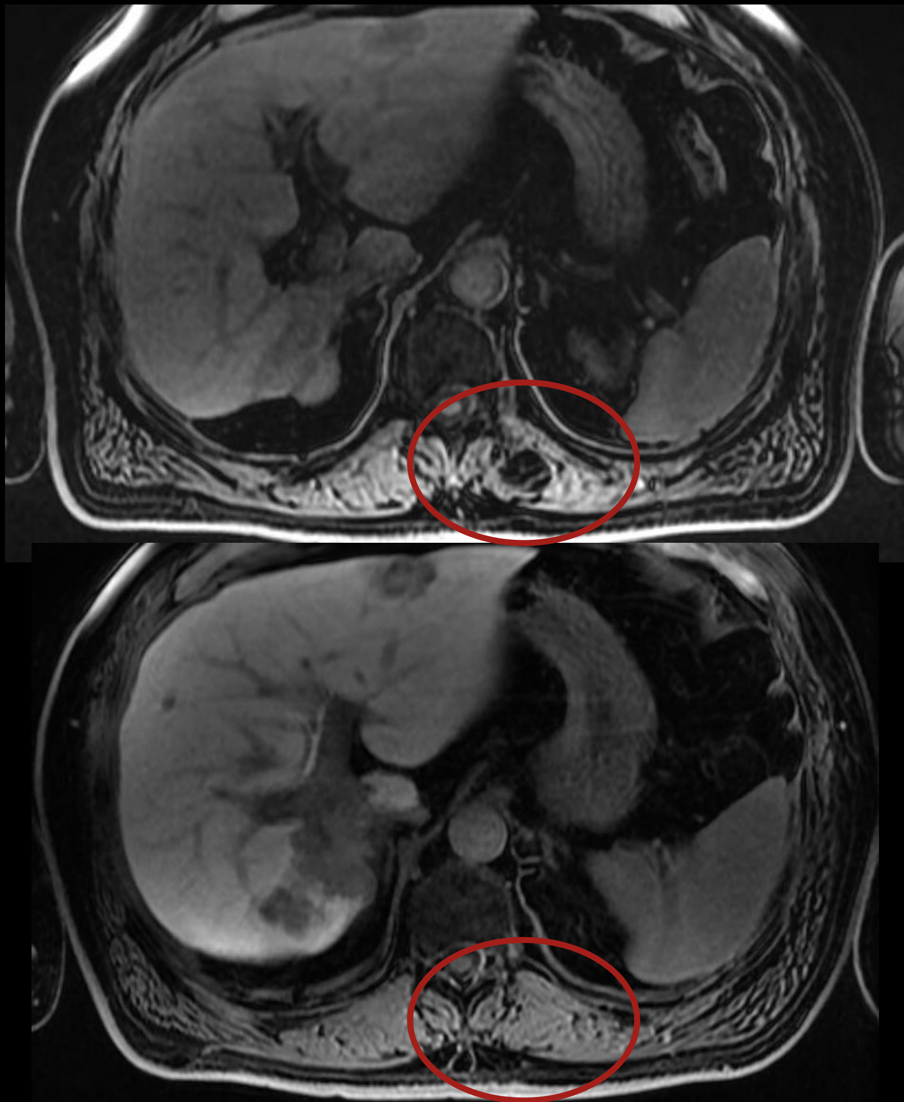




ARTEFACTS

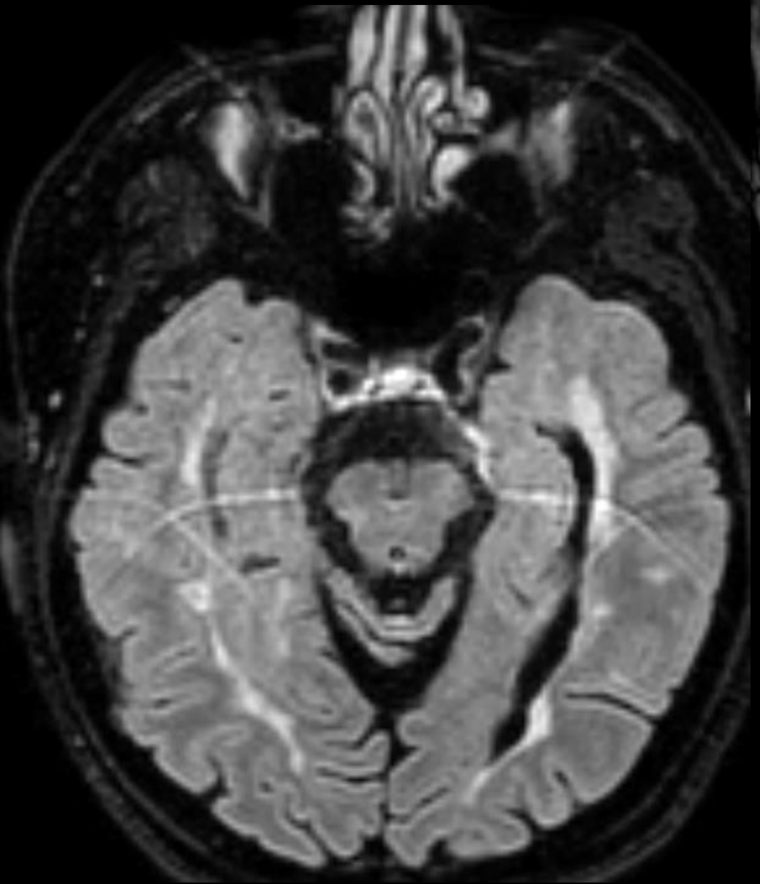
- Dixon

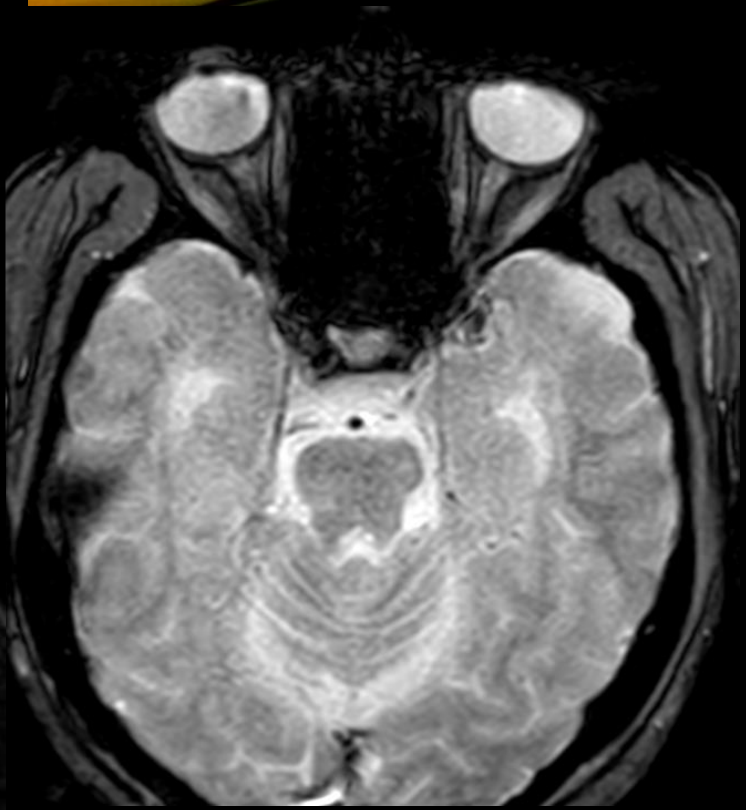




ARTEFACTS

- Human error





CONTRAST AGENTS

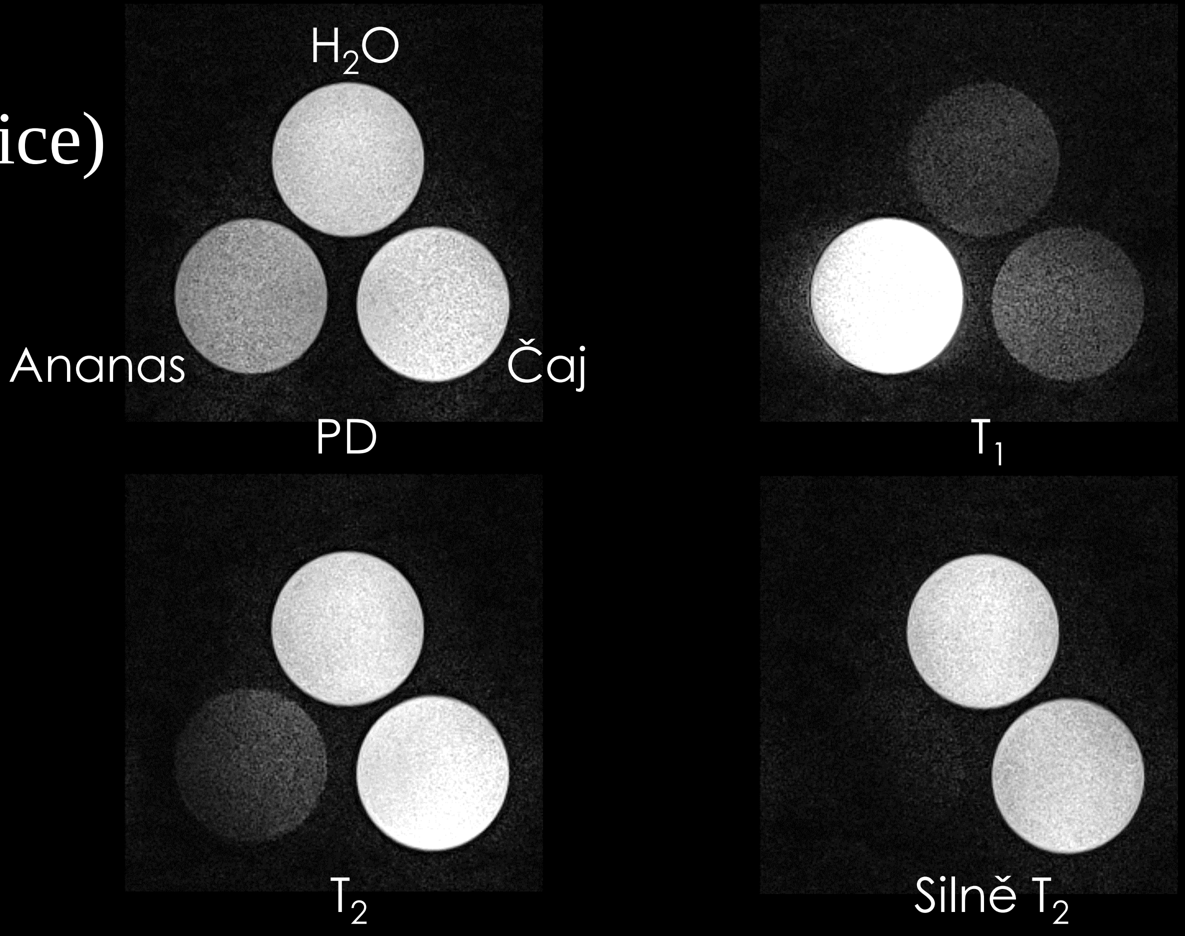
- Positive KL
- Mineral oils
- Sucrose polyesters
- Short T1 times protons =>
- positive signal on T1
-

CONTRAST AGENTS

- Negative KL
- Gases (CO_2, air)
- Kaolin porridge
- Dehydrating agents
- Rectally applied Perflubron
-

CONTRAST AGENTS

- Natural KL
- High content of Mn (pineapple juice)

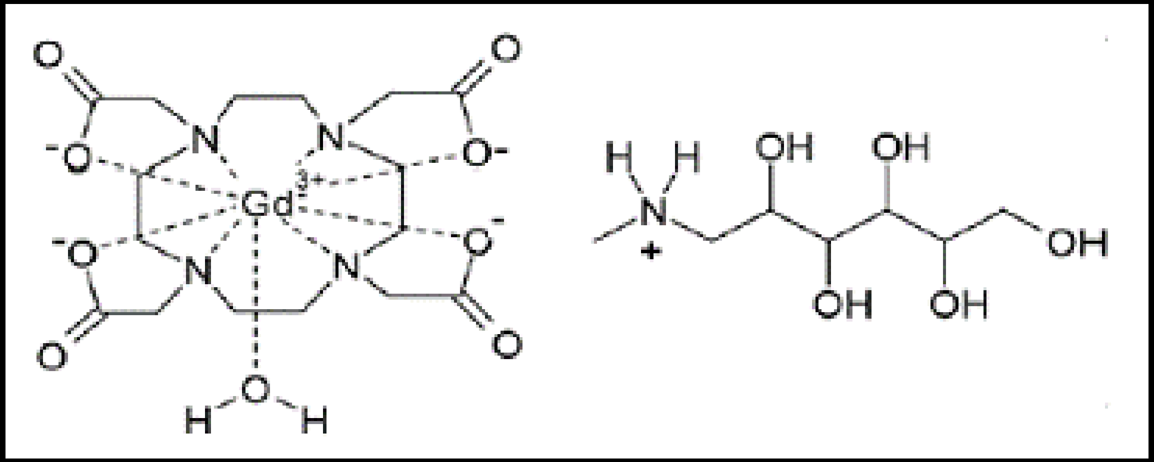


CONTRAST AGENTS

- Paramagnetic KL
- The substance itself is not displayed
- Significantly changes T1 time in its surroundings (Relaxivity)
- Nitrogen dioxide
- Stable free radicals
- Metal cations (Ni^{2+}, Fe^{2+}, Gd^{3+})
- Relaxivity ~ concentration, mag.moment, distance, nepár.e-
-

CONTRAST AGENTS

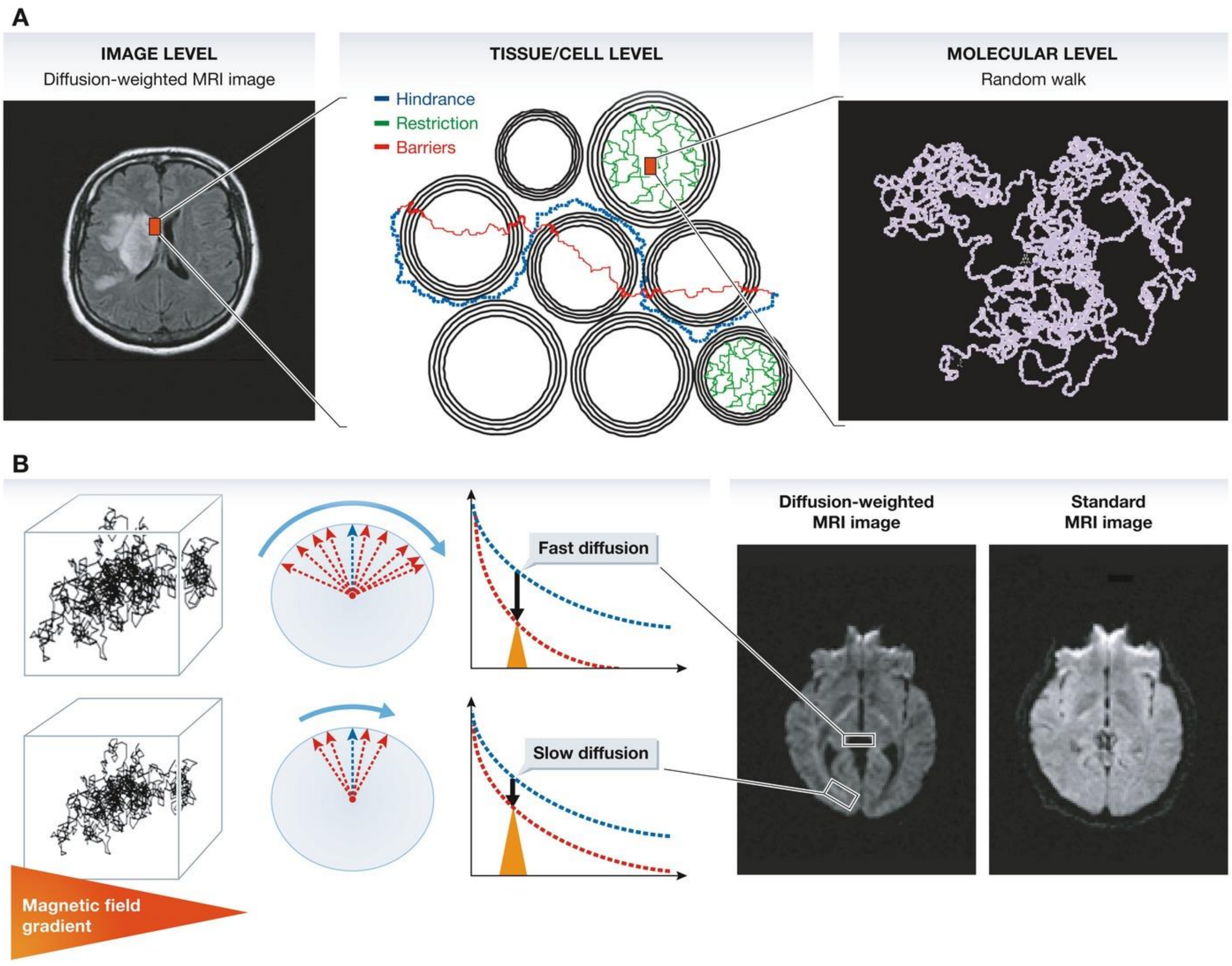
- Paramagnetic KL
- El. Configuration
- Fe2656 [Ar] 4s23d6 – 4 free e-
- Gd64158 [Xe] 6s24f75d1 – 8 free e-
- Need to bind stably to organic substances (toxicity of heavy metals)
- Chelates – coordination links
- E.g. Dotarem
-



CONTRAST AGENTS

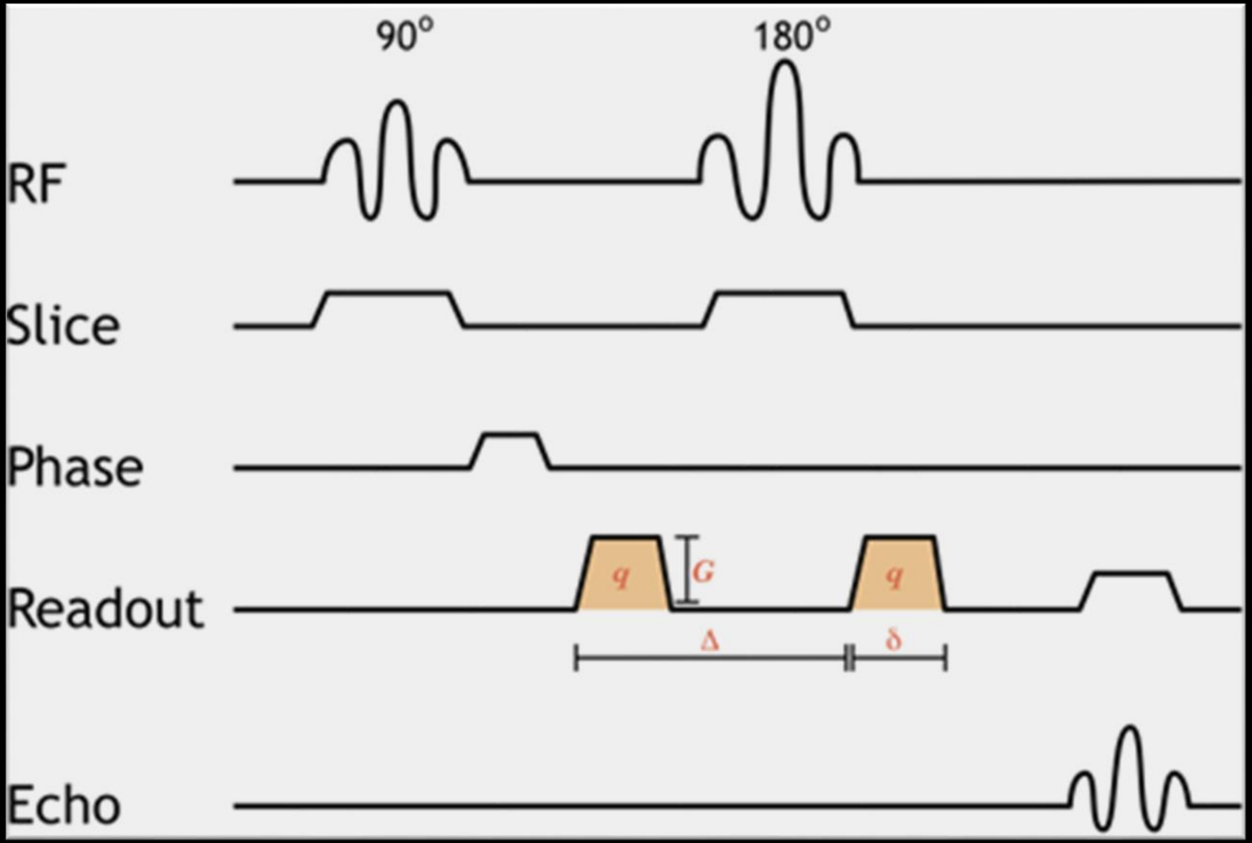
- Contraindication
- Pregnancy
- Breastfeeding
- Kidney disease
- Hypersensitivity to the KL component
- Contraindication
- Significantly less than iodine
- Headache, rashes, difficulty breathing
- Allergic reactions
- Systemic nephrogosis fibrosis
- It is not recommended to use linear non-ionic KL

DIFFUSE DISPLAY

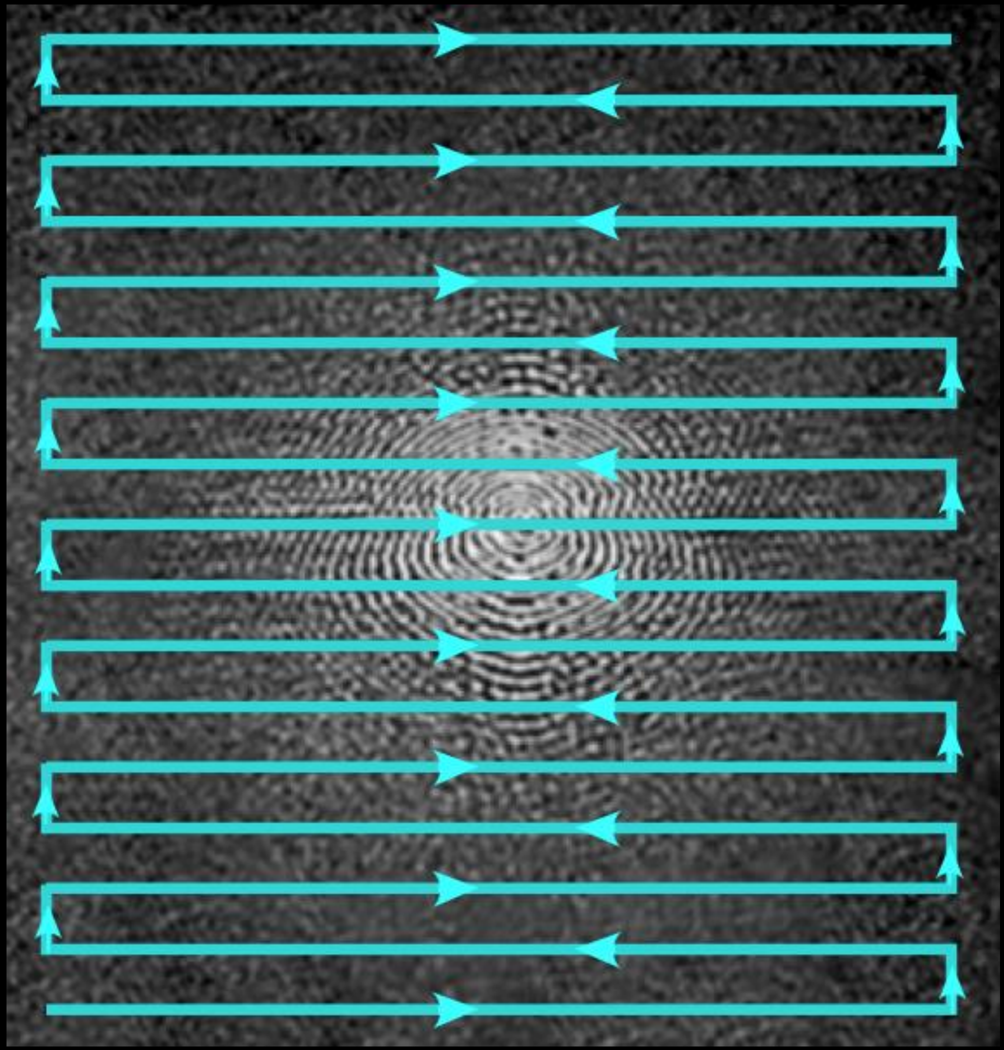


DWI

- Diffuse weighing with additional gradients
- Quality grad. machine equipment
- Max. amplitude (G) 40-80 mT/m
- Rise speed 80-200 T/m/s
- b=γ^2 G^2 δ^2 (Δ−δ/3)
- b = 0 – 1500 s/mm2 clinical
- b = 0 – 4000 s/mm2 scientific
- Quick pickup (~100 ms)
-

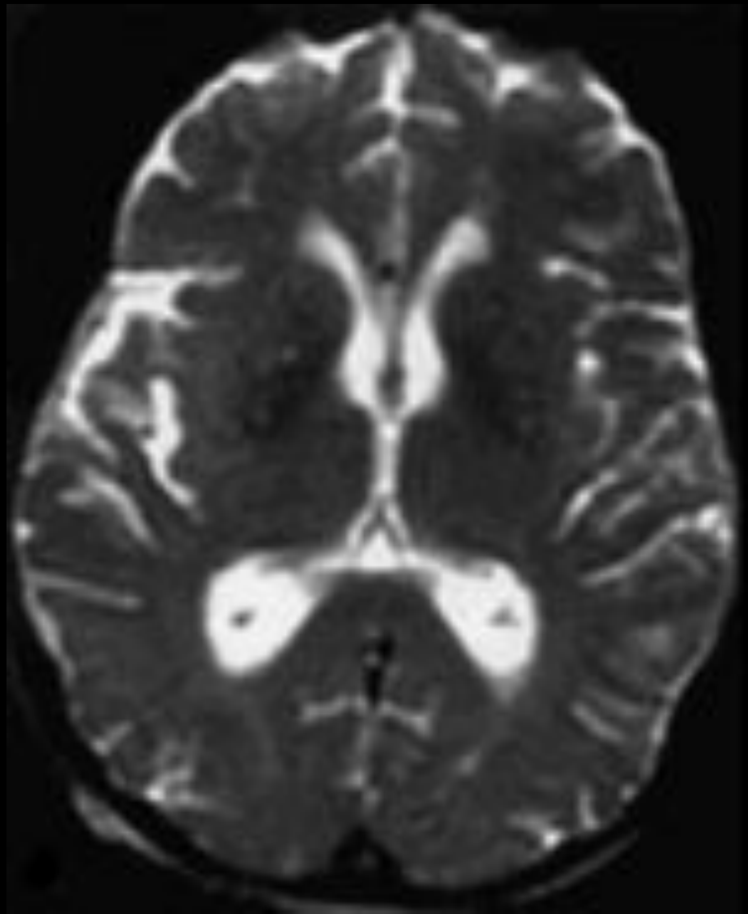


DWI – SS EPI

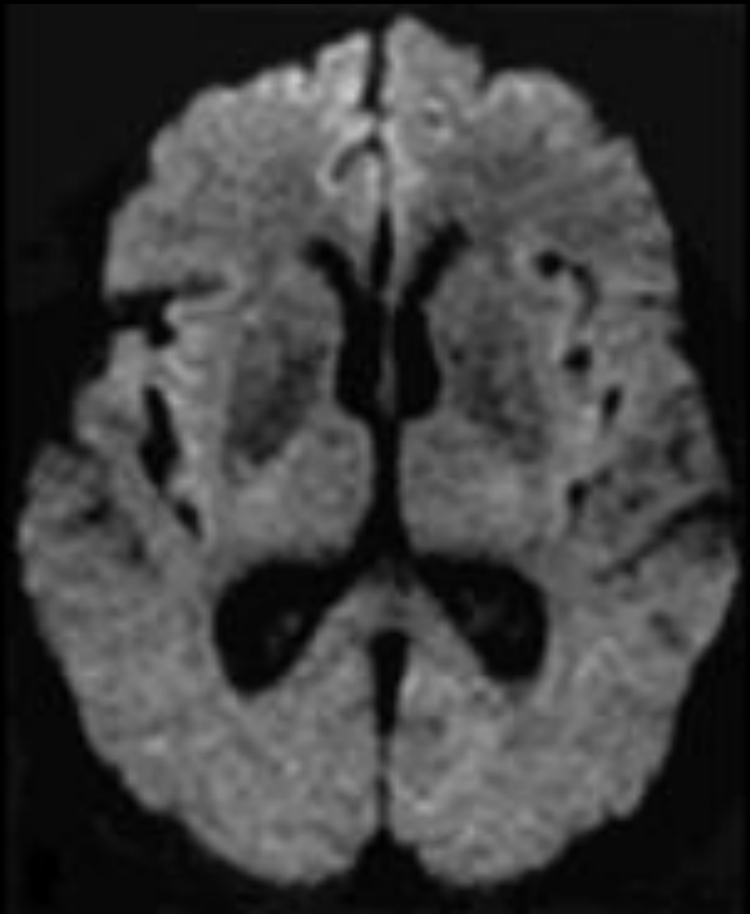


DWI – ADC

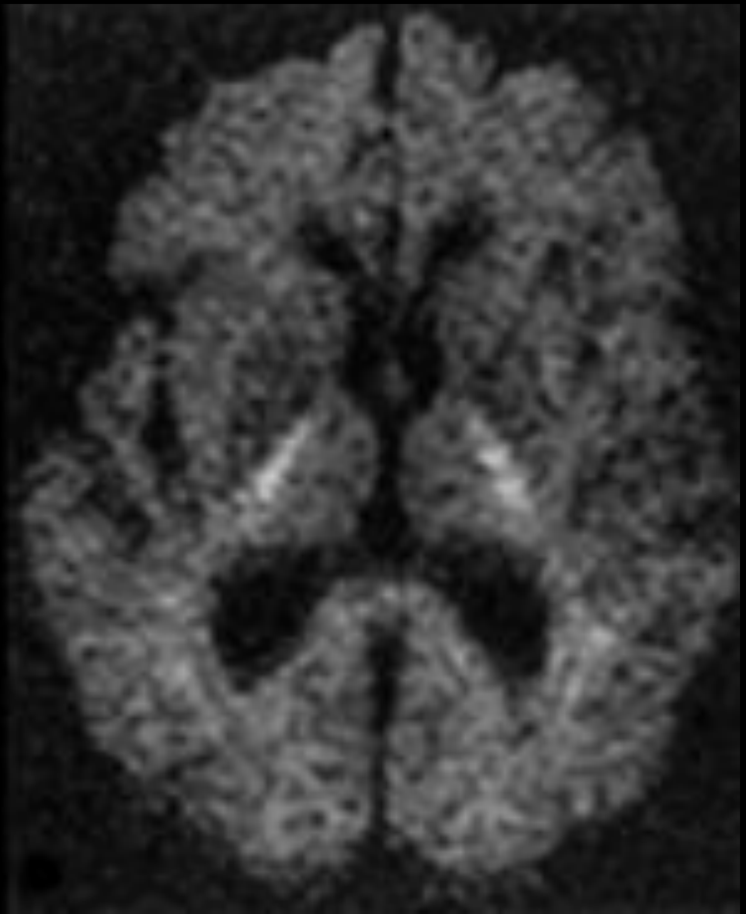
b = 0



b = 1000 s/mm²

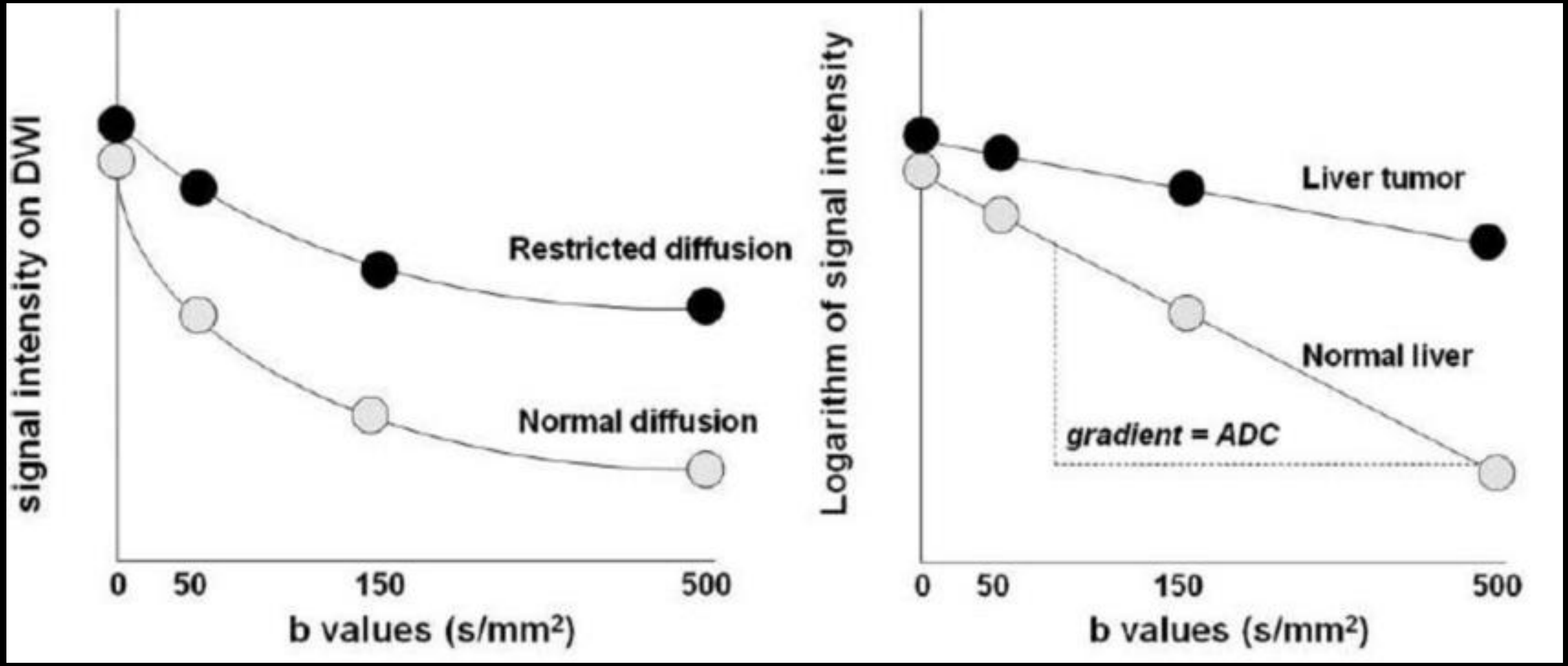


b = 3000 s/mm²



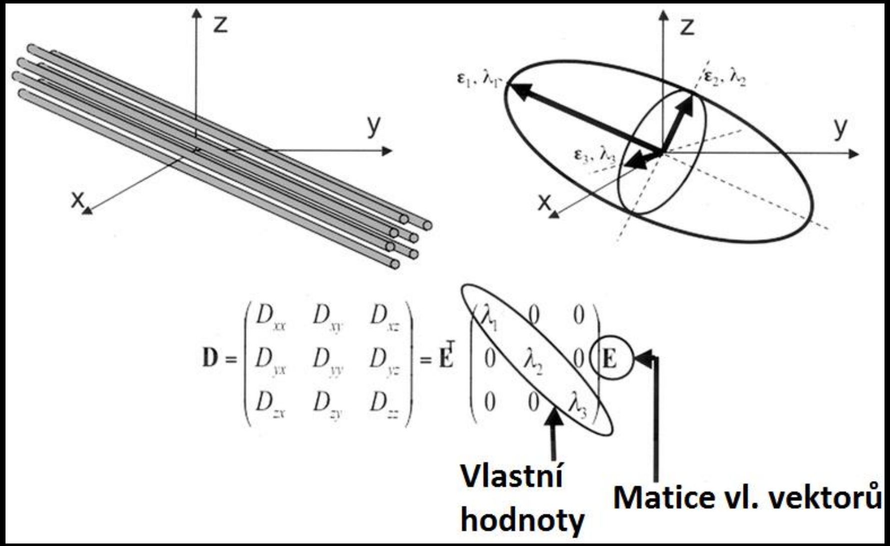
DWI - ADC

- $S = S_0 e^{-b\,ADC} \Rightarrow -\frac{1}{\mathrm{b}} \ln\left(\frac{S}{S_0}\right) = ADC$
- Brain
  - S_0 => b = 0
  - S => b = 1000
- Body:
  - S_0 => b = 50
  - S => b = 800
- Prostate:
  - S_0 => b = 0
  - S => b > 1500

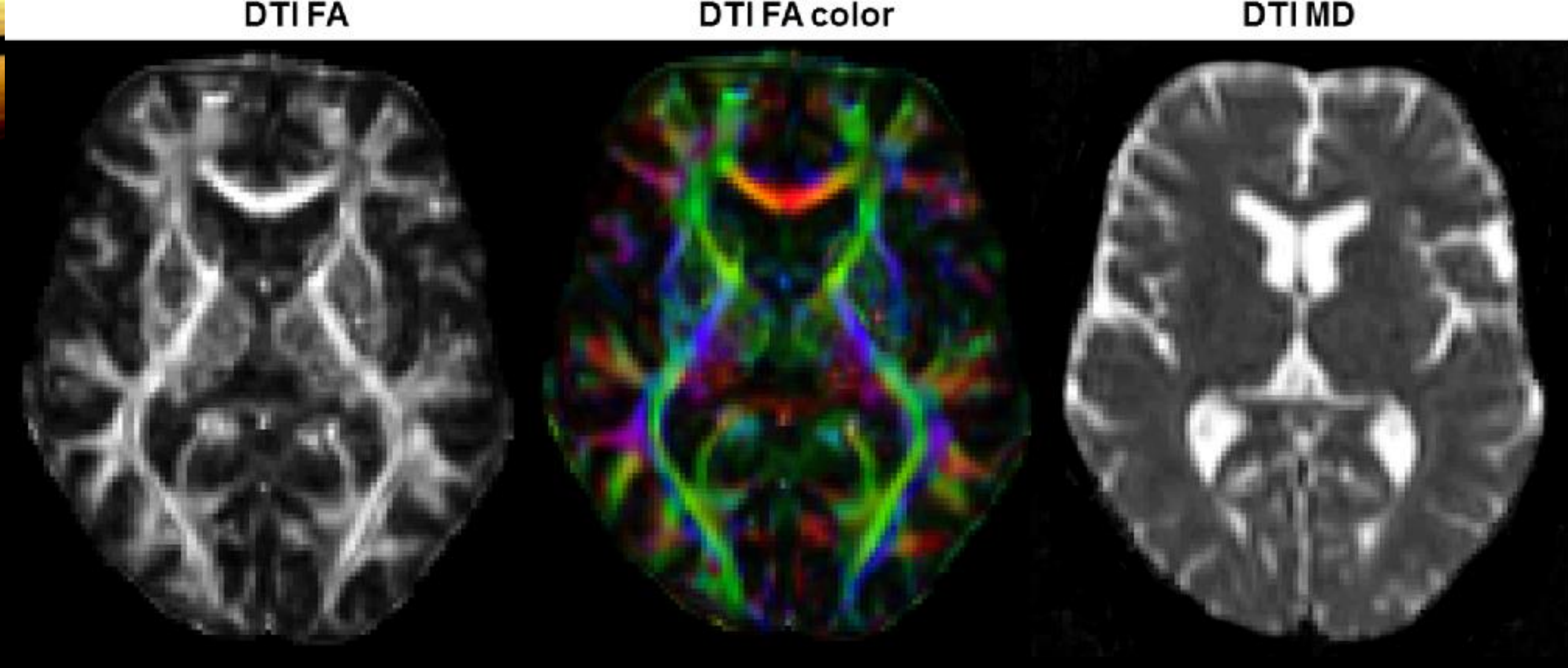


DTI

- Diffusion can be oriented in the same way as diffusion gradients
- Min 6 directions grad.
- Tensor calculation
- Ellipsoid characterization
- For a more accurate estimate of > 16 directions
-



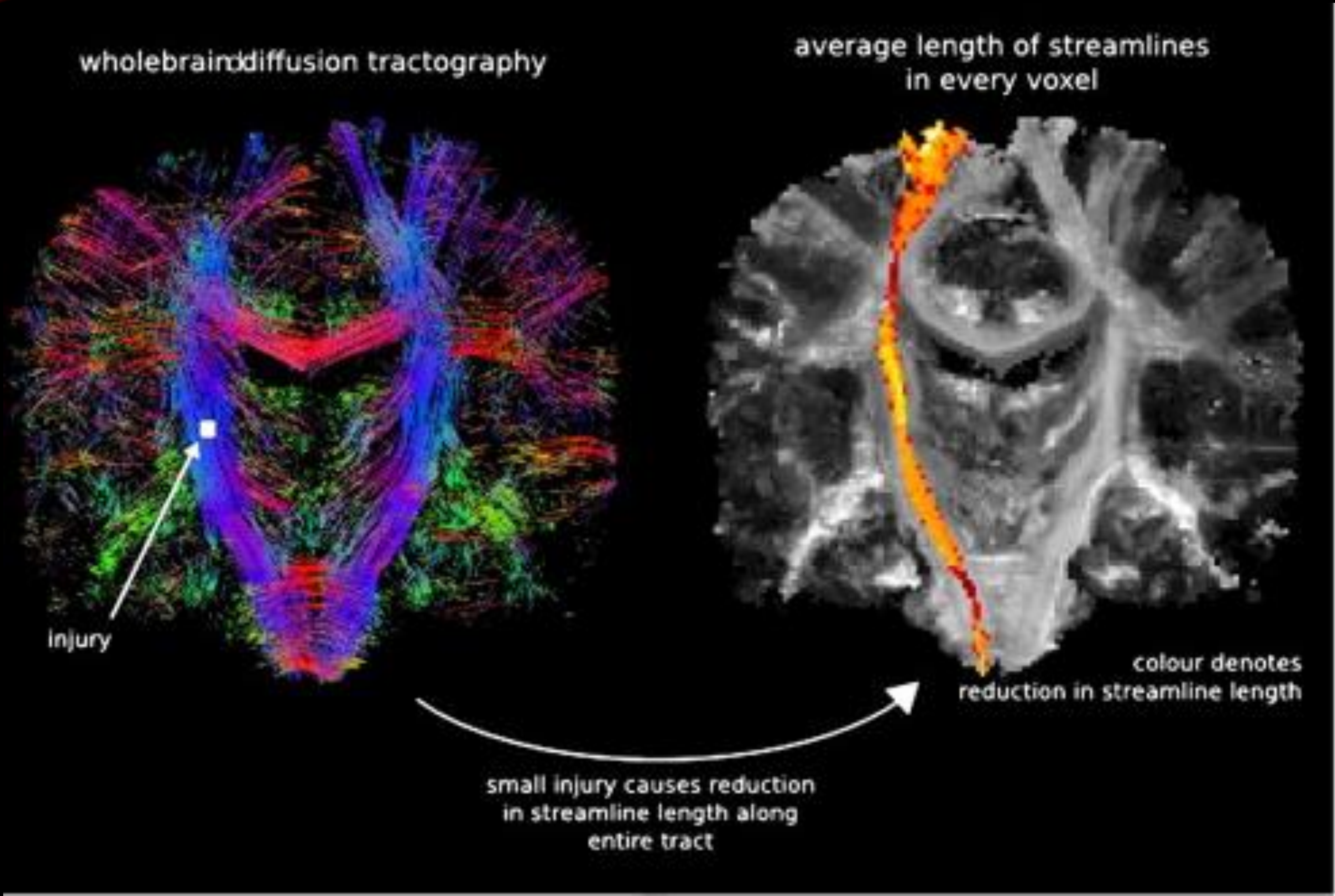
- Scalar parameters
-



	Unit of measure	Formula	Object measured
FA	Scalar value ranging between 0-1	$\sqrt{\frac{1}{2}}\frac{\sqrt{(\lambda_1-\lambda_2)^2+(\lambda_2-\lambda_3)^2+(\lambda_3-\lambda_1)^2}}{\sqrt{\lambda_1^2+\lambda_2^2+\lambda_3^2}}$	Fibers directionality/axonal loss
MD	mm^2/sec	$(\lambda_1+\lambda_2+\lambda_3)/3$	Amount of water diffusion/myelin loss
AD	mm^2/sec	λ_1	Diffusivity parallel to the fibers/myelin and axonal content
RD	mm^2/sec	$(\lambda_2+\lambda_3)/2$	Diffusivity perpendicular to the fibers/myelin content

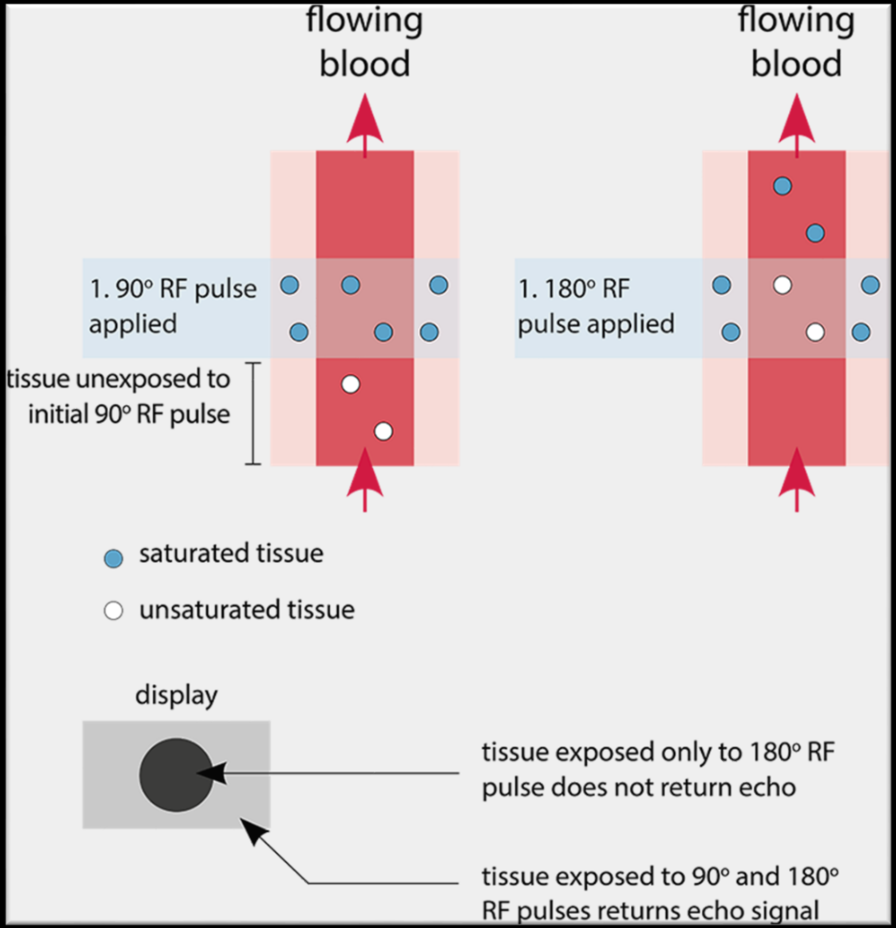
FA: fractional anisotropy; MD: mean diffusivity; AD: axial diffusivity; RD: radial diffusivity; mm: millimeters; sec: second.

- Tractography
-



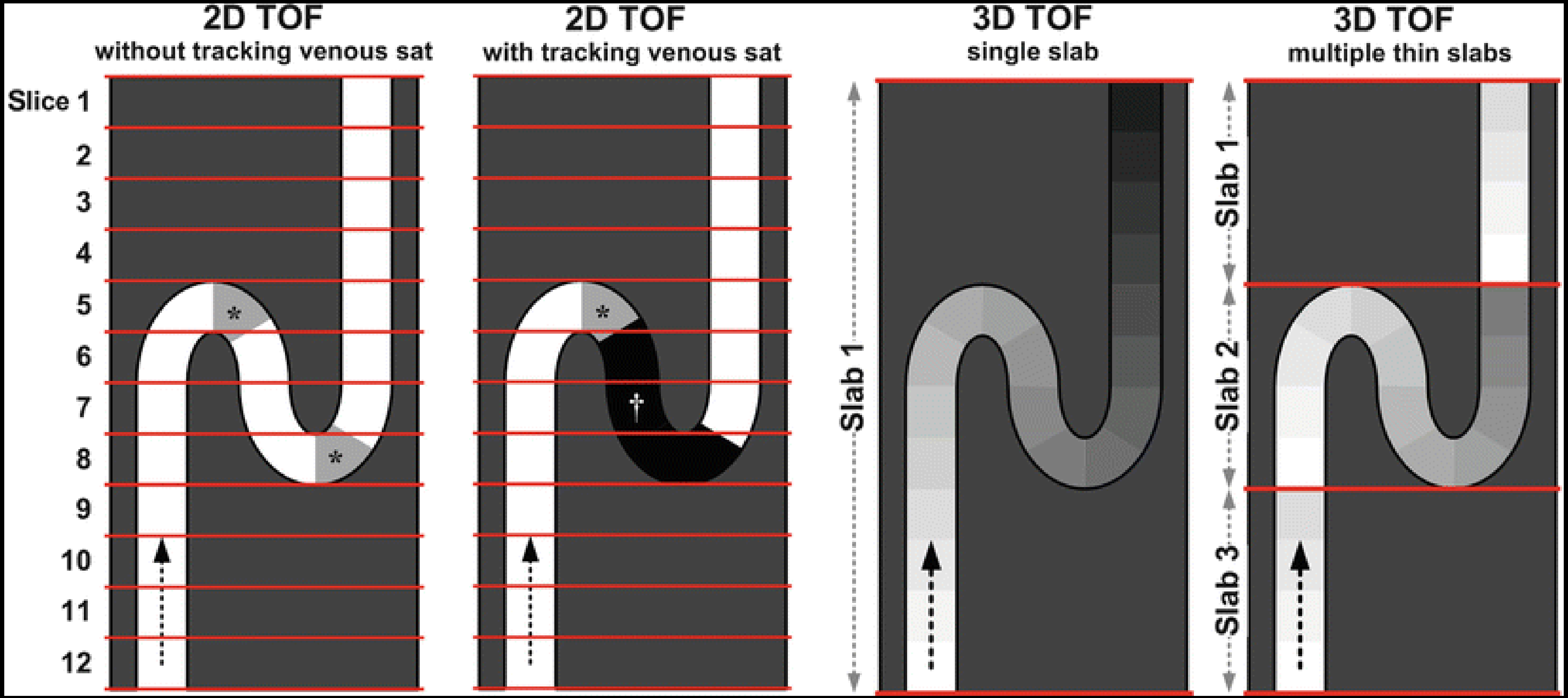
MRA

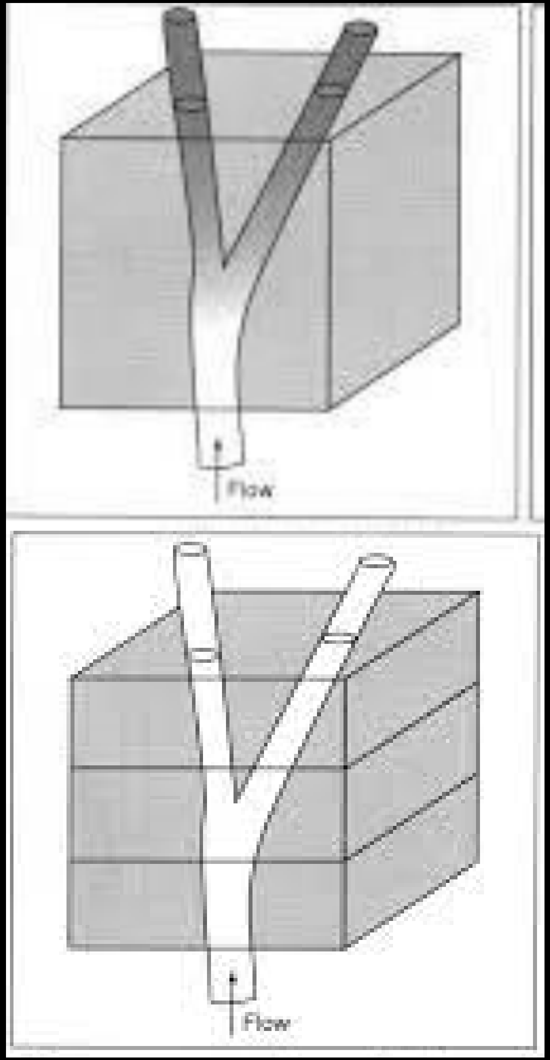
- Time of flight (TOF)
- Principle:
- 90° and 180° RF applications
- Blood from another layer only 180° RF
- Static tissue suppression
- The size of the signal is growing:
- With speed
- With TR, T1 and α
- The size of the signal decreases:
- Layer thickness
- With layer orientation



MRA - TOF

- Influence of flow direction
-

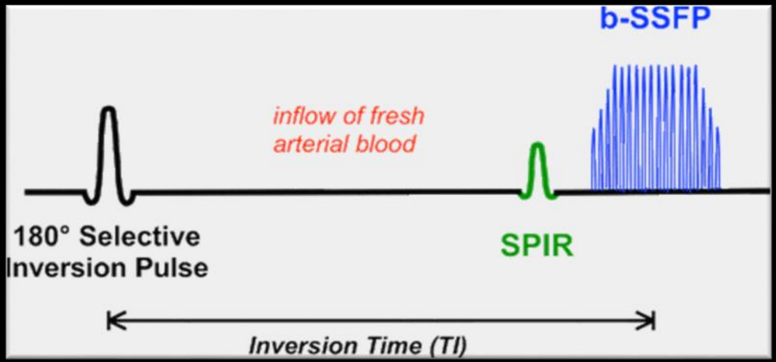


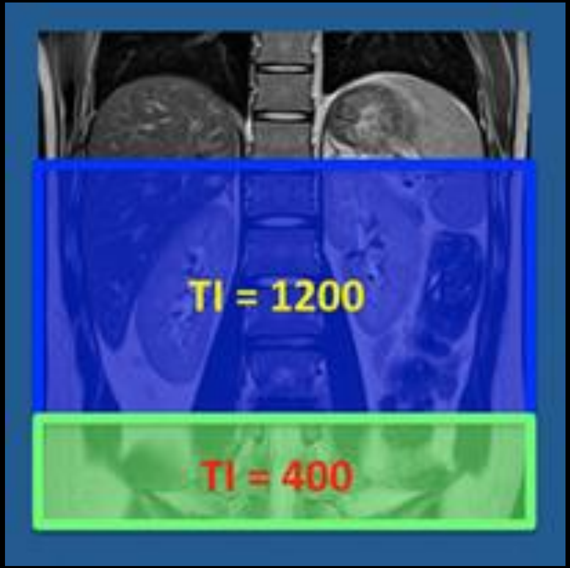


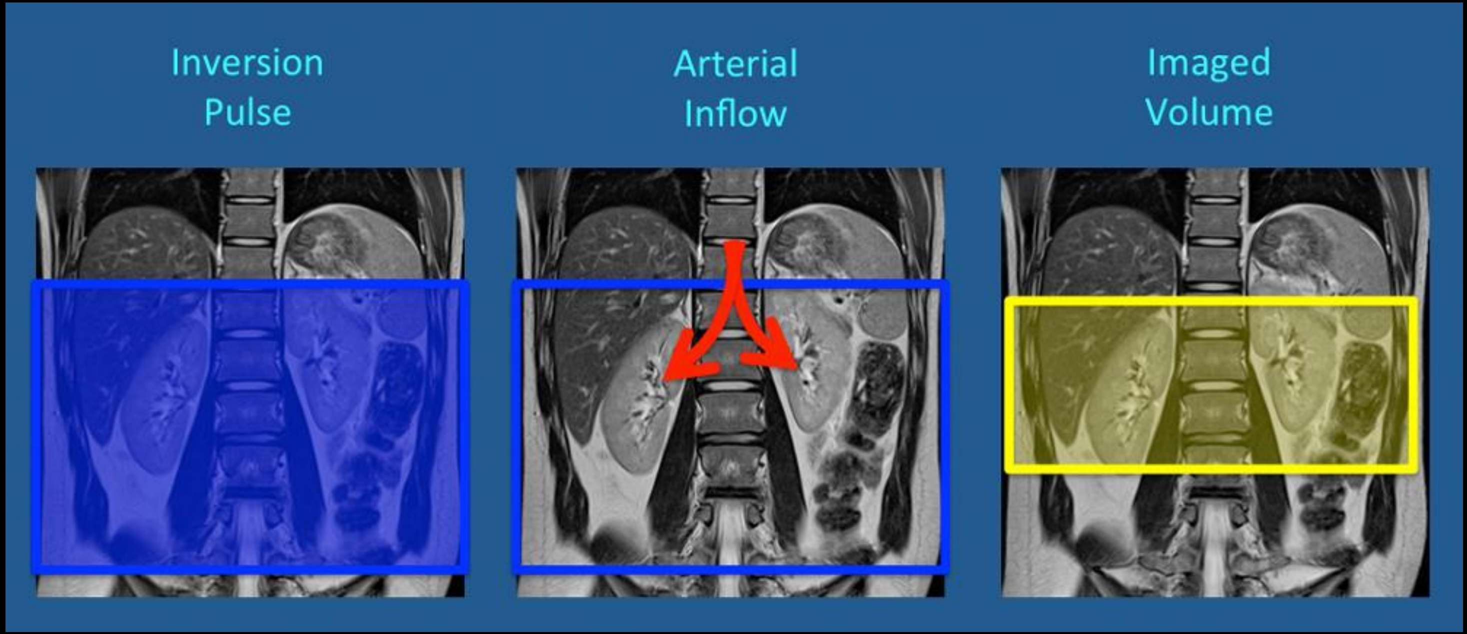
MRA - TOF

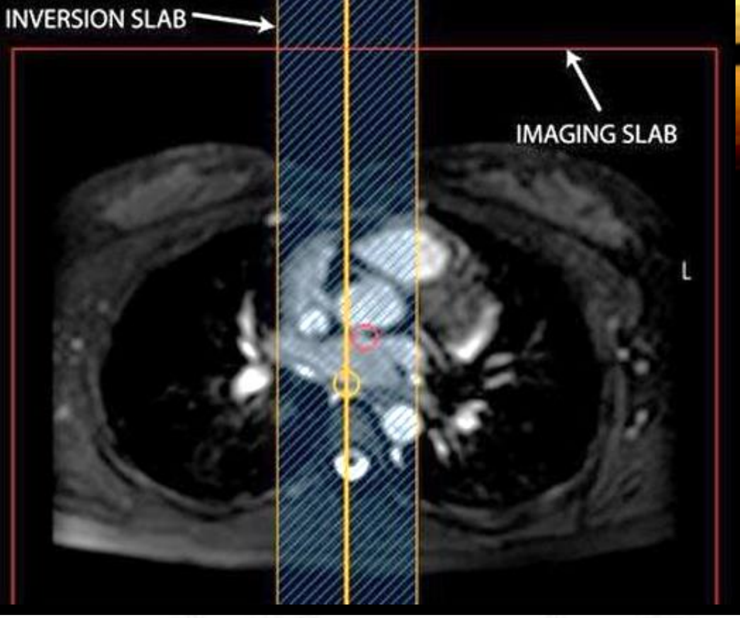
- TE = min
- TR 20 – 50 ms
- α 10° - 40°

MRA – BFFE/FIESTA

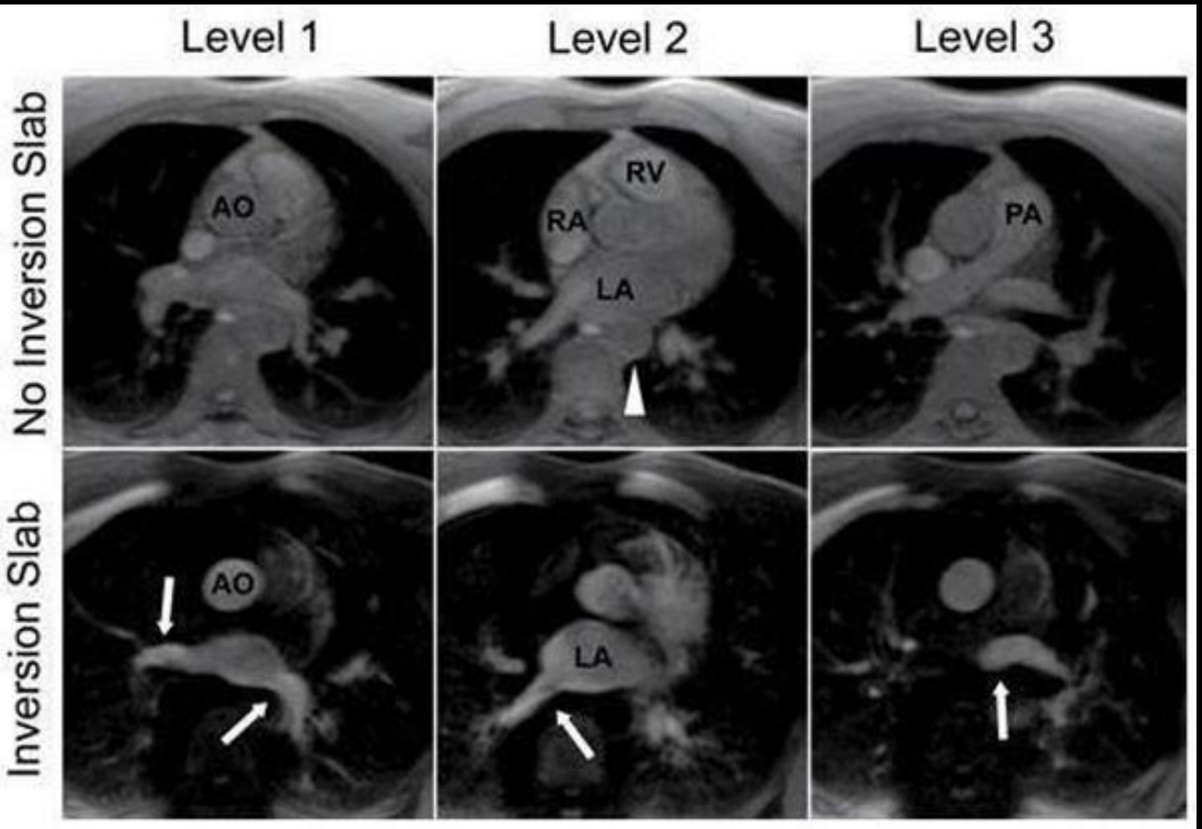


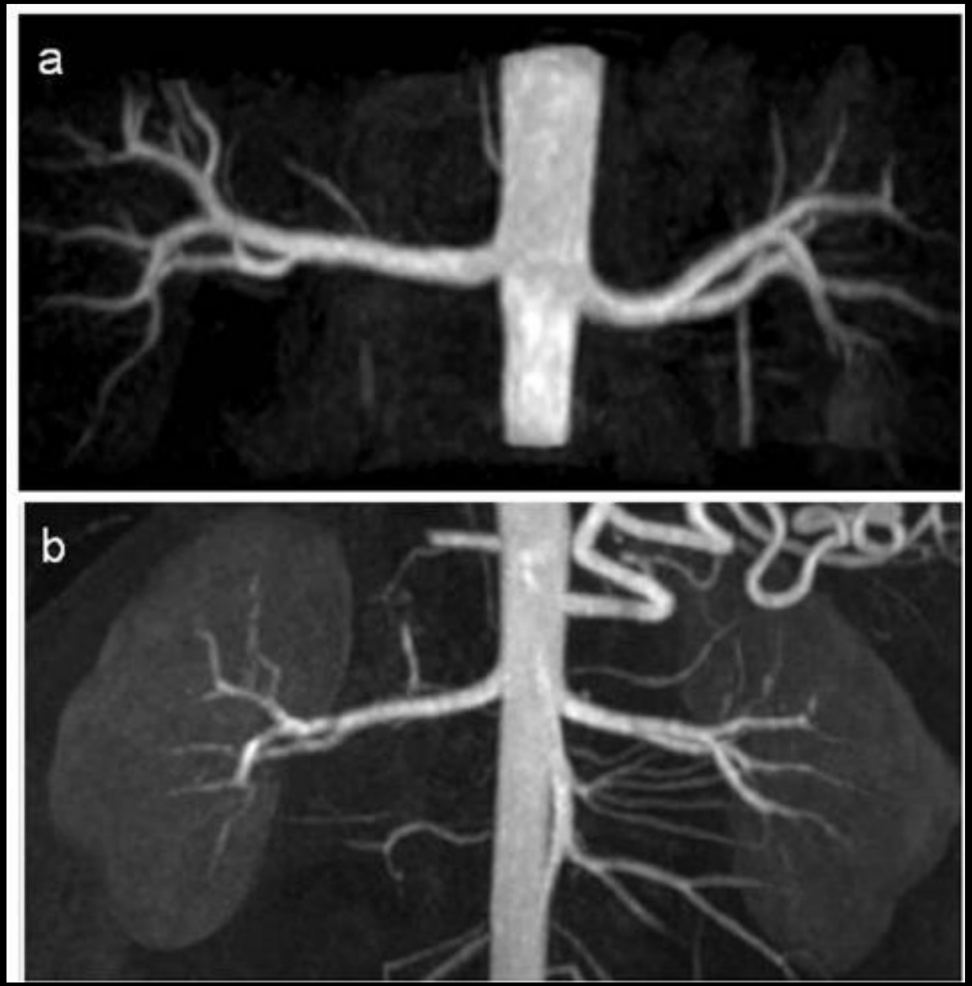
- Selective inverse pulse
- Incoming blood is univerted
- Quick acquisition required
- Breath triscopy/ECG
- 





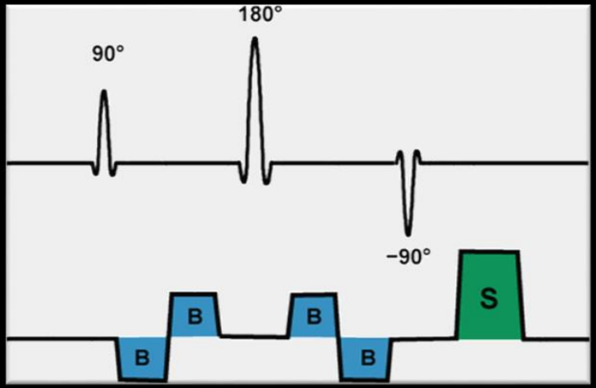
MRA – BFFE/FIESTA

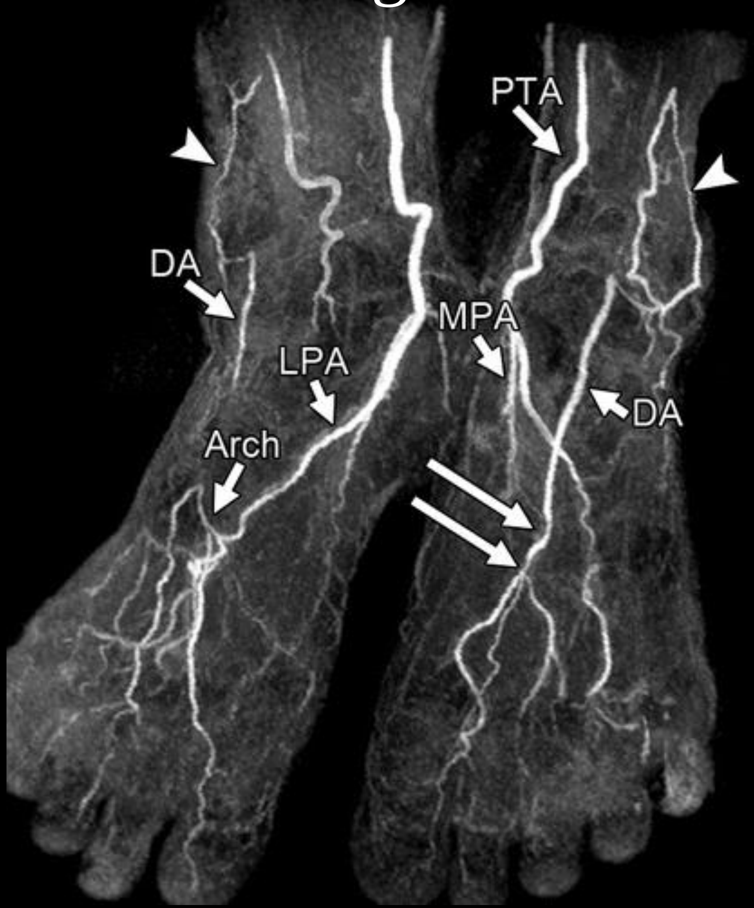


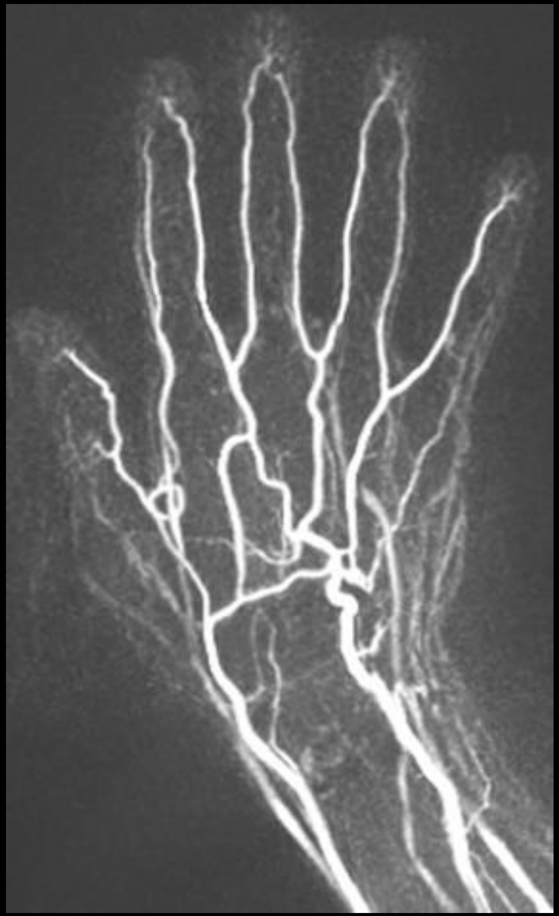


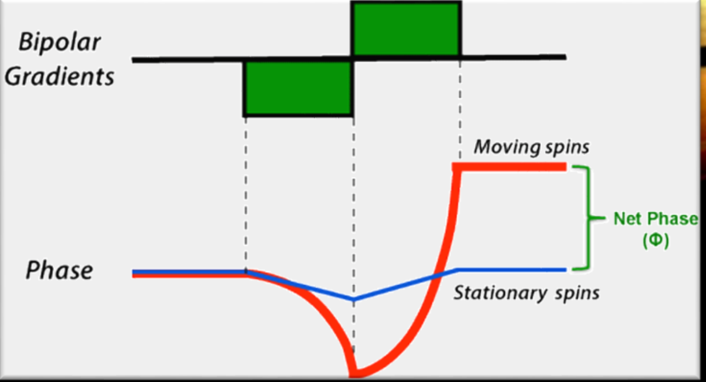
PERIPHERAL MRA

- Blood in the sys. And dias. Different signal
- Subtraction
- EcG tinging
- Pulsation is essential
-

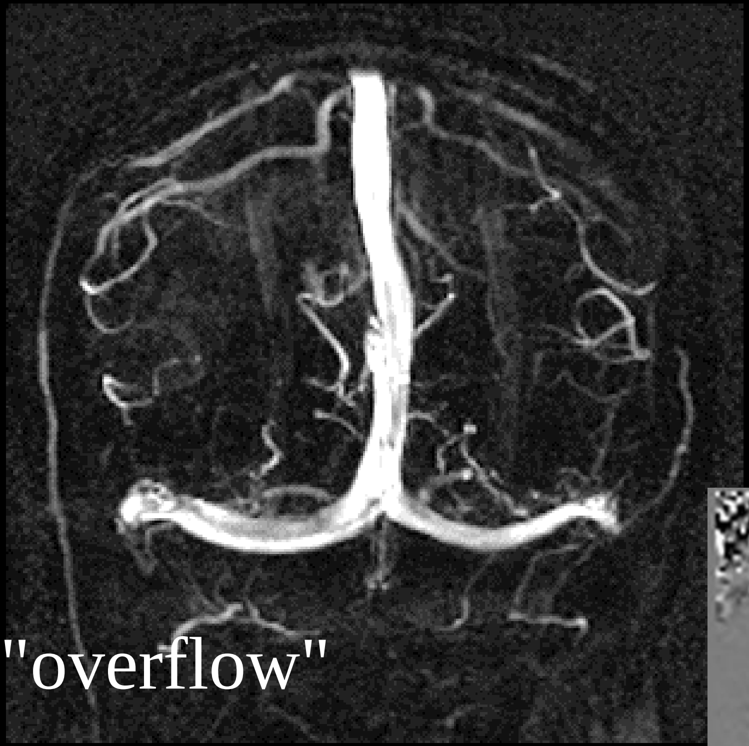


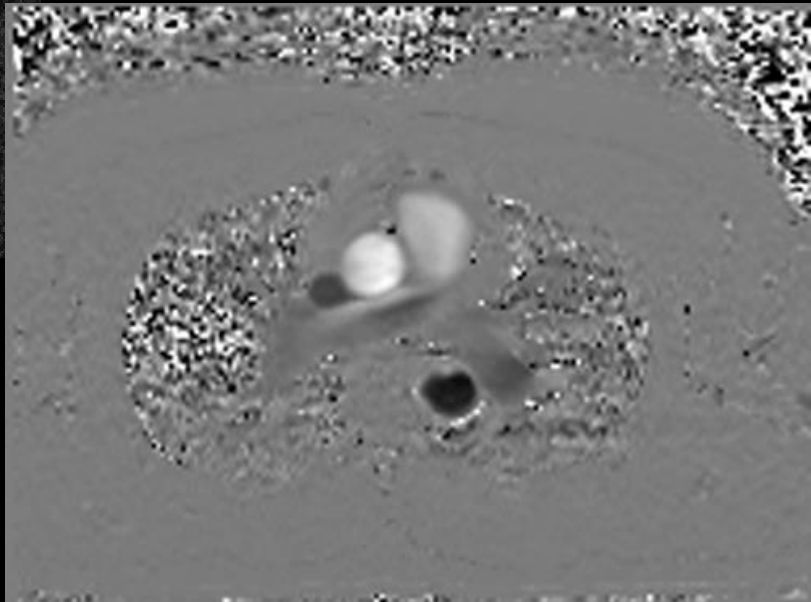






MRA – PHASE CONTRAST

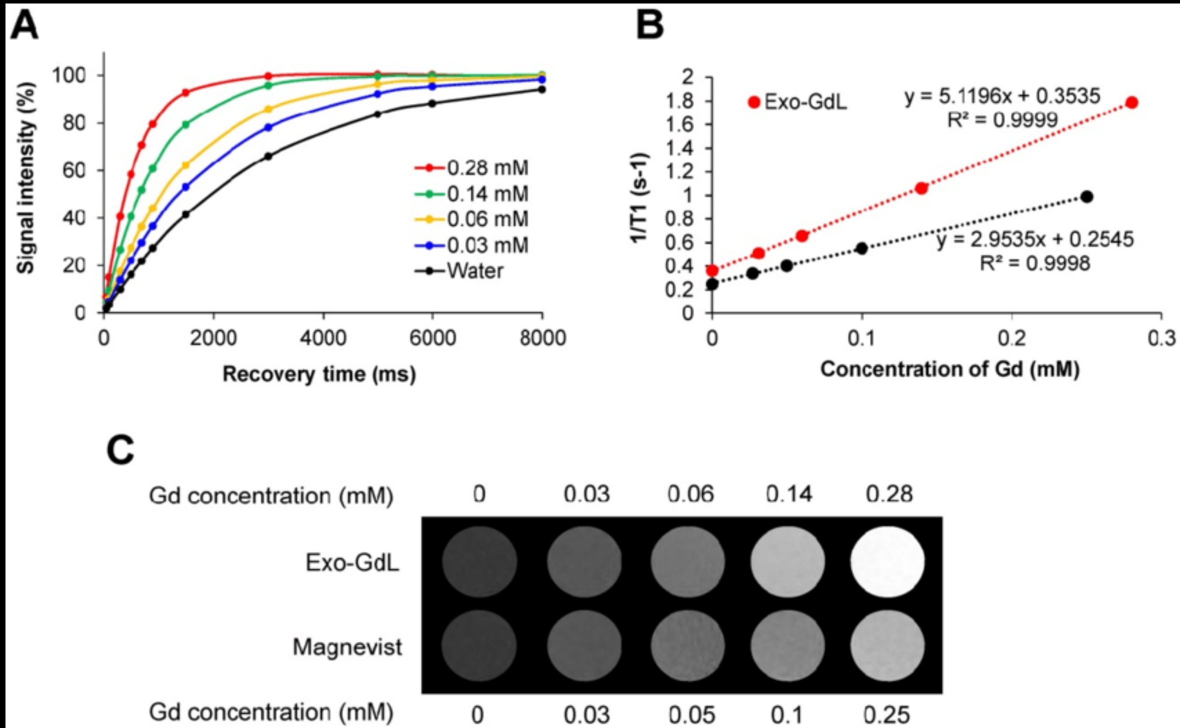




- Bipolar gradient
- Motion = phase shift
- Phase shift velocity ~
- Encoding in 3 directions
- Quantification
- Determination of vmax = > "overflow"
- Pulsation/turbulence artifacts
-

MRA – CONTRAST

- Principle:
- When TR << T1 = > low signal
- Presence of KL = destruction T1 = higher signal
- The more KL, the greater the shortening
- Quantity optimization
- Application speed optimization
- Optimization TE, TR, α
- Timely start of measurements
- The right choice of data collection
- Use of parallel techniques



MRA – CE

- Quick Sequence (3D GRE)
- Min TE i TR (~1 resp. ~4 ms)
- Suitable spatial resolution of the given vessel
- Suitable measurement volume
- Both above will affect accruals
- Optimal α (>Ernst angle)
- T1 blood 50 – 150 ms according to KL concentration
-

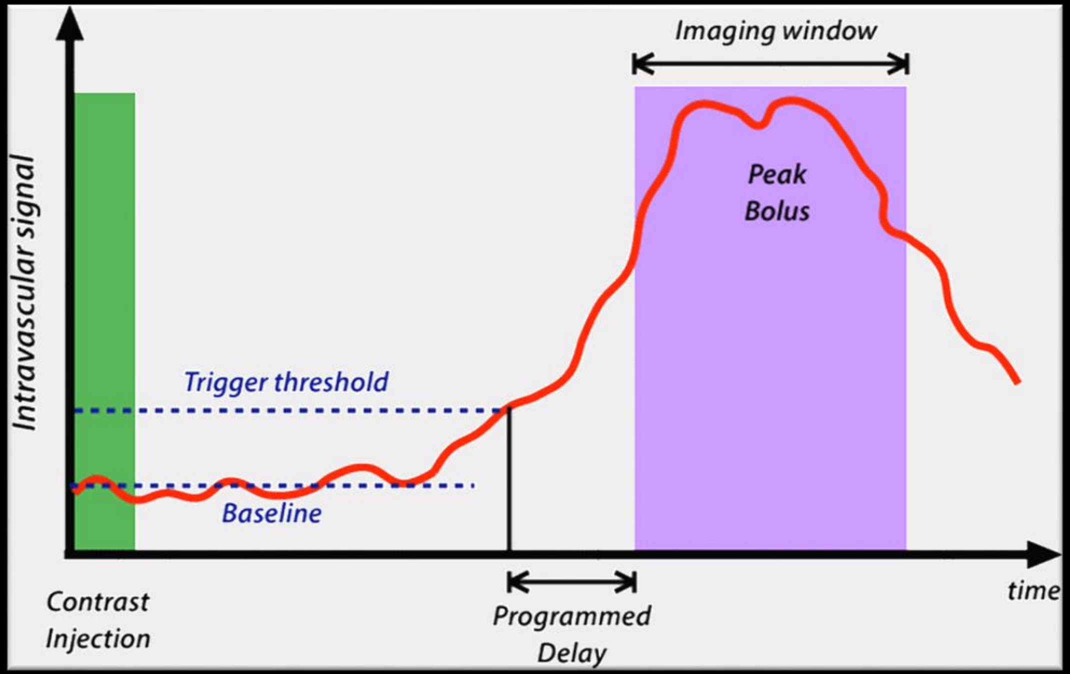
TR	Ernst angle (T1 = 25 ms)	Ernst angle (T1 = 50 ms)	Ernst angle (T1 = 100 ms)	Ernst angle (T1 = 150 ms)
6	38	28	20	16
5	35	25	18	14
4	32	22	16	13
3	28	20	14	11
2	23	16	11	9
1.5	20	14	10	8

MRA – CE TIMING

- Bolus
- Application ~2ml KL
- Measurement of inflow time
- Then the rest of the KL and measurements
- Advantages
- Precise determination of the beginning of the measu
- Disadvantages
- Part of KL not used
- Longer measurement
- Background contamination KL

MRA – CE TIMING

- Fluoro trigering/BolusTrak
- Quick artery scan
- When KL arrives, the measurement starts
- Advantages
- Use of all KL
- Semi/Automatic
- Disadvantages
- A more complex method for RA
-



MRA – CE TIMING

- Continuous shooting
- TRICKS/4D-TRAK
- Sensing on before KL administration
- Continuous image formation during KL
- Compromise prost. and time. resolution
- Advantages:
- No need to time
- Possibility to display the optimal phase
- Advanced data collection = possibility to improve time.
- Disadvantages:
- The necessity of compromise time and simplicity. resolu
- Max. gradients = > greater stimulus. perif. Nerves