

MRI: Encoding Artifacts, Sequence Types, and Contrast Mechanisms

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Module Bioimaging, Master degree course: „Biomedical Technologies“

Summary of spatial encoding in MRI

Three different principles

Slice selection: during RF-excitation

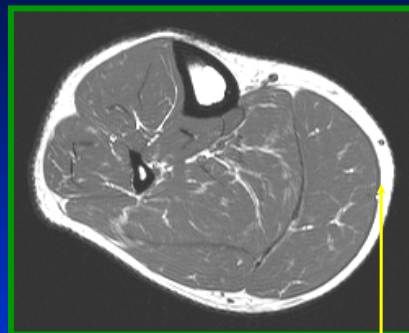
Problems: non-rectangular slice
profile, minimum slice thickness

Phase encoding: between RF-excitation and signal recording

Problems: long measuring time with inconstant conditions
during measurements, 360°-periodicity, moving artifacts

Frequenzkodierung: during signal recording

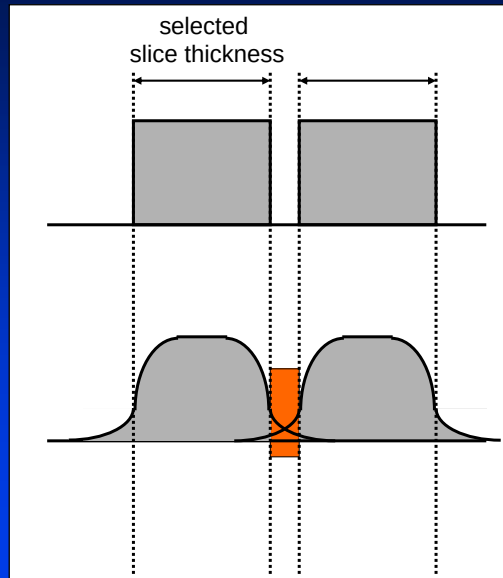
Problems: magnetic field inhomogeneities, chemical shift artifacts



Slice selection: Effects of overlapping slices

- *Ideal Slice Excitation:* The nominal flip angle acts inside the slice – in other areas no effective flip angle is present. Unfortunately, this goal cannot be reached.

- *Real Slice Excitation:* The nominal flip angle is only present in the centre of the slice. There is a continuous reduction of the flip angle towards the border of the slice and excitation even beyond.

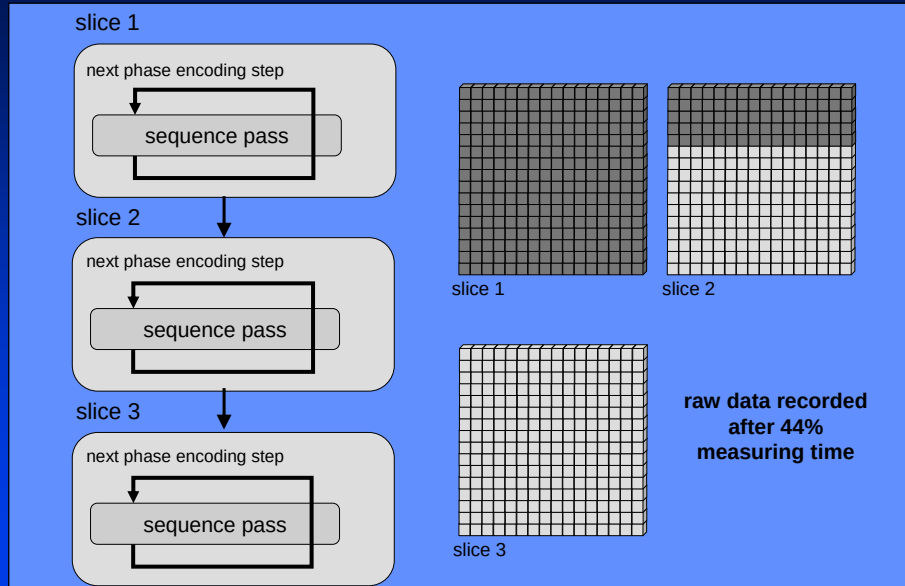


Slice selection:

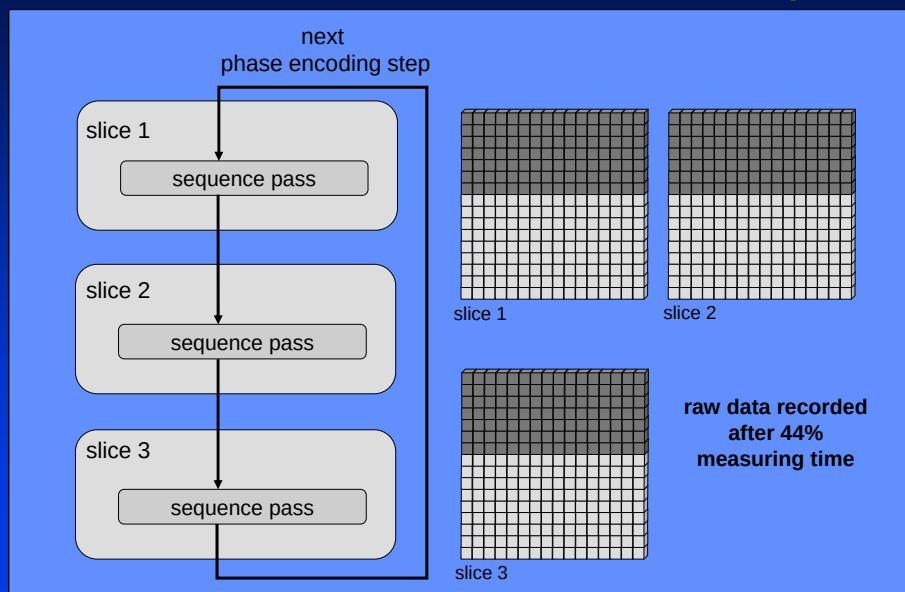
Solutions in cases with overlapping slices

- Question: which kind of multi-slice technique is used?
 - sequential (scout-record, single-shot-record)
 - nested (many anatomic recording techniques with GRE, SE or FSE/TSE)
- For nested recording techniques small gaps should remain between (parallel) slices
- For nested recording techniques images show dark lines at the positions of intersection, if images with different orientation are recorded

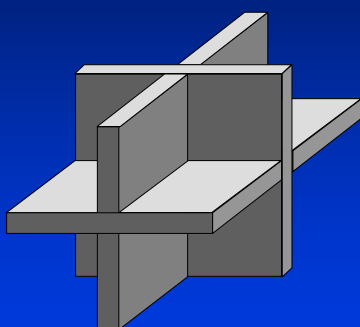
Sequential multi-slice recording



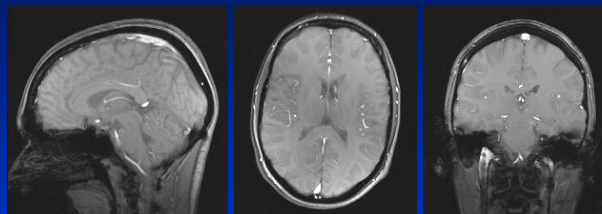
Nested multi-slice recording



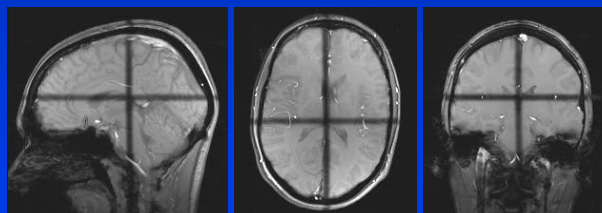
Overlapping slices



Sequential multi-slice recording

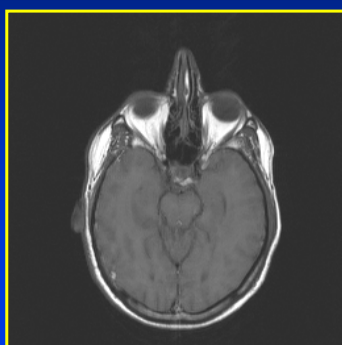


Nested multi-slice recording



Phase direction: Foldover artifacts

...arise for structures inside the slice, but outside the field of view – in phase-encode direction



phase
encode a-p

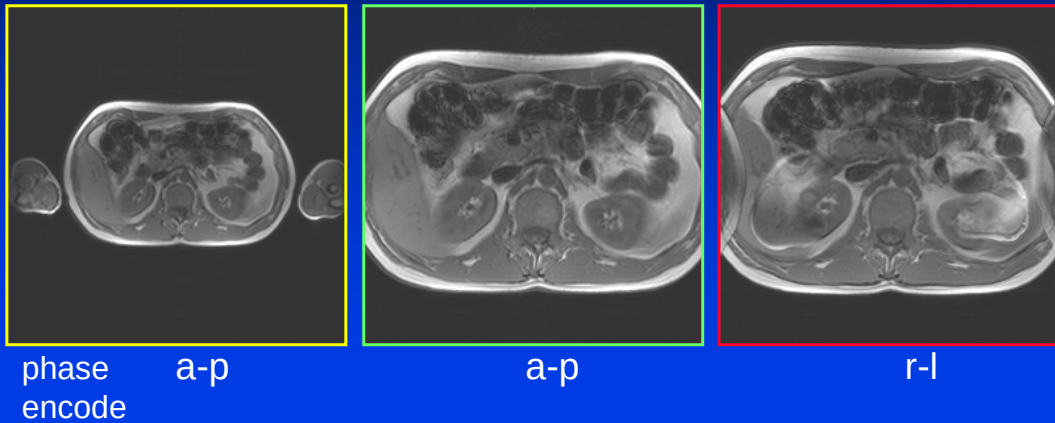


a-p

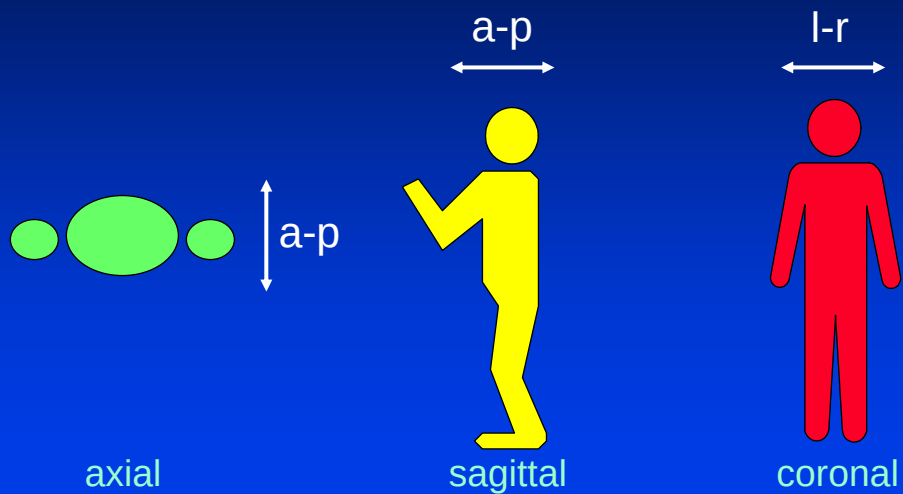


r-l

The optimum choice of the phase encode direction depends on the geometry of the body parts



Usually the scanner selects the phase encode direction automatically:



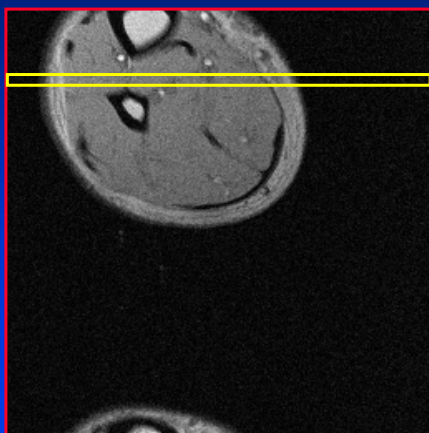
Avoiding foldover artifacts in phase-encode direction

- no „protruding“ body parts in phase-encode direction
 - patient positioning (e.g. coronal knee scans)
 - select large FoV (evtl. with enlarged matrix)*
- if „protruding“ body parts in phase-encode direction are unavoidable:
 - so-called phase oversampling*
 - RF-shielding cover
- for 3D measurements: choose block thickness generously*

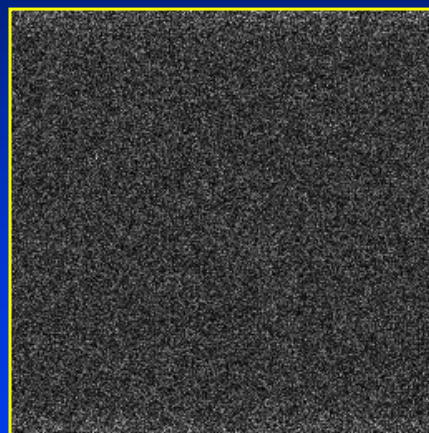
* leads to longer measuring time!

Problems with foldover in positioning

scout

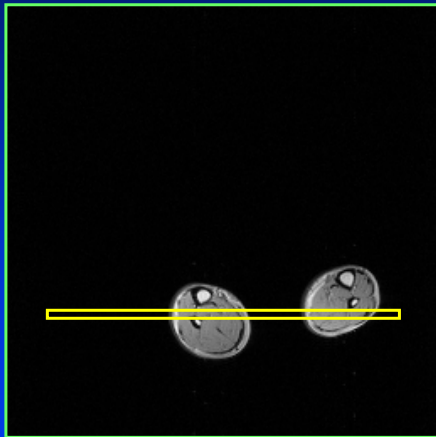


resulting image



Better: to avoid foldover,
select a large FoV at the beginning

scout



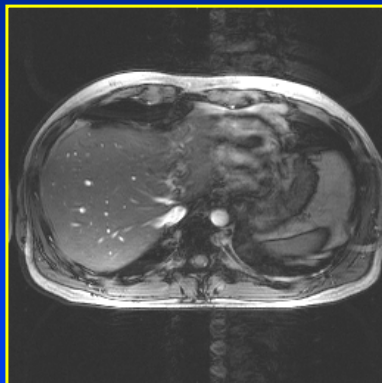
resulting image



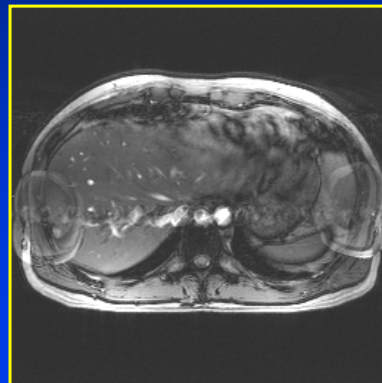
Phase direction: Flow artifacts

...more prominent for arterial vessels

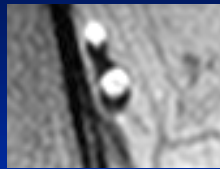
phase-encode



phase encode



Frequency encoding: Chemical-shift artifacts



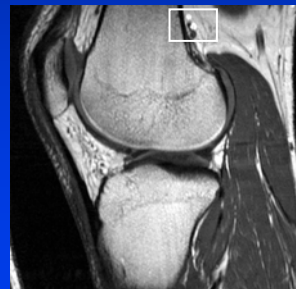
BW 130 Hz/px
at 1.5 T

large read-out bandwidth:

- small chemical-shift artifact
- poor signal-to-noise ratio

small read-out bandwidth:

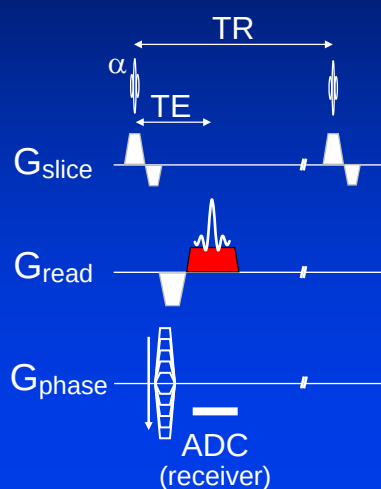
- distinct chemical-shift artifact
- good signal-to-noise ratio



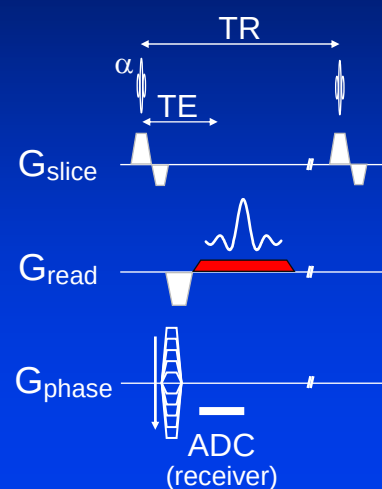
BW 32 Hz/px
at 1.5 T

Read-out of raw-data lines using different bandwidths

large bandwidth

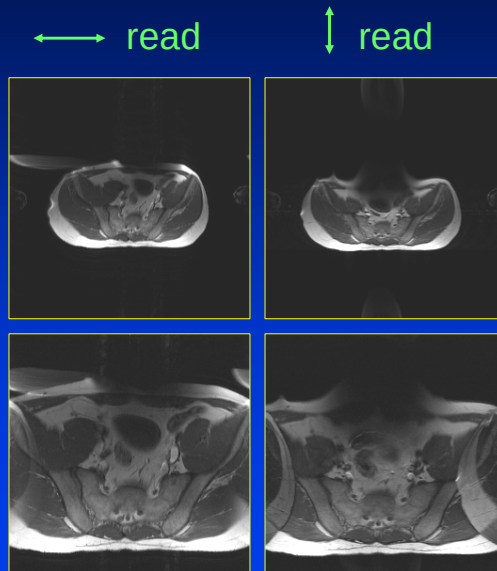


small bandwidth



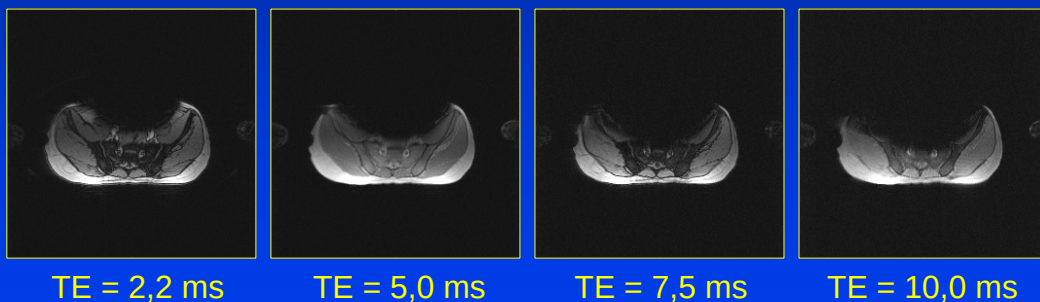
Metal artifacts in spin-echo sequences

- misencoding in read direction due to field distortions
- artifacts depend on the selection of the phase- and read direction
- artifacts depend on the read-out gradient strength (i.e. on **FoV** und **BW**)
- independent of echo time TE
- only little signal extinction

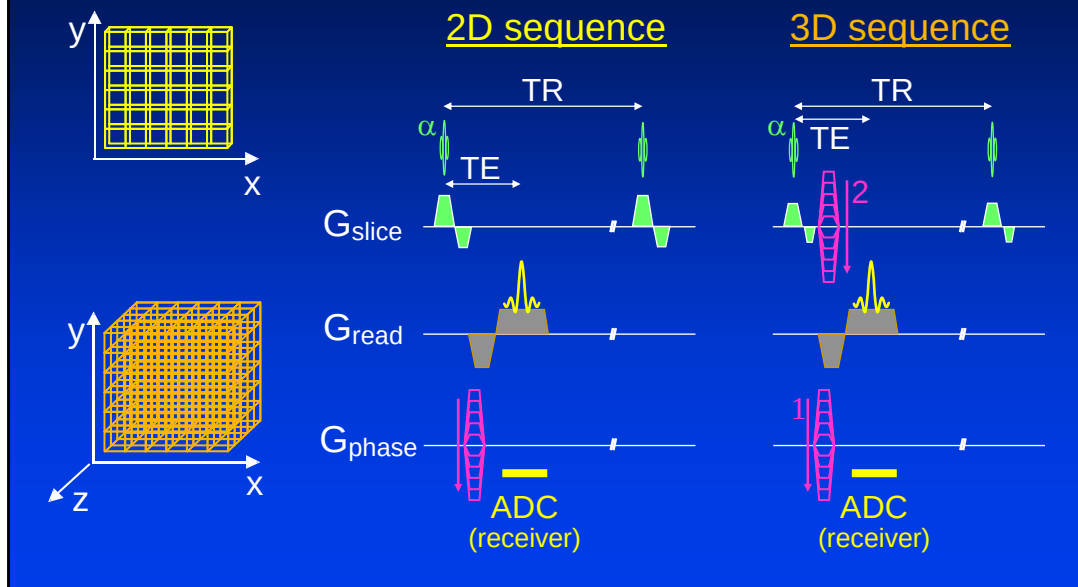


Metal artifacts in gradientecho sequences

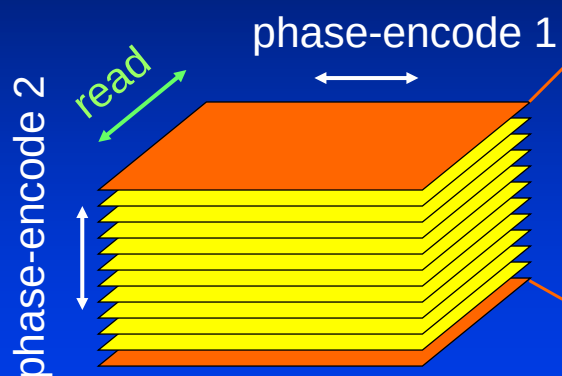
- signal voids in areas with inhomogeneous B-field
- Increasing effects with longer echo times
- somewhat more extinction with larger pixels
- negligible visible distortions
- artifacts are independent of phase-/read direction



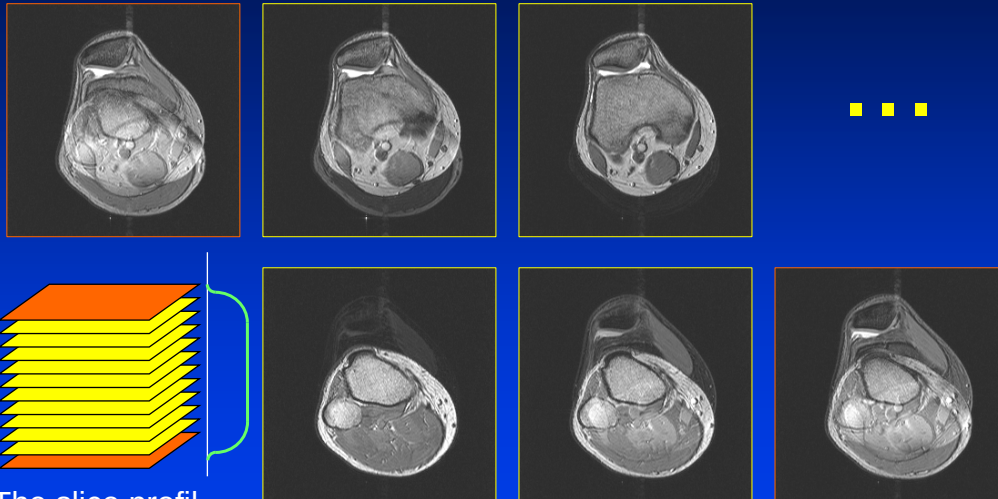
2D and 3D gradient-echo sequences



Foldover in 3D recording:
also in „slice direction“



Marginal slices of a 3D data-set of a knee out of 20 phase-encoded „partitions“



The slice profile
of the RF pulse causes a decreasing flip angle at the margin

Little sequence zoo

standard
technique

gradient-echo
sequences

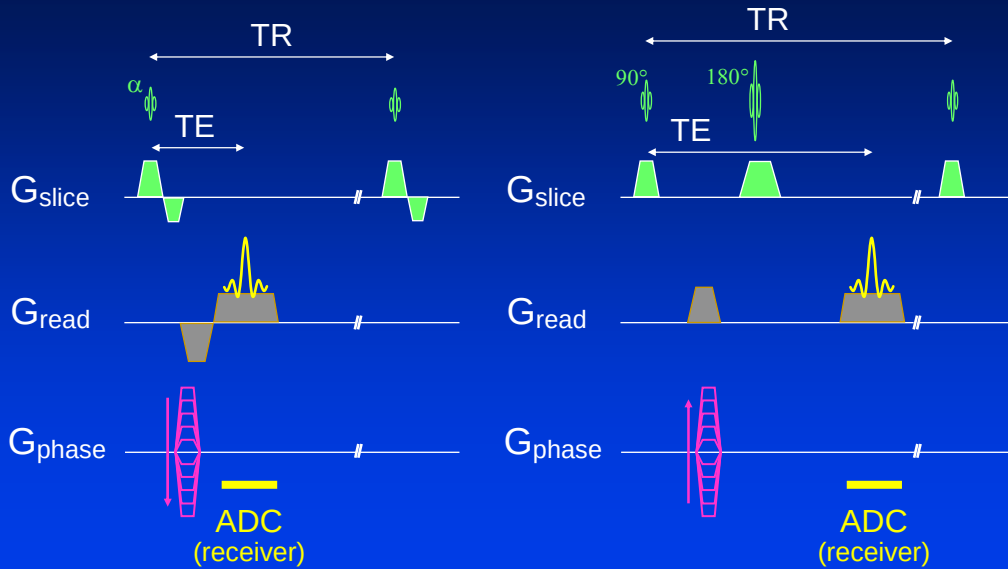
spin-echo
sequences

newer
faster
technique

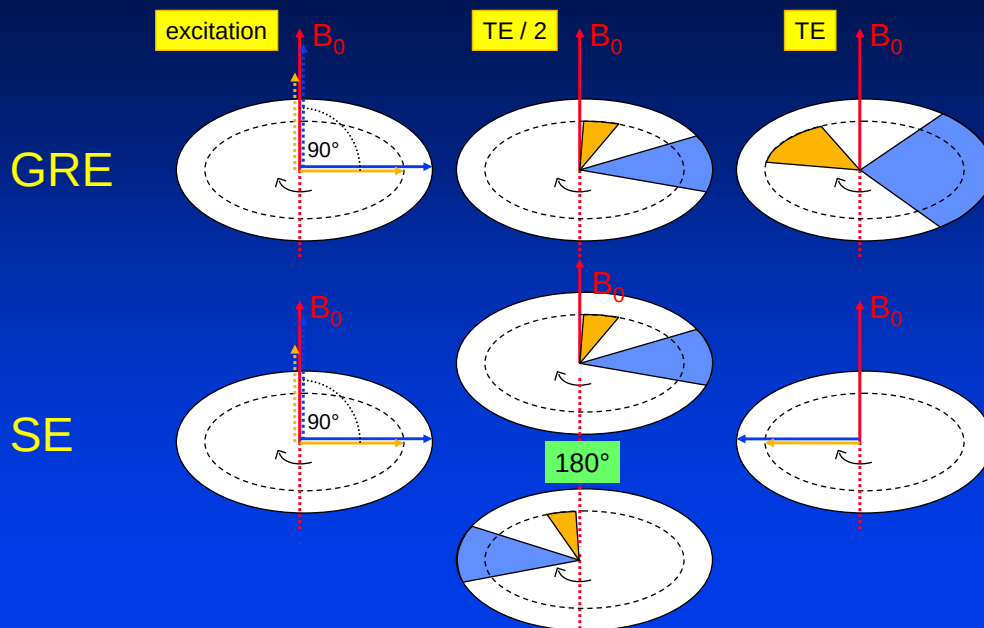
echo-planar
sequences

fast spin-echo
sequences

Gradient-echo and spin-echo sequence

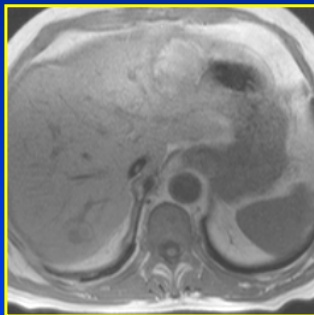


Dephasing in the voxels for GRE and SE sequences

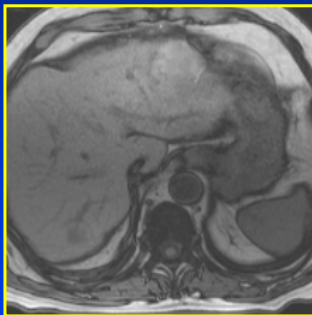


Effects of dephasing within the voxels for gradient-echo sequences

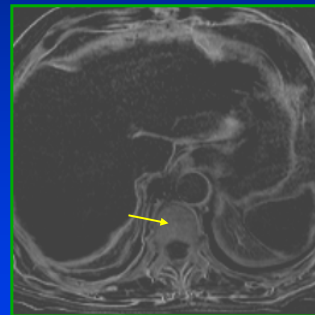
echo time is responsible for „in-phase“ or „opposed-phase“ condition !



in-phase



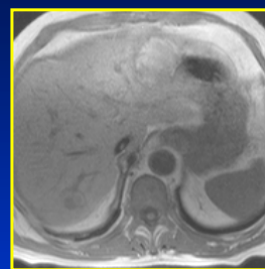
opposed-phase



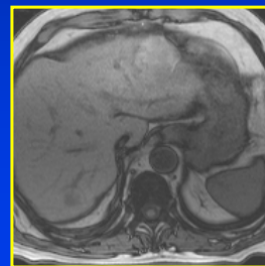
difference

At 1T field strength the difference of the Larmor frequencies of water and fat (CH_2) is approx. 150 Hz

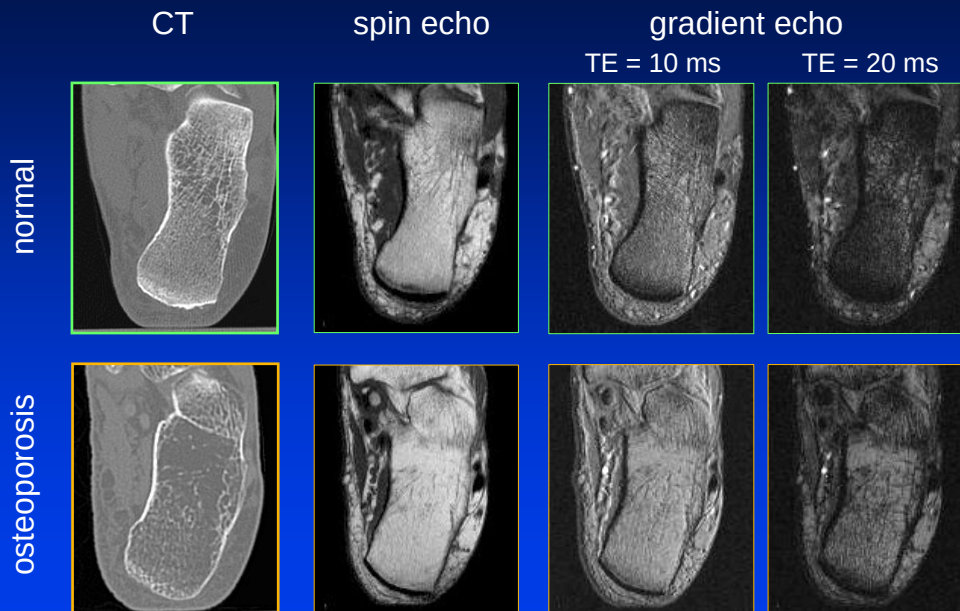
In-phase: at echo times of 6.7 ms or 13.3 ms water and fat signals are in phase.



Opposed-phase: at echo times of 3.4 ms or 10.0 ms water and fat signals are in opposed phase. Pixels containing water and fat show a clearly visible signal reduction



Gradient-echo and spin-echo sequence



Gradient-echo and spin-echo sequence

GE-imaging

- Excitation with a slice selective RF pulse with 1° - 90° flip angle
- no rephasing of field inhomogeneities and different chemical shift within the voxels
 - T2* weighting und opposed-phase imaging are possible
- short minimal echo times can be realized
- short repetition times possible, with relatively high signal yield at small flip angles

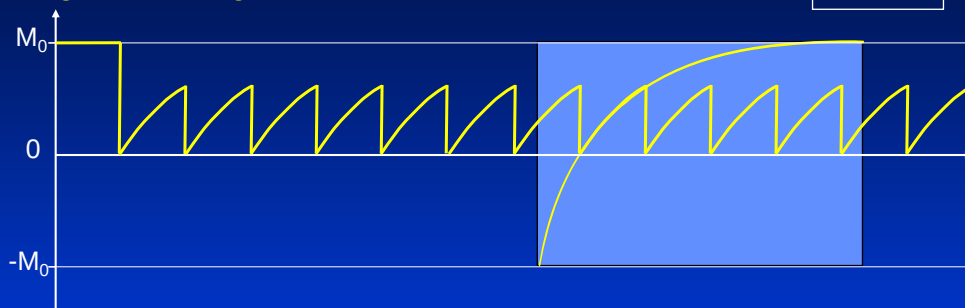
SE-imaging

- Excitation by a slice selective pulse sequence: 90° - 180°
- rephasing of field inhomogeneities and different chemical shift within the voxels are always guaranteed
 - T2* weighting und opposed-phase imaging are impossible
- prolonged minimal echo times due to the additional 180° pulse
- for reasonable signal yield prolonged repetition times (> 300 ms) are necessary

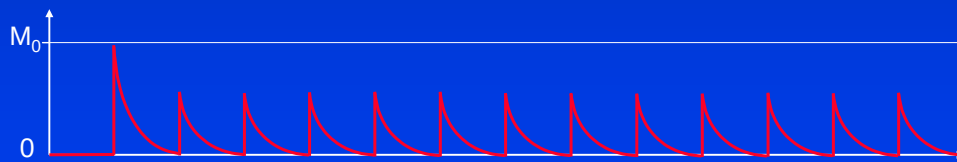
Course of the magnetization (gradient echo, 90°excitation)

longitudinal magnetization

TR = T1



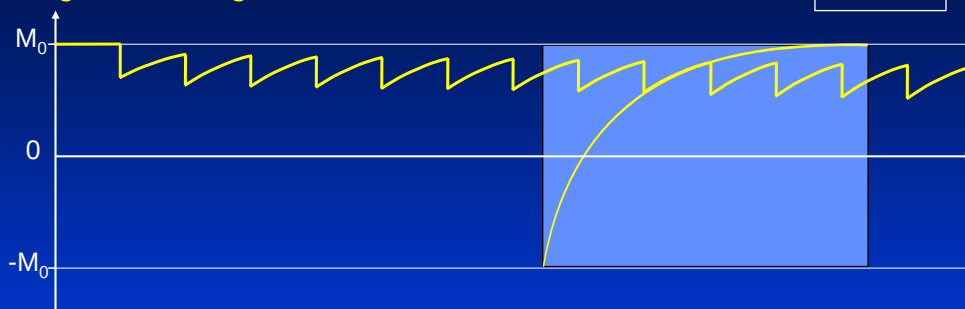
transverse magnetization



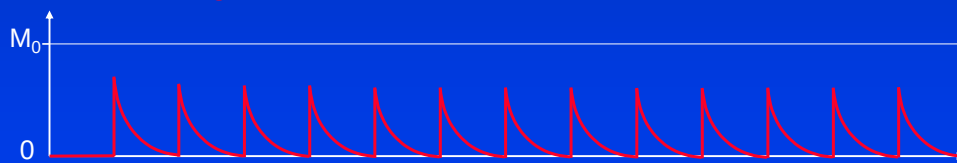
Course of the magnetization (gradient echo, 45°excitation)

longitudinal magnetization

TR = T1



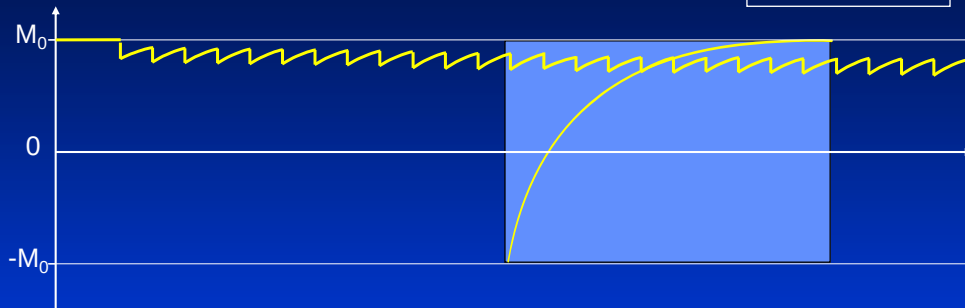
transverse magnetization



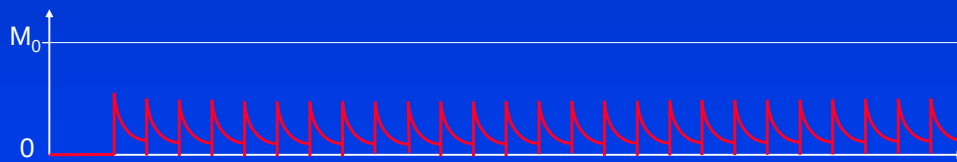
Course of the magnetization (gradient echo, 30°excitation)

longitudinal magnetization

$$TR = 0.5 * T1$$



transverse magnetization



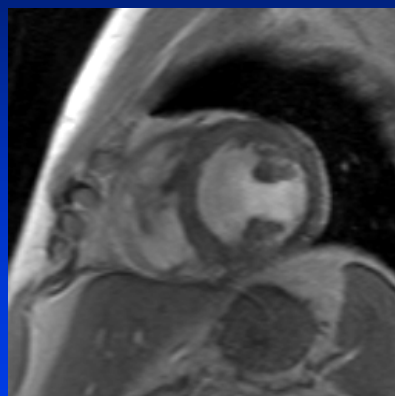
Fast imaging techniques

Gradient-echo imaging (GRE)

CINE technique

segmented GE sequence
for the display of the function
of the heart

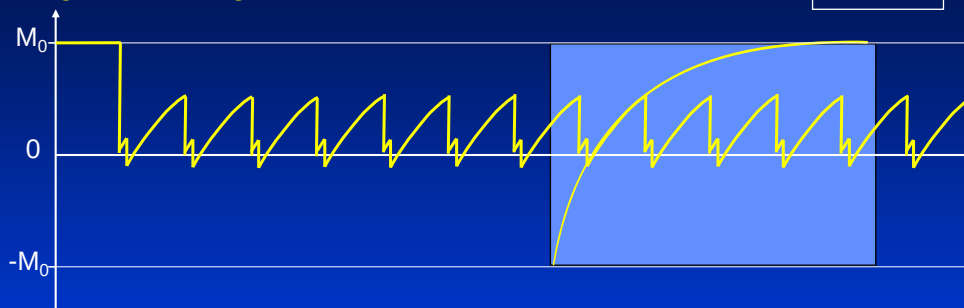
acquisition time approx. 15 s
in breath-hold technique



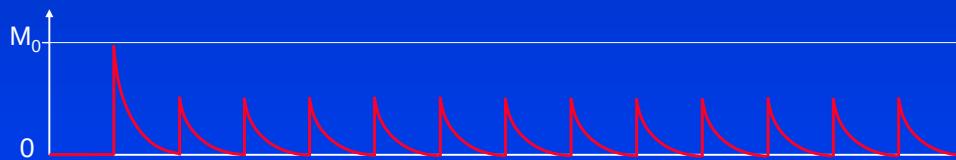
Course of the magnetization (spin-echo, 90°-180°-excitation)

longitudinal magnetization

TR = T1

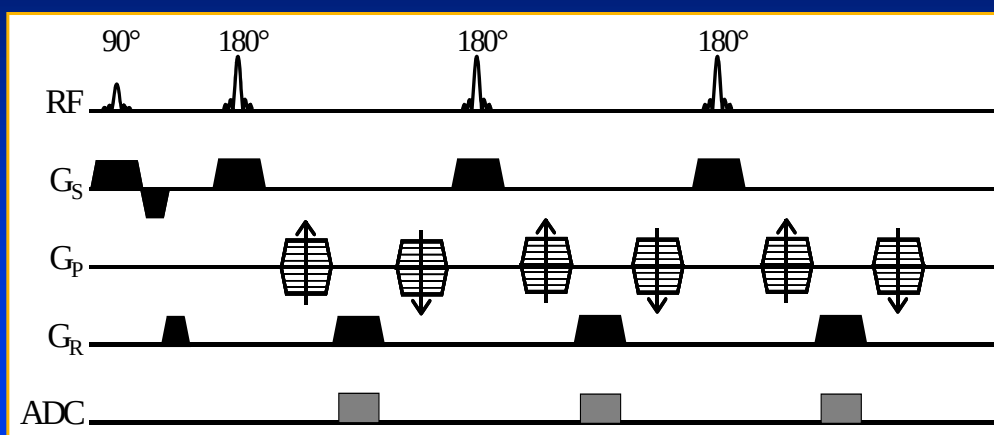


transverse magnetization



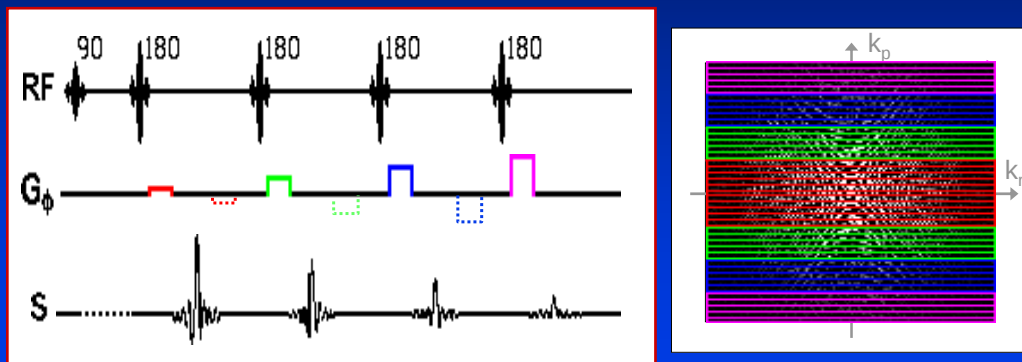
Fast imaging techniques

Fast spin-echo imaging (FSE or TSE)



Fast imaging techniques

Fast spin-echo imaging (FSE)



Fast imaging techniques

Fast spin-echo imaging (FSE)

- after an excitation several echos are generated and recorded (several lines in k-space)
- phase-encoding is different for different echos
- The number of echos recorded per excitation is called „echo train length“ (ETL) or „turbo factor“

Example.: ETL 7 $\rightarrow$ 7 lines per excitation
 $\rightarrow$ 1/7 of measurement time
typical ETLs: between 3 and 23

Fast imaging techniques

Fast spin-echo imaging (FSE)

T1 weighting: (short effective TE)

- Initial echos are used for the central lines of the raw-data matrix (k-space)
- later echos are used for the outer lines
- resolution and contrast sharpness in the images can be impaired
- the higher the ETL, the worse the resolution in the image

Fast imaging techniques

Fast spin-echo imaging (FSE)



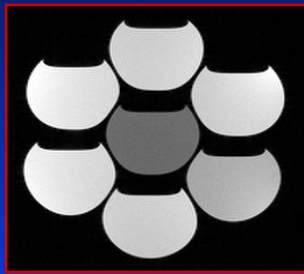
SE tomogram
TR = 300 ms, TE = 15 ms
TA = 2:37 min



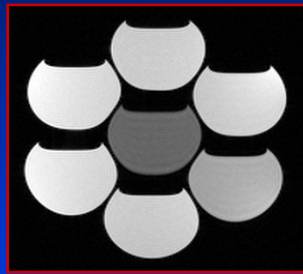
FSE-7 tomogram
TR = 300 ms, TE = 15 ms
TA = 23 sec

Fast imaging techniques

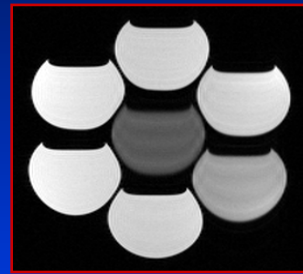
Fast spin-echo imaging (FSE)



SE
TR = 3 s, TE = 15 ms
TA = 12:52 min



FSE-3
TR = 3 s, TE = 15 ms
TA = 4:19 min



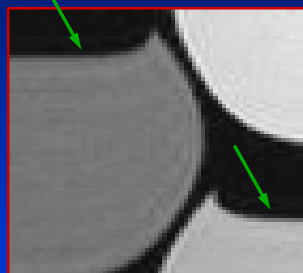
FSE-7
TR = 3 s, TE = 15 ms
TA = 1:52 min

Fast imaging techniques

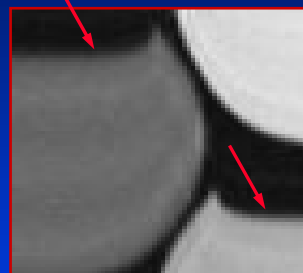
Fast spin-echo imaging (FSE)



SE
TR = 3 s, TE = 15 ms
TA = 12:52 min



FSE-3
TR = 3 s, TE = 15 ms
TA = 4:19 min



FSE-7
TR = 3 s, TE = 15 ms
TA = 1:52 min

Fast imaging techniques

Fast spin-echo imaging (FSE)

T2 weighting:

- echos, which correspond to the desired effective echo time, are written into the central lines of the raw data matrix
- marginal quality loss compared to SE imaging

The effective echo time is given by the echo time, for which the central lines of the k-space are recorded

Fast imaging techniques

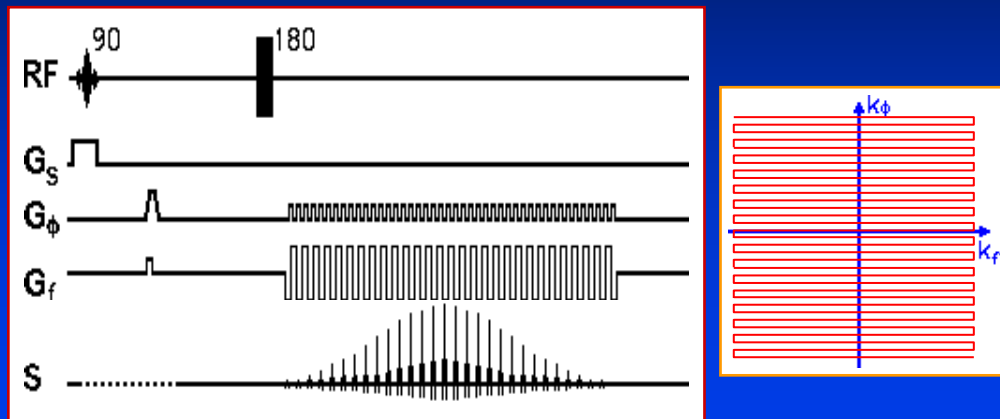
Fast spin-echo imaging (FSE)

Advantages and Disadvantages

- + reduction of measuring time, especially for T2-weighted recording
- worse detectability of small lesions (cerebral cortex, meniscus)
- fat signal is slightly enlarged compared to spin-echo records

Fast imaging techniques

Echo-planar imaging (EPI)



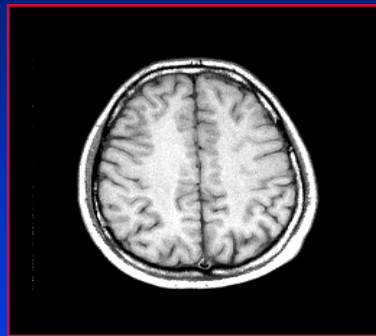
Fast imaging techniques

Echo-planar imaging (EPI)

- the entire k-space is recorded after **one single excitation**
- a fast oscillating gradient (in read-out direction) is applied
- phase encoding is done by short gradient pulses (blips)
- data recording should be done in the time range of T_2^* (T_2 relaxation, inhomogeneities)
- read-out gradients have to be switched very fast; **short rise times and a homogenous gradient system** are necessary

Fast imaging techniques

Echo-planar imaging (EPI)



SE tomogram
TA > 1 min



EPI tomogram
TA = 0.3 s

Fast imaging techniques

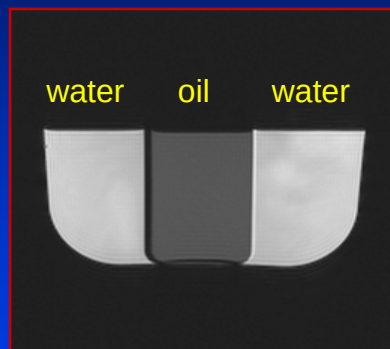
Echo-planar imaging (EPI)

Advantages and Disadvantages

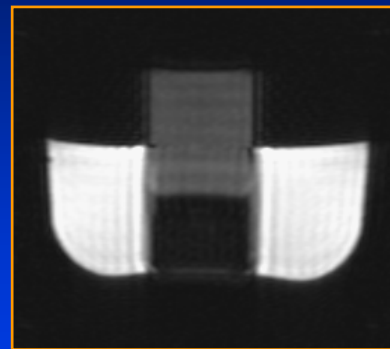
- + very short acquisition time ($\ll 1$ s)
- extreme homogeneity of the magnetic field required
due to T_2^* effect, otherwise signal vanishes too fast
- no 180° RF-pulses $\rightarrow$ phase errors add up $\rightarrow$ image artifacts
phase shifts lead to the fact that fat signal is depicted with a shift of many pixels $\rightarrow$ fat saturation necessary

Fast imaging techniques

Echo-planar imaging (EPI)



SE tomogram
TA = 2:37 min.



EPI tomogram
TA = 0.3 s

Fast imaging techniques

Echo-planar imaging (EPI)

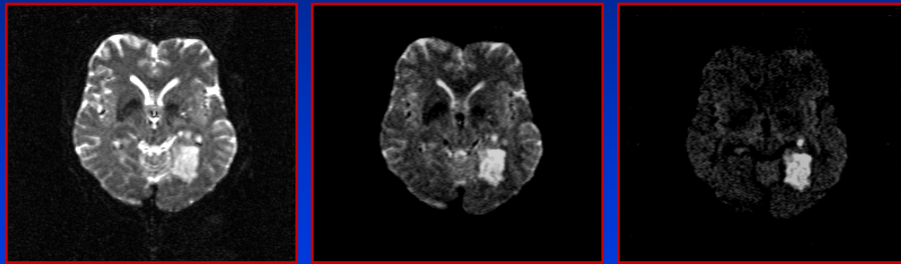
Typical Applications

- diffusion imaging
- perfusion imaging
- functional imaging

Fast imaging techniques

Echo-planar imaging (EPI)

Diffusion imaging: mobility of the water molecules

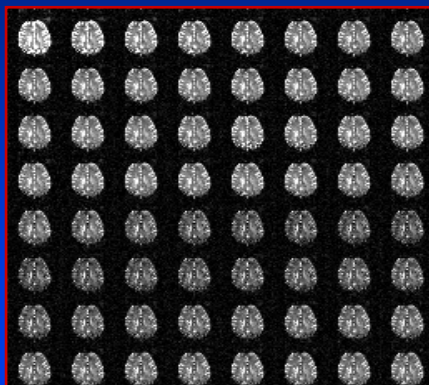


increasing diffusion weighting (patient after stroke)

Fast imaging techniques

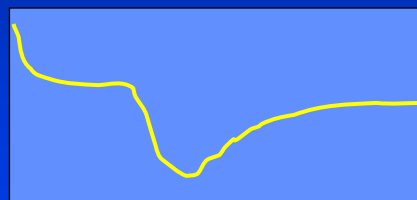
Echo-planar imaging (EPI)

Perfusions imaging: contrast medium passing tissue



time resolution: 0.6 s

signal reduction during inflow
of contrast medium
due to susceptibility effects



signal course in
96 measurements

Fast imaging techniques

Echo-planar imaging (EPI)

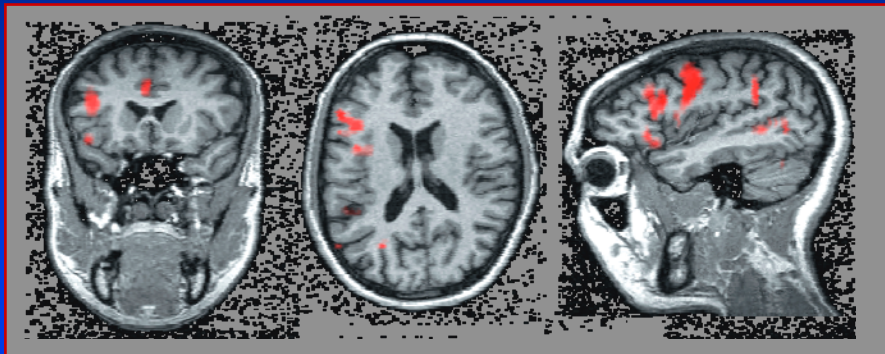
Functional imaging:

- analysis of the **oxygen content of blood** with susceptibility sensitive measurement sequences - „BOLD“ (blood oxygen level dependent) effect
- active regions in the brain are well supplied with blood
- oversupply with oxygen leads to increasing fraction of oxygenated hemoglobin → **higher signal from the active area**

Fast imaging techniques

Echo-planar imaging (EPI)

task for the Proband: generation of words (in mind...)

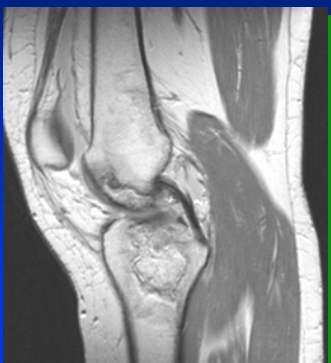


Tissue characteristics usable for contrast formation in MRI

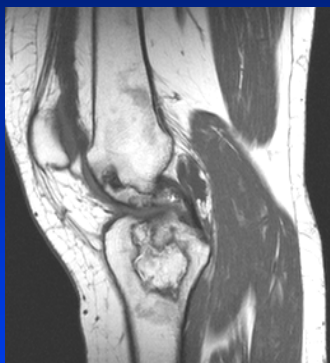
- proton density (or density of other nuclei)
- relaxation along and perpendicular to direction of the B_0 -field (relaxation times T1 and T2)
- chemical shift (allows also spectroscopy)
- motion: macroscopic blood flow / perfusion / diffusion
- magnetization transfer
- susceptibility (e.g. functional imaging (fMRI), hemosiderosis, osteoporosis)
- temperature (in thermo-therapy)

Contrasts in standard MR imaging

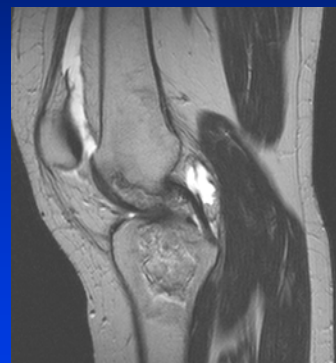
proton density



T1-weighted

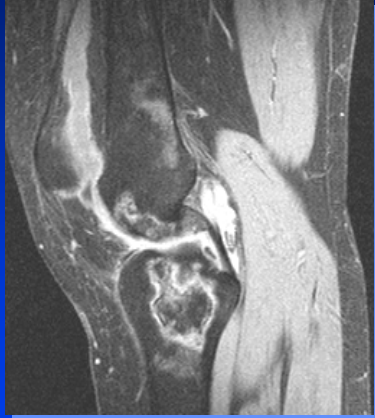


T2-weighted

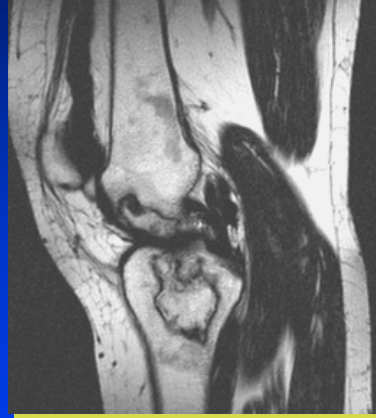


Chemical shift selective imaging

water selective



fat selective



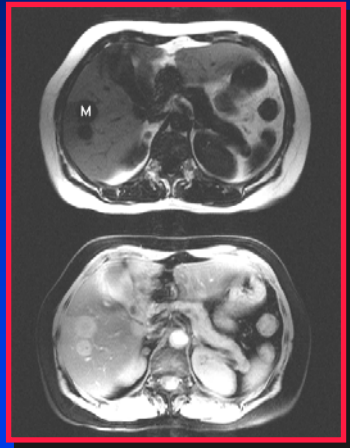
Principle of chemical shift imaging

- The differences in the resonance frequencies of protons with different chemical bond are used for selective depiction
- Water protons have a higher resonance frequency than methylen and methyl protons of fatty acids (for the same applied field strength)

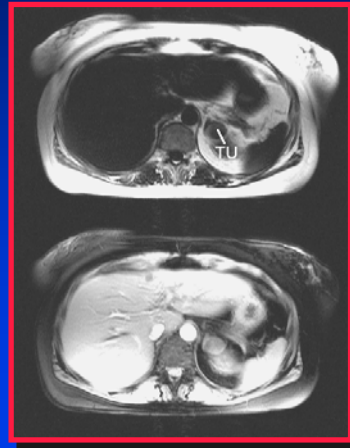
Chemical shift selective imaging of the abdomen

differential diagnostics for tumors (fat content)

colon carcinoma metastases



adrenal gland adenoma

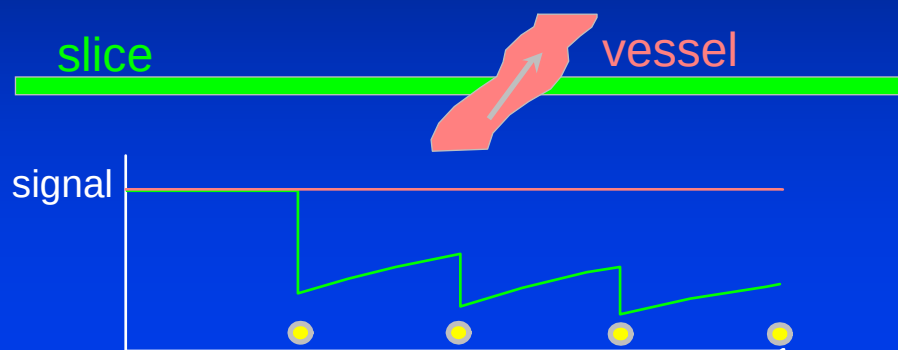


macroscopic motion

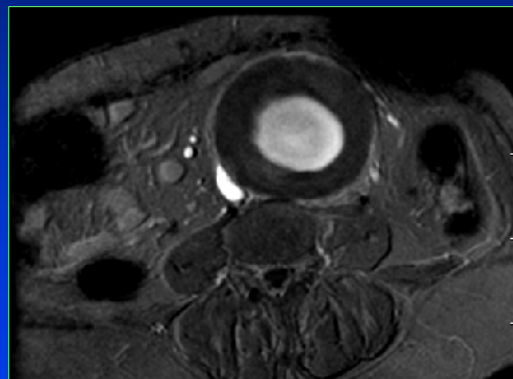
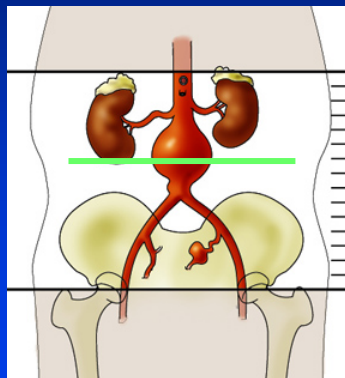
- imaging parameters can be chosen in a way that the signal intensity is motion dependent
- angiographic depictions without contrast agent become possible

MR angiography

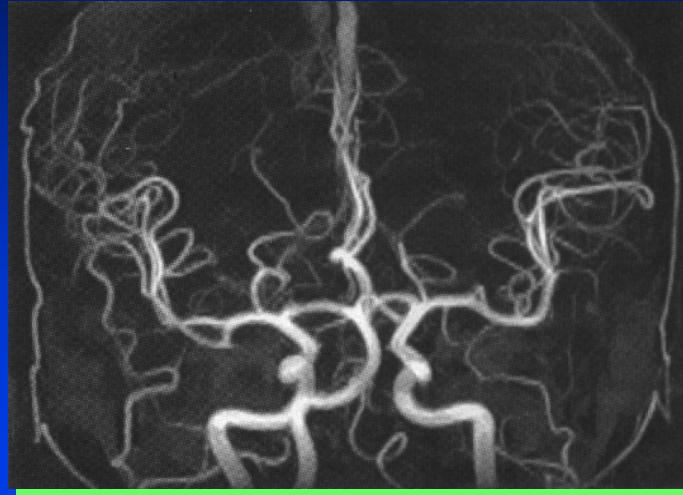
- “inflow” imaging generated by partial saturation of the stationary tissue



Time-of-flight effect:
slice of an abdominal aorta aneurysm,
marginal thrombosis



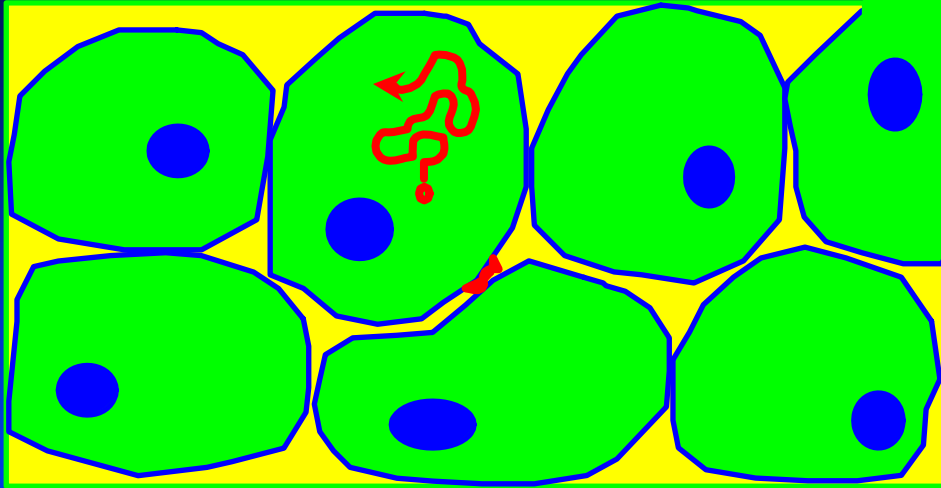
MIP reconstruction of a 3D data set (inflow technique without contrast agent)



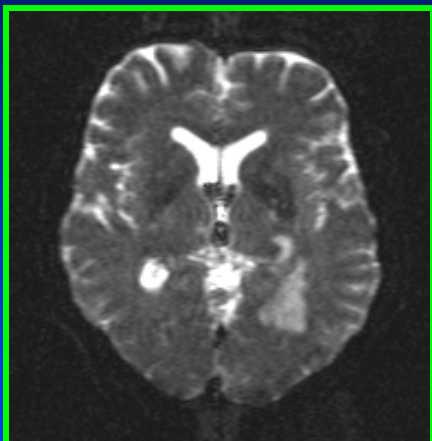
Microscopic motion

- diffusion is a random motion of the molecules – This motion can be hindered by boundary structures (e.g. cell membranes)
- diffusion is hindered in the narrow extracellular edematous spaces of infarctions

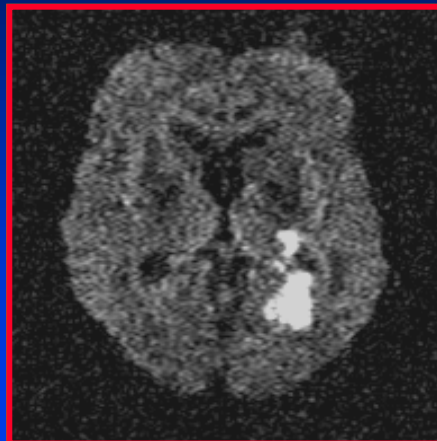
Diffusion



Diffusion-sensitive echo-planar imaging of ischemic brain lesions

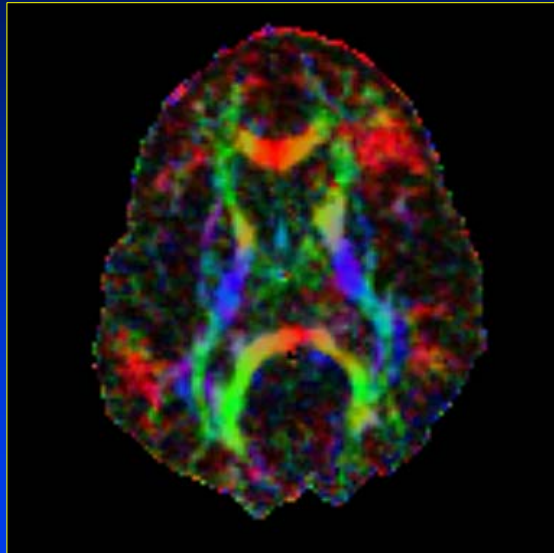


weak diffusion weighting



strong diffusion weighting

Diffusion tensor color-map



↔ left-right
↕ anterior-posterior
⊗ superior-inferior

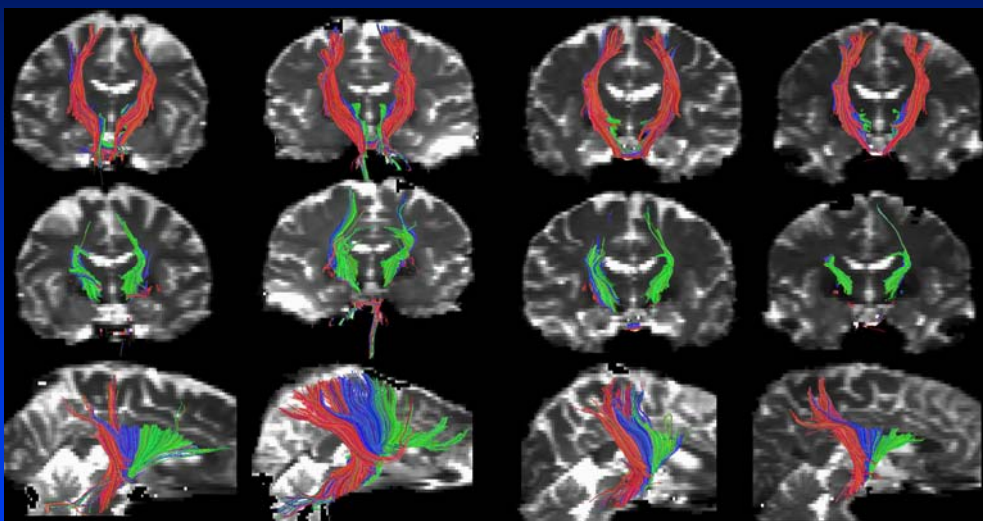
Fiber tracking

subject 1

subject 2

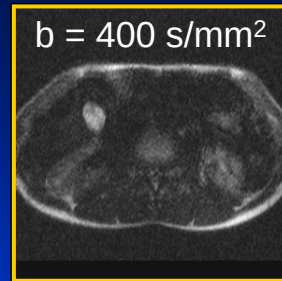
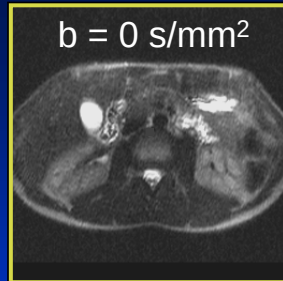
subject 3

subject 4

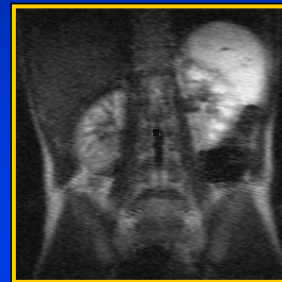
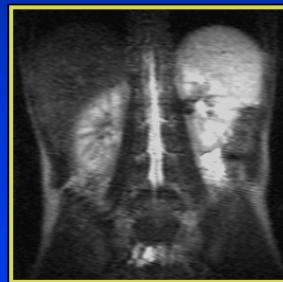


Abdominal diffusion imaging at 1.5 Tesla

transverse



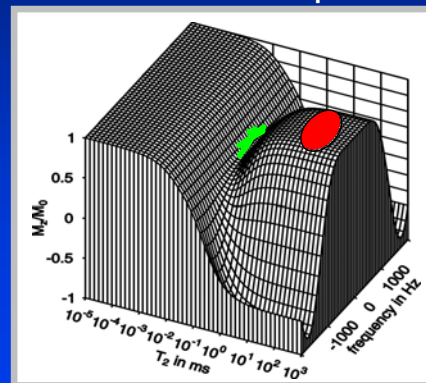
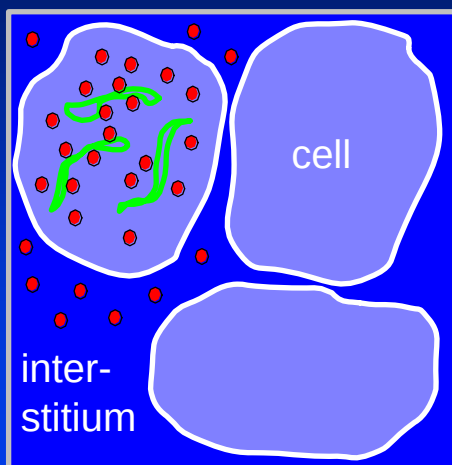
coronal



Magnetization transfer as „marker of tissue compartments“

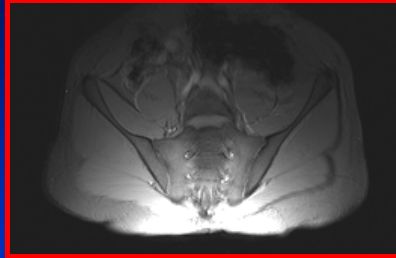
interaction between free **water protons** and **macromolecules**

selective saturation of the
macromolecular protons

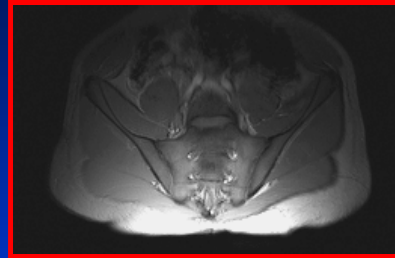


Magnetization transfer tomography

without pre-pulses

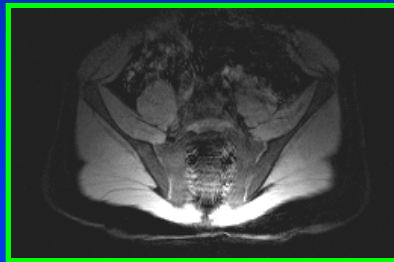


with pre-pulses



—

=



MT tomogram

Magnetization transfer in bone marrow progression in peripher stem-cell transplantation

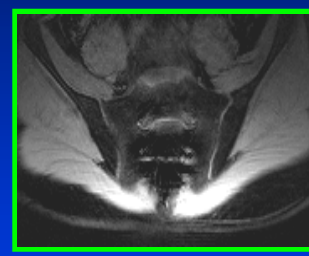
before therapie



aplasia



4w. rekonstitution



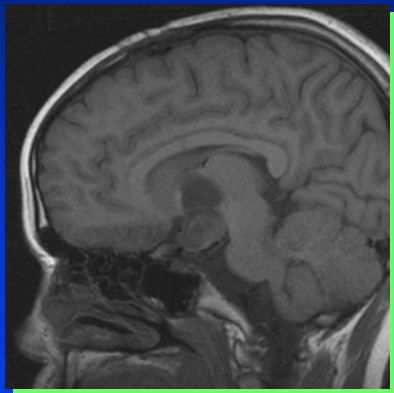
MT effect correlates with cellularity in marrow

MR contrast agents

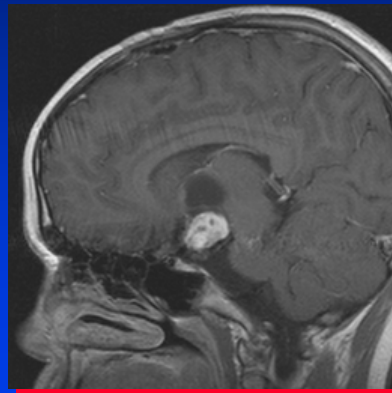
- Complexes as Gd-DTPA are administered intravenously
- Longitudinal relaxation time T1 of the protons near Gd-DTPA complexes is clearly reduced

T1 weighted images of a patient with opticus glioma

before CM application

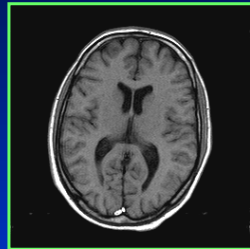


after application of Gd-DTPA

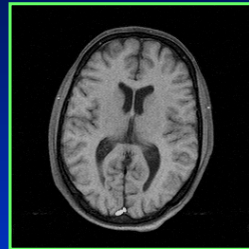


Sequence types with low and high sensitivity to magnetic field inhomogeneities

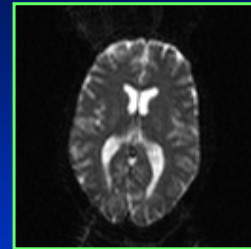
after shimming
without
disturbation



spin echo

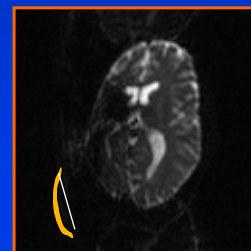
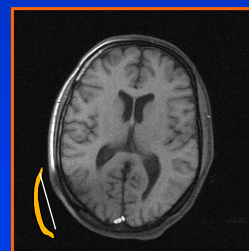
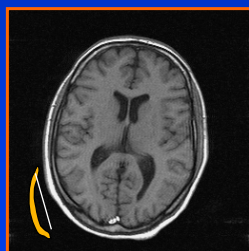


fat-sat spin echo

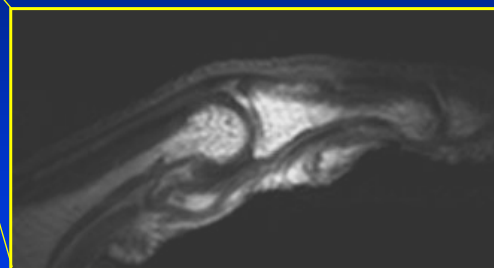
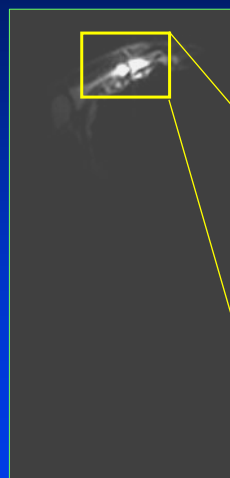
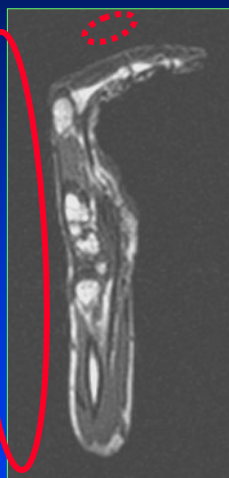


EPI

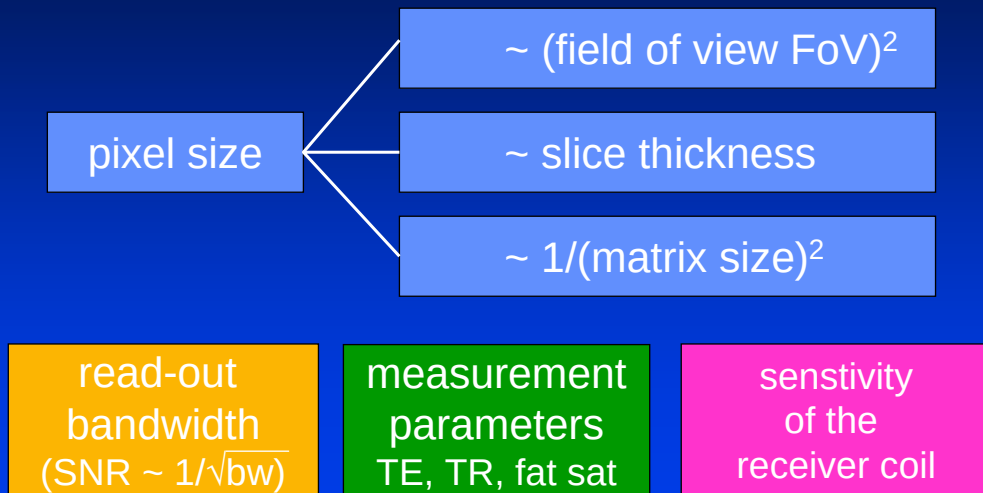
with small
hairslide



Choice of receiver coil and noise level in images



Influences on the signal-to-noise ratio (SNR):



This is the end...