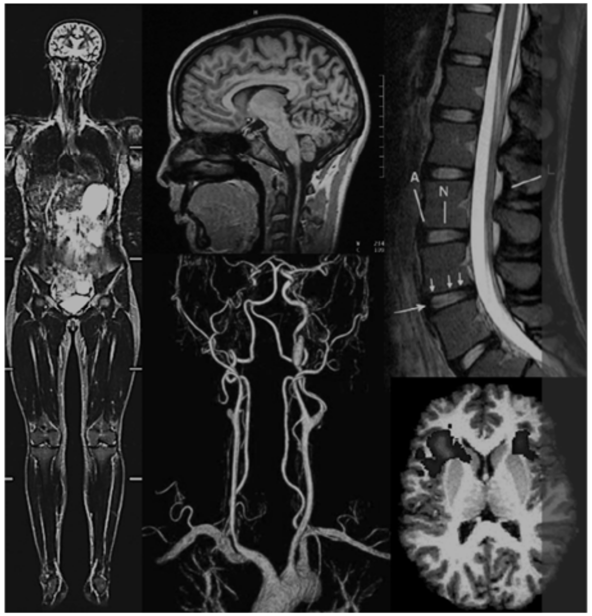

快速脈衝程序II
組織壓抑技術
A Course of MRI

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本週課程內容

- Echo Planar Imaging (EPI)
- 組織壓抑技術(Tissue suppression imaging)

Echo Planar Imaging

EPI

Echo Planar Imaging, EPI

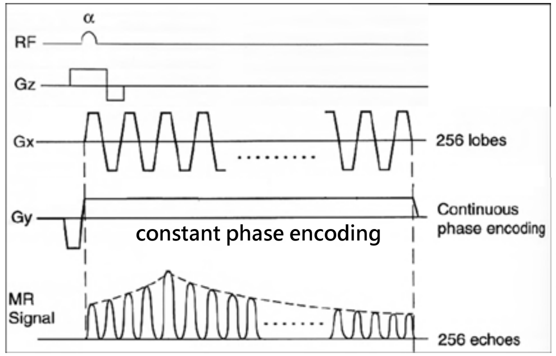
- **EPI**: the fastest MRI technique
  - Diffusion tensor imaging, perfusion imaging, functional MRI
- Single-shot EPI, multi-shot EPI
- Constant phase encoding, blipped phase encoding

Hardware requirements in EPI

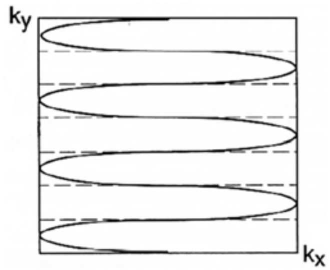
- High performance gradients
  - Rapid on/off switching of the gradients
  - Gradient strength of 20~100 mT/m
  - Gradient rise time of less than 300μsec
- Fast computers
  - Fast digital manipulations and signal processing
- Fast-sampling ADC
  - $\frac{T_s}{Nx} = \frac{1}{BW}$, T_s ↓ → BW ↑ (in MHz) → SNR ↓

Single-shot EPI

- Readout gradient: reversed rapidly from maximum positive to negative Ny/2 times

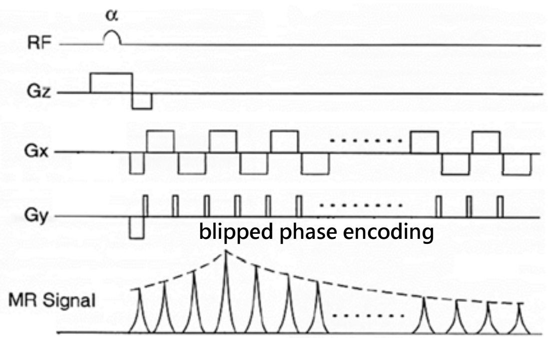


A zigzag coverage of k-space

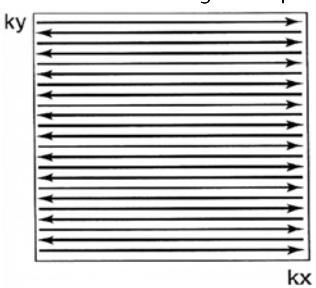


Single-shot EPI

- The phase-encode gradient is subsequently applied briefly during the time when the readout gradient was zero.

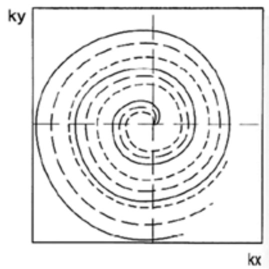


An odd-even coverage of k-space



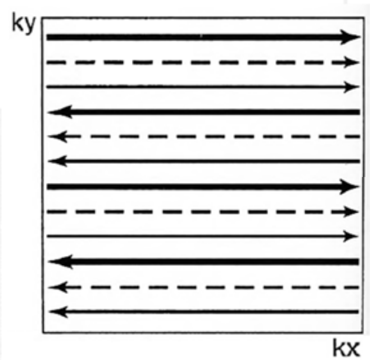
Multi-shot EPI

- Also called segmental EPI
- The readout is divided into multiple shots or segment (Ns)
  - Ny = Ns x ETL



A spiral coverage (using oscillating Gx and Gy)

An interleaved coverage of k-space



Multi-shot vs. single-shot EPI

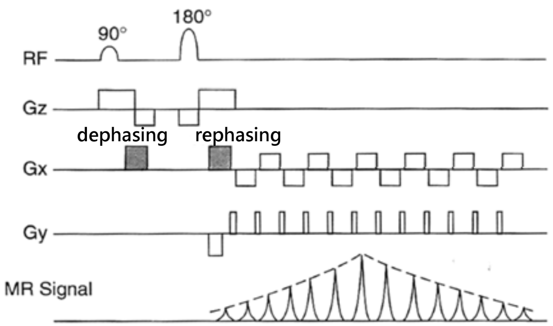
- Advantages
  - Less stress on the gradients (fewer duty cycles → better cooling)
  - Less time to build up phase errors→ reducing susceptibility artifacts
- Disadvantages
  - Longer scan time
  - More susceptible to motion artifacts
- Scan time
  - T(single-shot EPI) = ESP x Ny x NEX
  - T(multi-shot EPI) = TR x Ns x NEX = TR x Ny/ETL x NEX

Contrast in EPI

- SE-EPI (90^o-180^o-EPI)
  - eliminate ΔB_{ext}
  - T1 and T2 weighting
  - Diffusion-weighted imaging
- GRE-EPI (α^o-EPI)
  - T2* weighting
  - Faster imaging speed
  - Perfusion imaging
- IR-EPI (180^o-90^o-180^o-EPI)
  - Heavy T1 weighting

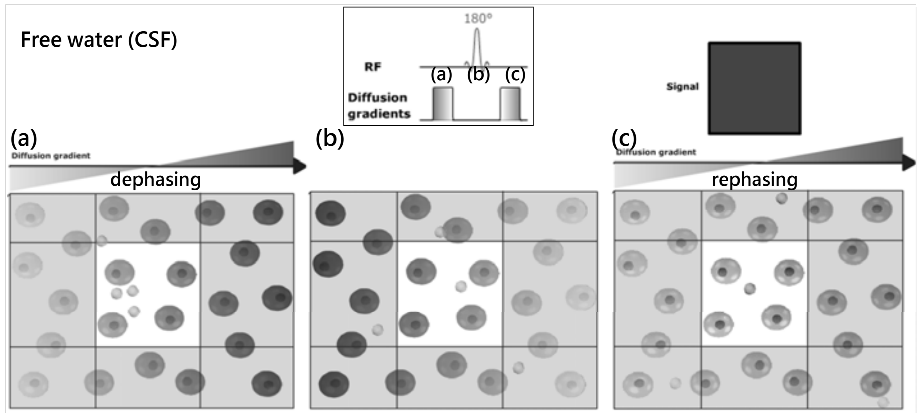
Diffusion weighted imaging, DWI

- Apply a pair of diffusion gradients before and after the 180^o RF pulse (SE-EPI)



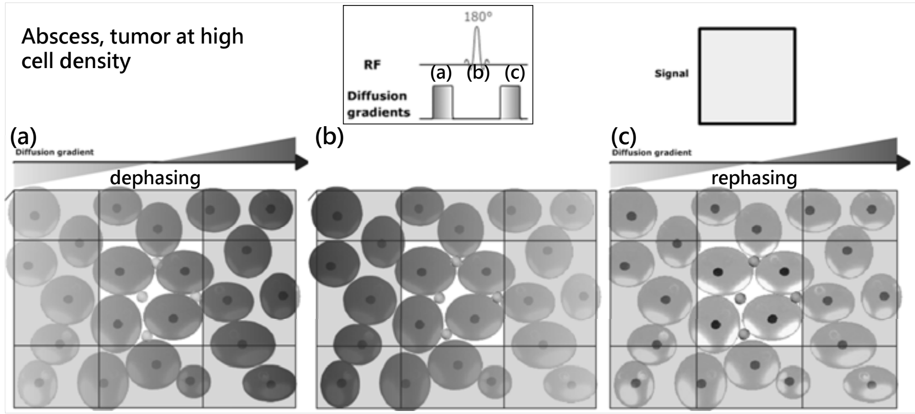
For a "fixed-position" proton, this pair of gradients won't cause dephasing.

Diffusion weighted imaging, DWI



IMAIO 2014, http://www.imaios.com/en/e-Courses/e-MRI/Diffusion-Tensor-Imaging/diffusion-principles

Diffusion weighted imaging, DWI



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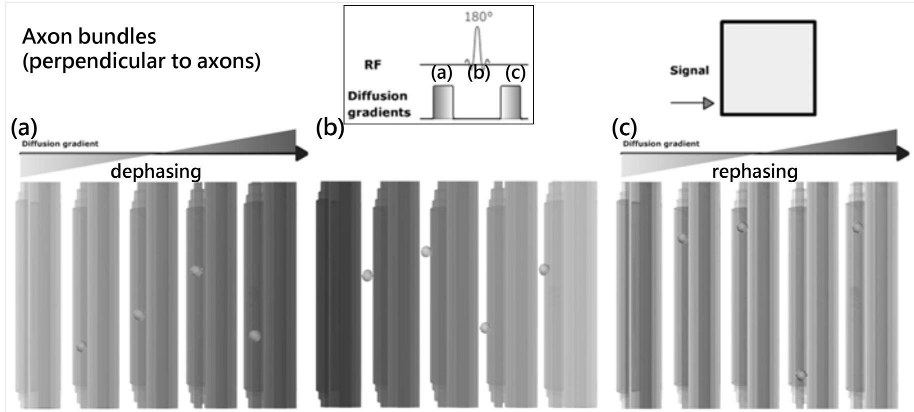
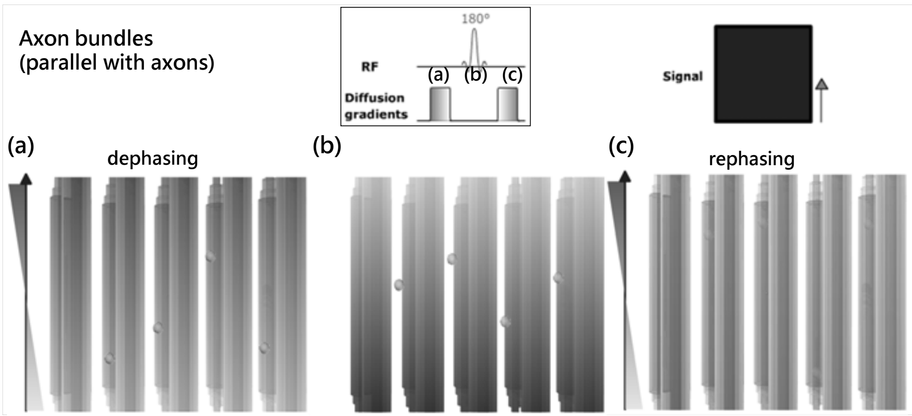
Diffusion weighted imaging, DWI



IMAIO 2014, http://www.imaios.com/en/e-Courses/e-MRI/Diffusion-Tensor-Imaging/diffusion-principles

Diffusion weighted imaging, DWI



IMAIO 2014, http://www.imaios.com/en/e-Courses/e-MRI/Diffusion-Tensor-Imaging/diffusion-principles

Diffusion weighted imaging, DWI

- Diffusion is defined as the process of random molecular thermal motion (Brownian motion)
  - High (free) diffusion along gradients → low signal
  - Low (restricted) diffusion along gradients → high signal
- DW-MRI aims at highlighting the differences in water molecule mobility, irrespective of their direction of displacement.
  - Applying diffusion gradients in at least 3 spatial directions
  - Diffusion magnitude (trace image)
  - T2-weighted image

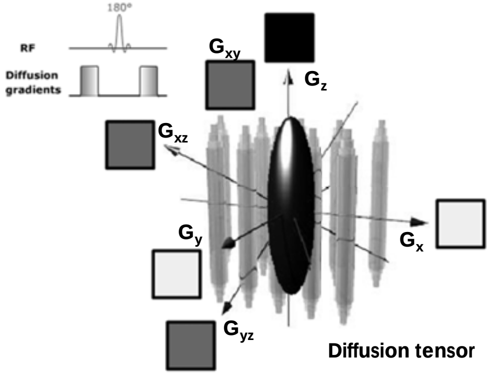
Diffusion weighted imaging, DWI

- Diffusional signal loss by the gradient application
  - $\frac{S}{S_0} = e^{-\gamma^2 G^2 \delta^2 \left(\Delta - \frac{\delta}{3}\right) D} = e^{-bD}$
    - S_0 is the signal intensity with out the diffusion weighting (no gradient application)
    - S is the signal with the gradient application
    - D is a diffusion constant
    - γ is the gyromagnetic ratio
    - G is the gradient strength
    - δ is the gradient duration
    - Δ is the time interval between dephasing and rephasing gradients

b↑, diffusion weighting↑, SNR↓

Diffusion tensor imaging

- Perform diffusion-weighted acquisitions in at least 6 directions
- We can reconstruct the diffusion tensor



IMAIO 2014, http://www.imaios.com/en/e-Courses/e-MRI/Diffusion-Tensor-Imaging/diffusion-tensor-anisotropy

Advantages of EPI

- Scan time is approximately 100 msec or less (32~50 msec).
- Cardiac and respiratory motion won't pose problems.
- PD, T1, and T2 weighted images free of motion artifacts can be achieved.
- It allows the functional studies rather than the mere depiction of anatomy.
- Resolution can be improved due to fast scanning speed.

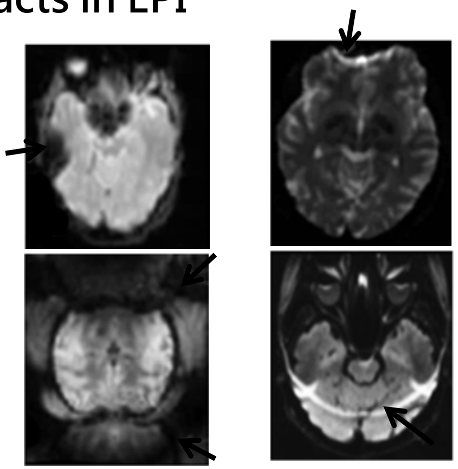
Disadvantages of EPI

- Fat suppression with presaturation techniques is always required (to cancel fat-water chemical shift artifacts).
- Rapid on/off switching of the gradients ➔ possible "electric shock" in the subject
- Potential for phase error (less effect for multi-shot EPI)
- Intrinsic non-uniformities in B0 and susceptibility effects (less effect for multi-shot EPI)

Artifacts in EPI

Signal Dropout

Distortion



Ghosting

Chemical shift

組織壓抑技術

Tissue suppression imaging

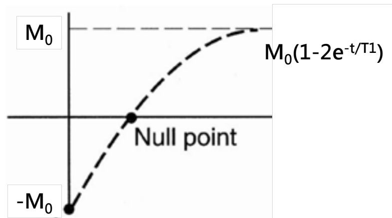
Suppression techniques

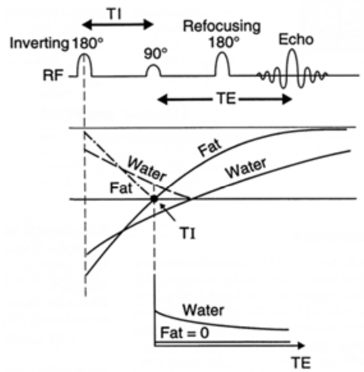
- Two common targets (tissues): fat and water

- Suppression techniques
  - Inversion recovery (IR) techniques
  - Chemical/spectral saturation or frequency-selective presaturation
  - Spatial presaturation in the field of view (FOV)

Inversion recovery, IR

- After the 180º RF pulse, the magnetization starts to recover from $-M_0$ instead of zero.
- TI(null) = (ln2)T1 ≒ **0.693 T1.**



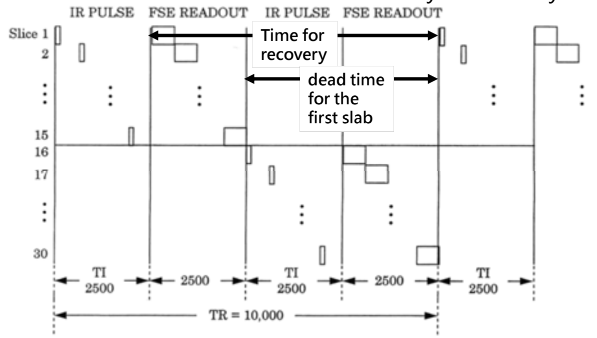


Tissue Suppression: STIR & FLAIR

- STIR: Short TI inversion recovery, fat suppression
  - At 1.5T, TI = 0.693 x 200 = 138.6 msec
- FLAIR: Fluid attenuated inversion recovery, water suppression
  - At 1.5T, TI = 0.693 x 3600 = 2494.8 msec
- Fast FLAIR: IR for water + fast spin echo (FSE)

Fast FLAIR: an example

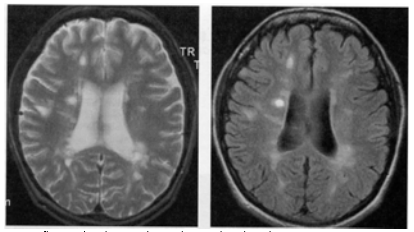
- Two slabs of 15 slices each
- Multi-slice + FSE (ETL = 8, FSE takes 8 x 17 = 136 msec)
- The maximum # of slice in one TR is usually limited by TI



Advantages/Disadvantages of IR

- Advantage
  - No variability caused by magnetic field inhomogeneities
- Disadvantages
  - Tissues with similar T1 values are all suppressed.
  - Long acquisition times caused by long TRs
  - Low SNR

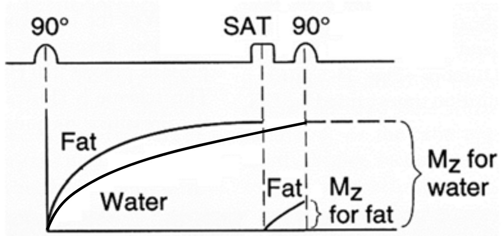
T2



FLAIR
(Better differentiation for multiple sclerosis)

Chemical/spectral presaturation

- A frequency-selective presaturation pulse is applied before the RF excitation pulse.
- We select appropriate frequency (based on the Larmor equation) to suppress fat or water.
- At 1.5T, water protons precess 220 Hz faster than fat protons.



Chemical/spectral presaturation

- Advantages
  - Resolves tissues with similar T1 values (fat and Gd-enhanced tumors)
  - No influence on the signal from other tissues (in contrast, IR affects the contrast of all tissues)
- Disadvantages
  - Suffers from sensitivity to magnetic field inhomogeneities (e.g. metallic susceptibility artifacts).
  - Cause extra RF heating
  - May lengthen TR, thus increasing the scan time (5~8 ms)

Spatial presaturation

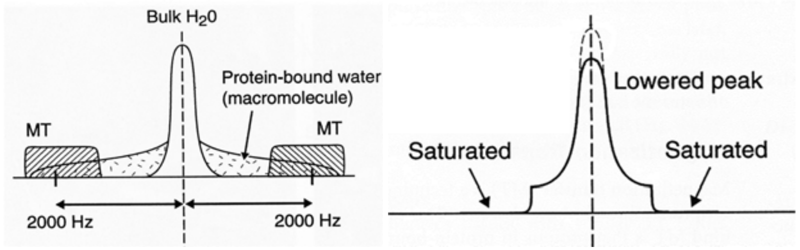
- 90^o saturation pulses are applied on either side of selected volume (anterior/posterior, superior/inferior, right/left).
- To suppress phase ghosts caused by…
  - Motion artifacts
  - Flow-related artifacts
- Applications
  - **Imaging of spine**: a sat. band is placed within the FOV anterior to the vertebral bodies to suppress artifacts arising from the heart and great vessels.
  - **MR angiography**: sat. pulses are placed outside the FOV at one end of a vessel to suppress either venous or arterial flow.

Spatial presaturation

- Advantages
  - Minimize phase ghosts
  - Minimize flow artifacts
- Disadvantages
  - May cause signal suppression in the reminder of the FOV
  - May lengthen TR, thus increasing the scan time (5~8 ms)

Magnetization transfer, MT

- To suppress protein-bound water
- Protons in protein-bound water exhibit a resonant frequency that is approximately 500 to 2500 Hz away from that of bulk water protons.



Magnetization transfer, MT

- MT is similar to spectral fat suppression techniques except that here, the off-resonant frequency is up to 2000 Hz as opposed to 220 Hz in the case of fat suppression.
- Used in time of flight (TOF) MR angiography to suppress the background brain tissue and enhance visualization of smaller vessels

Common Pulse Sequences

Acronym	Phrase	Explanation	Synonyms
CISS	Constructive interference in steady state	Data merging of two 3D trueFISP sequences with and without RF phase alternation to eliminate destructive interference pattern	PC-3D-FIESTA
DESS	Double-echo steady state	Image data merging of FISP and PSIF appearing in adjacent acquisition windows	
DRIVE		TSE with a –90° RF pulse at the end of an echo train in order to increase the signal for tissue with a long T_2 relaxation time	RESTORE, FRFSE
EPI	Echo planar imaging	Single-shot technique using only one excitation, followed by multiple phase-encoded gradient-echoes to fill the *k*-space	
FFE	Fast field echo	GRE with low–flip angle excitation and rephasing in the direction of phase encoding after data acquisition of a single Fourier line	FISP, GRASS
FIESTA	Fast imaging–employing steady-state acquisition	GRE with low–flip angle excitation and rephasing in all directions after data acquisition of a single Fourier line	trueFISP, bFFE

Magnetic Resonance Tomography, Reiser et al, 2008 by Springer.

Acronym	Phrase	Explanation	Synonyms
FISP	Fast imaging with steady-state precession	GRE with low–flip angle excitation and rephasing in the direction of phase encoding after data acquisition of a single Fourier line	FFE, GRASS
bFFE	Balanced FFE	GRE with low–flip angle excitation and rephasing in all directions after data acquisition of a single Fourier line	trueFISP, FIESTA
FLASH	Fast low-angle shot	GRE with low–flip angle excitation and "spoiling" after data acquisition of a single Fourier line	T_1-FFE, SPGR
FLAIR	Fluid-attenuated inversion recovery	Liquor suppressed imaging protocol using an IRM sequence (long inversion time)	–
FRFSE	Fast-recovery fast spin echo	FSE with a –90° RF pulse at the end of an echo train in order to increase the signal for tissue with a long T_2 relaxation time	DRIVE, RESTORE
FSE	Fast spin echo	SE using multiple phase–encoded echoes for faster filling of *k*-space	TSE, RARE
FSPGR	Fast spoiled GRASS	Spoiled GRASS with inversion or saturation pulse preceding the whole measurement in order to establish T_1 weighting or for the nulling of the signal of a specific tissue	TFL, TFE
GRASE	Gradient and spin echo	FSE with multiple phase–encoded gradient-echoes within a SE envelope	TGSE
GRASS	Gradient-recalled acquisition in the steady state	GRE with low–flip angle excitation and rephasing in the direction of phase encoding after data acquisition of a single Fourier line	FISP, FFE

Magnetic Resonance Tomography, Reiser et al, 2008 by Springer.

Acronym	Phrase	Explanation	Synonyms
HASTE	Half-Fourier single-shot turbo spin echo	TSE utilizing the half-Fourier technique	
IR	Inversion recovery	SE with preceding RF inversion pulse	
MP-RAGE	Magnetization prepared rapid gradient echo	3D TFL version	
T_1-FFE	T_1 fast field echo	GRE with low–flip angle excitation and "spoiling" after data acquisition of a single Fourier line	FLASH, SPGR
PSIF	Backward-running FISP	Acquiring an RF refocused signal using a time reversed FISP sequence	T_2-FFE, SSFP
RARE	Rapid acquisition with relaxation enhancement	SE using multiple phase–encoded echoes for faster filling of *k*-space	TSE, FSE
RESTORE	Fast-recovery fast spin echo	TSE with a –90° RF pulse at the end of an echo train in order to increase the signal for tissue with a long T_2 relaxation time	DRIVE, FRFSE
SE	Spin echo	90–180° sequence	
SPGR	Spoiled gradient-recalled acquisition in the steady state	GRE with low–flip angle excitation and "spoiling" after data acquisition of a single Fourier line	FLASH, T_1-FFE
STEAM	Stimulated echo acquisition mode	Sequence using three 90° RF pulses	

Magnetic Resonance Tomography, Reiser et al, 2008 by Springer.

Acronym	Phrase	Explanation	Synonyms
STIR	Short T_1 inversion recovery	TIRM sequence using a short inversion time suitable for suppressing the signal from fat	
TGSE	Turbo gradient spin-echo	TSE with multiple phase-encoded gradient-echoes within an SE envelope	GRASE
TIR	Turbo inversion recovery	TSE with preceding inversion pulse (phase sensitive)	IR-FSE
TIRM	Turbo inversion recovery magnitude	TSE with preceding inversion pulse and utilizing only the magnitude of the signal (phase insensitive)	
trueFISP	True fast imaging with steady-state precession	GRE with low-flip angle excitation and rephasing in all directions after data acquisition of a single Fourier line	FIESTA, bFFE
TSE	Turbo spin echo	SE using multiple phase-encoded echoes for faster filling of *k*-space	FSE, RARE
TFE	Turbo field echo	T_1-FFE with inversion or saturation pulse preceding the whole measurement in order to establish T_1 weighting or for the nulling of the signal of a specific tissue	TFL, FSPGR
TFL	Turbo fast low-angle shot	FLASH with inversion or saturation pulse preceding the whole measurement in order to establish T_1 weighting or for the nulling of the signal of a specific tissue	TFE, FSPGR
VIBE	Volume-interpolated breath-hold examination	3D GRE with low-flip angle excitation and "spoiling" after data acquisition of a single Fourier line and Fourier interpolation in the direction of partition encoding	

Magnetic Resonance Tomography, Reiser et al, 2008 by Springer.

THE END

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