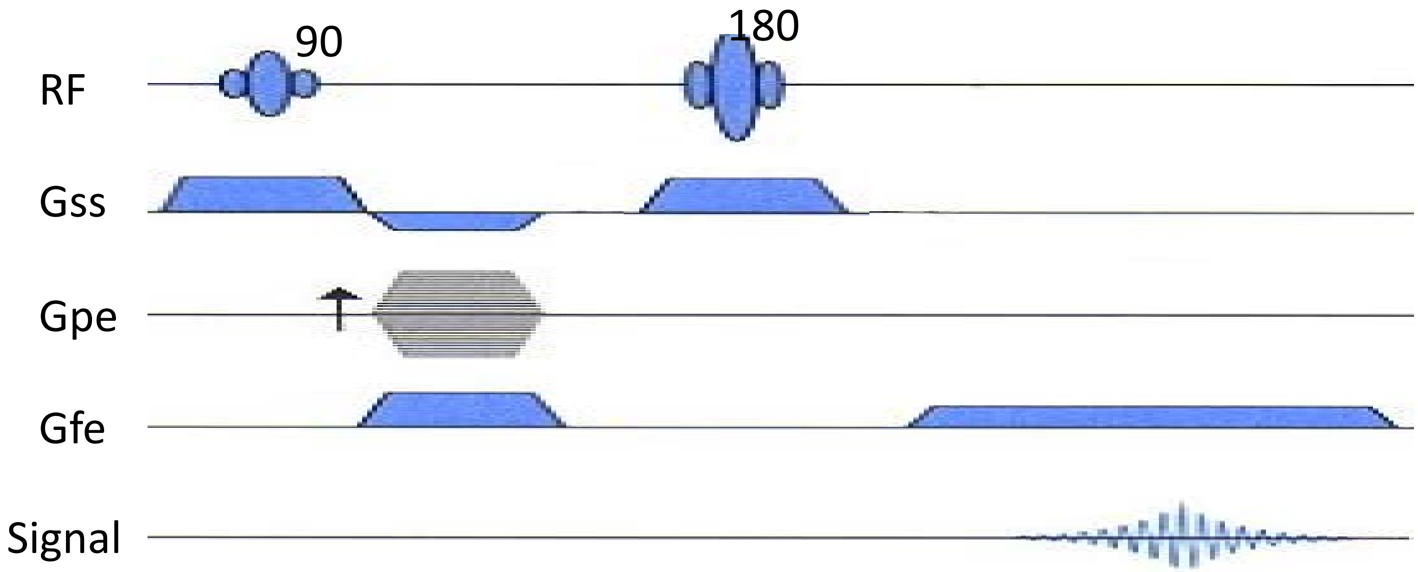
Pulse Sequences

Lei Qin, PhD
Dana-Farber Cancer Institute

Outline

- Spin echo
  - Conventional spin echo
  - Fast spin echo
- Gradient echo
- Echo-planar imaging (EPI)
- Inversion recovery
- Fat Saturation

Conventional spin echo



- Gold standard for most imaging
- May be used for every examination
- T1 images useful for demonstrating anatomy – because high SNR. With contrast enhancement T1 images show pathology
- T2 images also demonstrate pathology. Diseased tissues are generally more edematous and/or vascular. They have increased water content and, have a high signal on T2 images

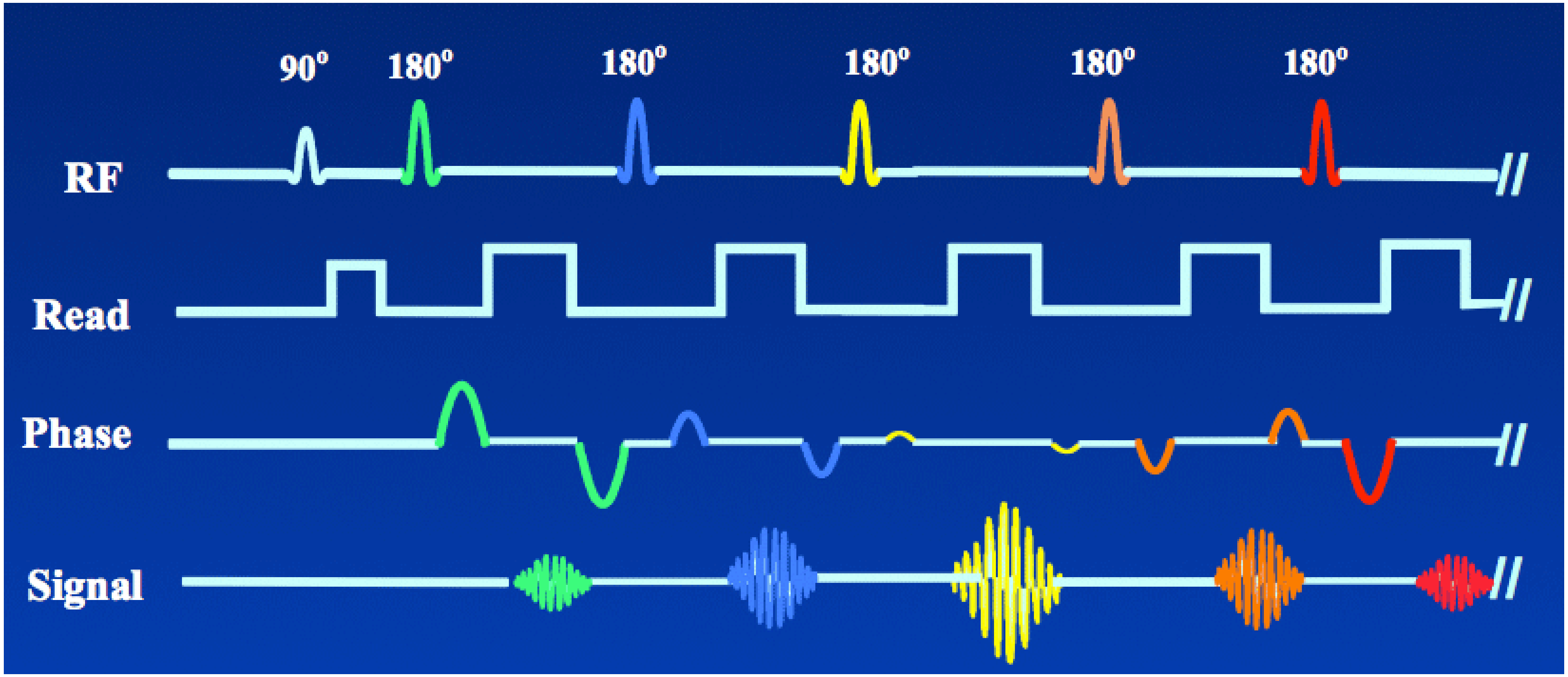
Parameters

- T1 weighting
  - Short TE 10-20 ms
  - Short TR 300 – 600 ms
  - Typical scan time 4-6 min
- Proton density/T2
  - Short TE 20 ms/long TE 80 ms+
  - Long TR 2000 ms+
  - Typical scan time 7-15 min

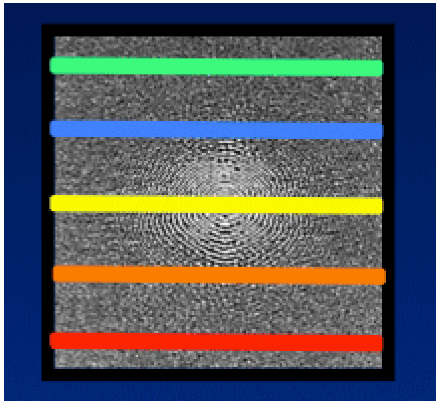
Conventional spin echo (SE)

- Advantages
  - Good image quality
  - Very versatile
  - True T2 weighting sensitive to pathology
- Disadvantages
  - Scan times relatively long

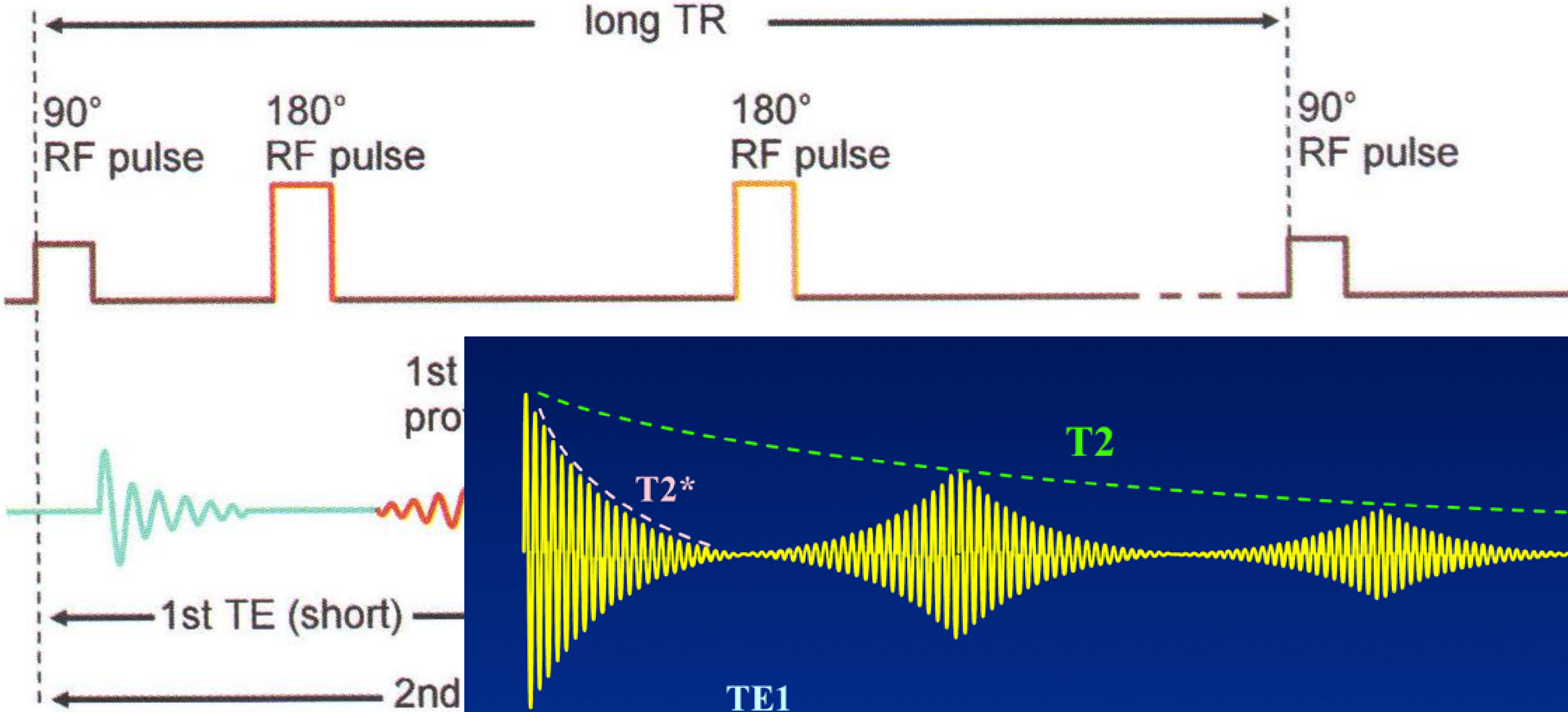
Fast spin echo (FSE)

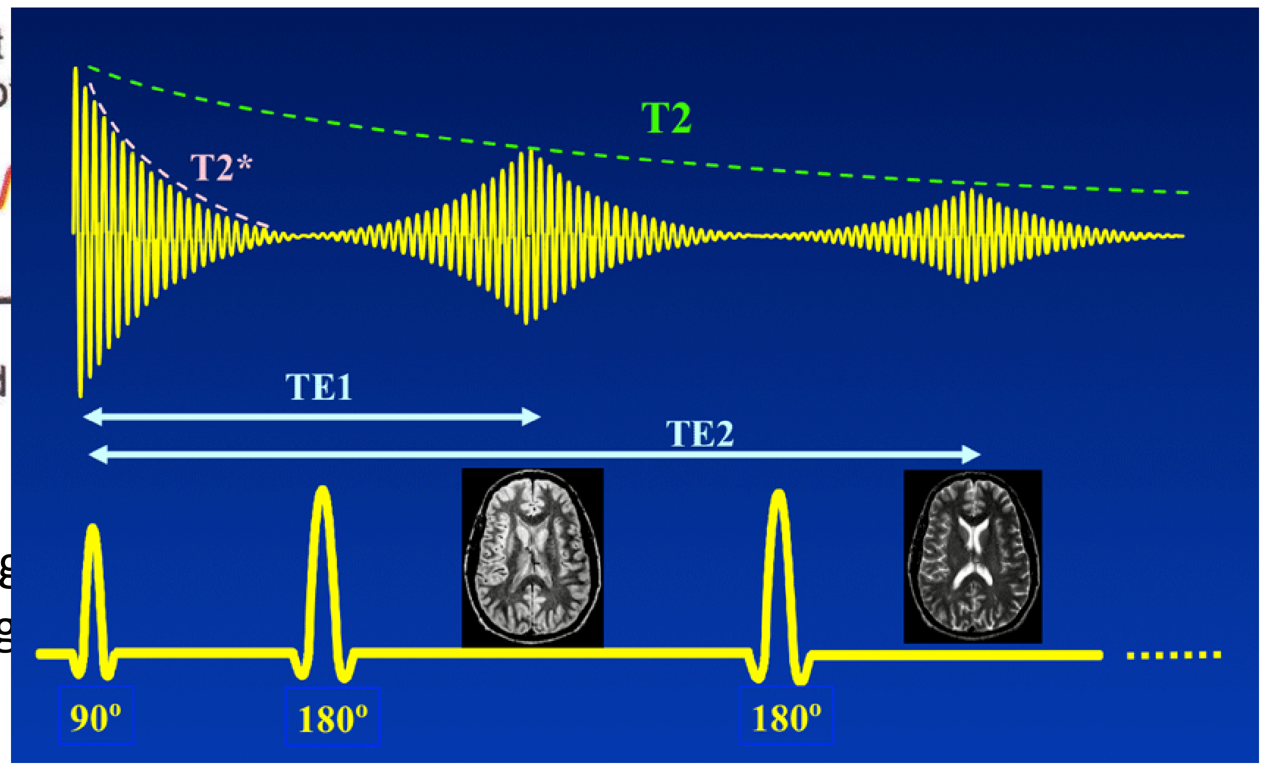


In contrast to conventional spin echo, fast spin echo applies a train of 180^0 pulses per TR and different phase encoding steps are used.



Multi-echo spin echo

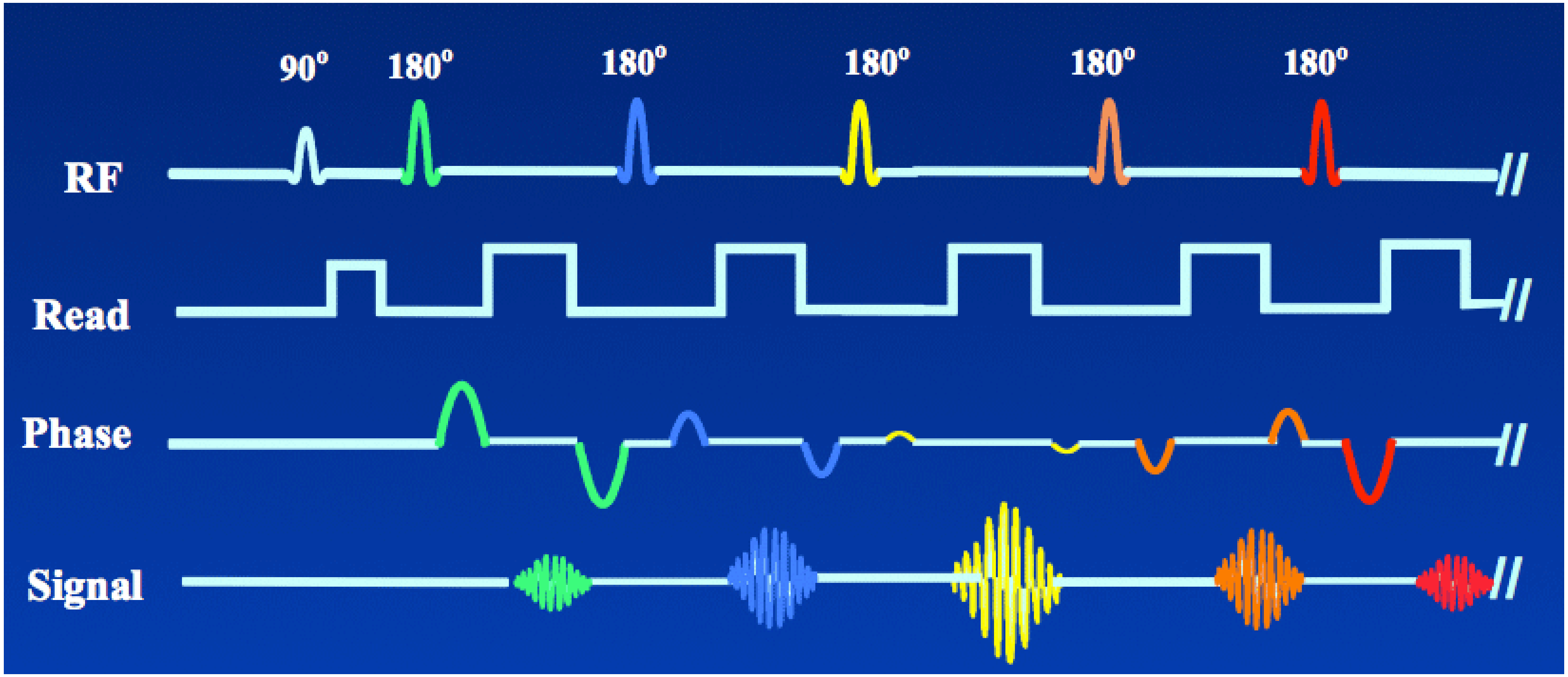




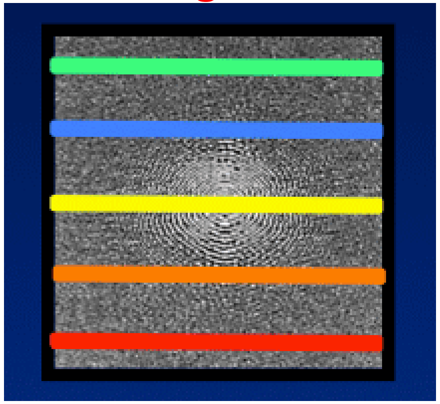
T2 weighting: long

PD weighting: long

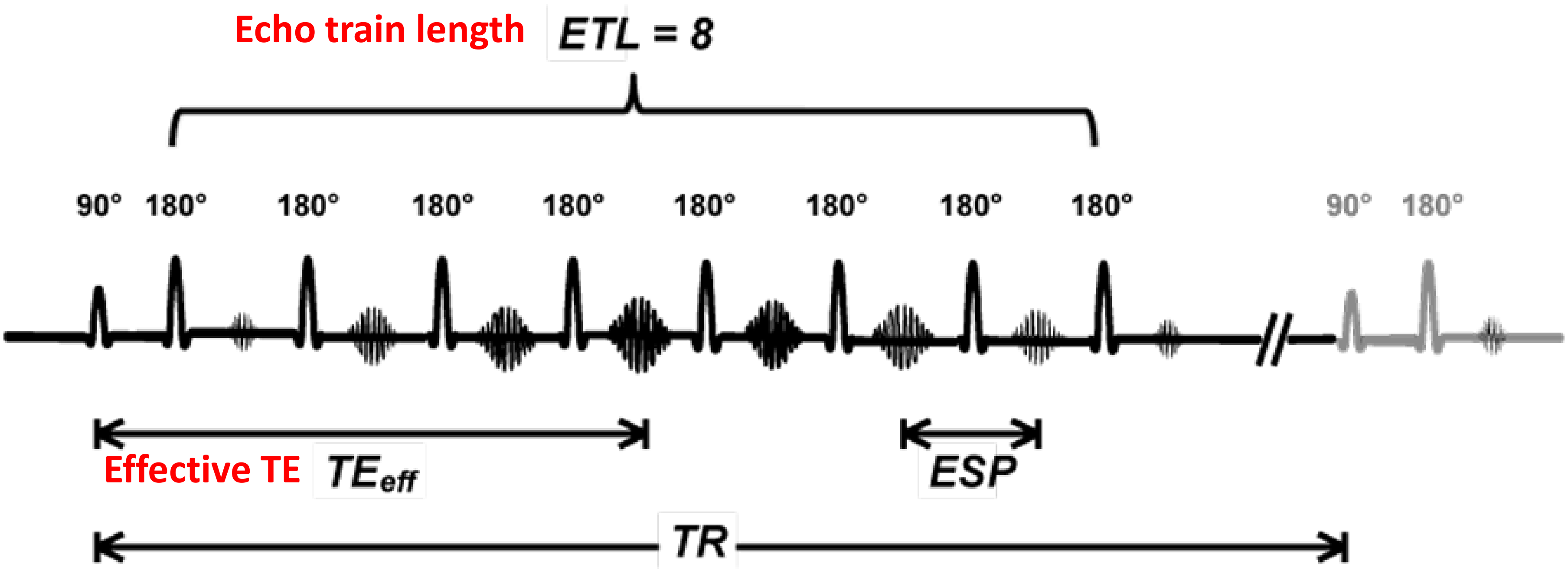
Fast spin echo (FSE)



Why the echoes are not uniformly diminishing in size with increasing *TE* ?

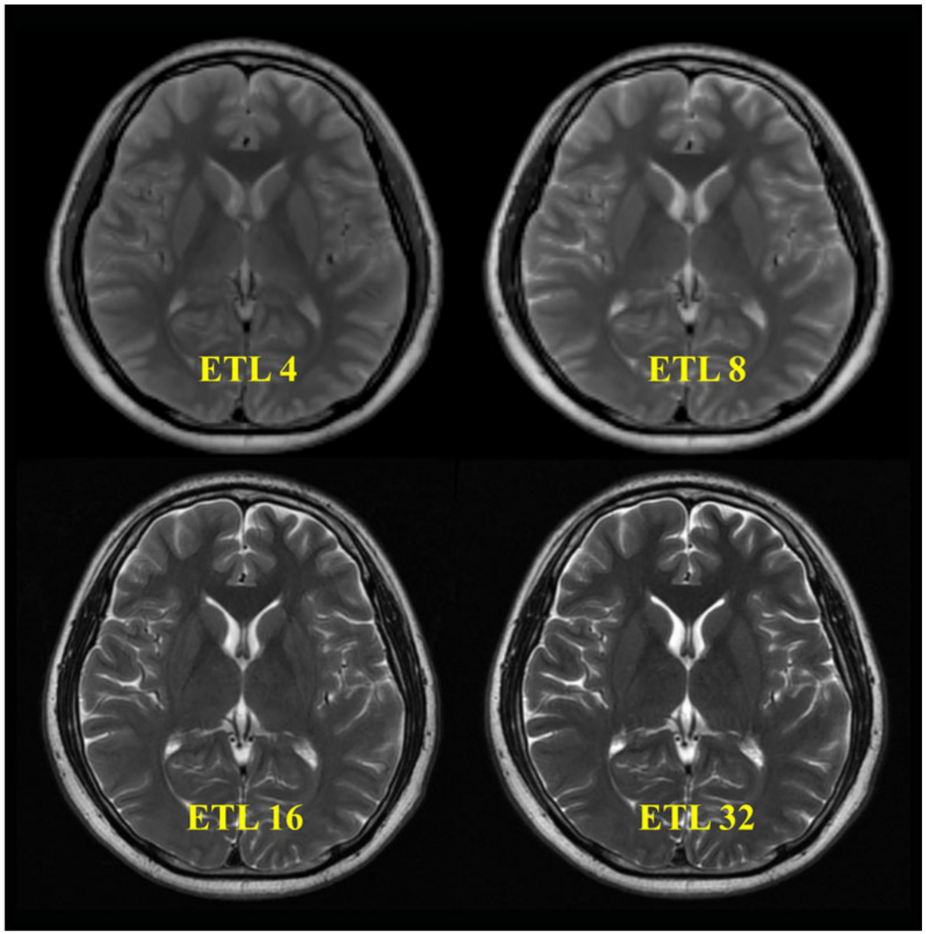


FSE Parameters



The ***effective TE*** dictating overall image contrast is determined by the *TE* at which the low-order steps were performed.

Echo Train Length (ETL)



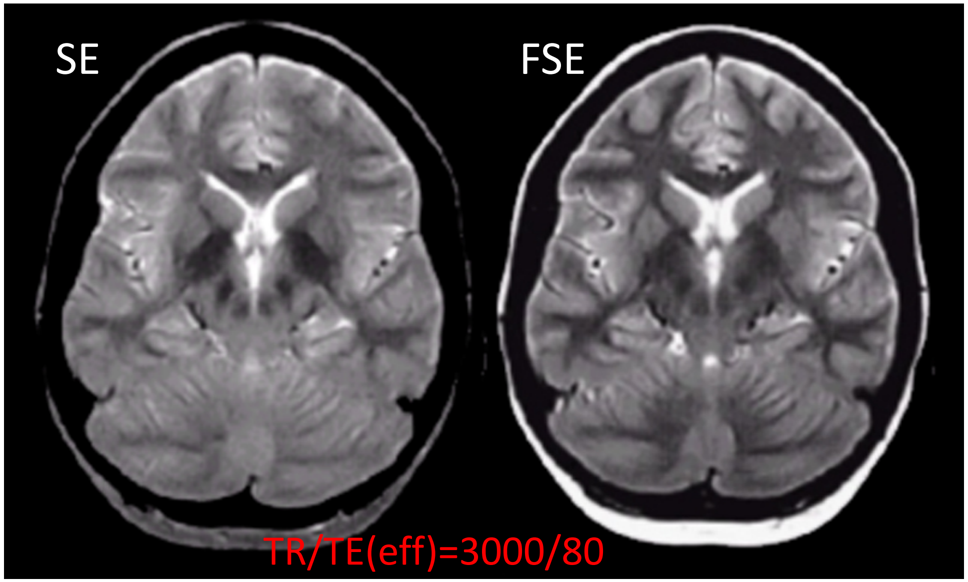
- Longer ETLs result in more T2-weighting because more late echoes with longer TE's contribute to the overall signal
- Longer ETL's are also associated with a decrease in overall SNR because the later echoes are weaker
- Later echoes at very long TE's also produces more spatial blurring

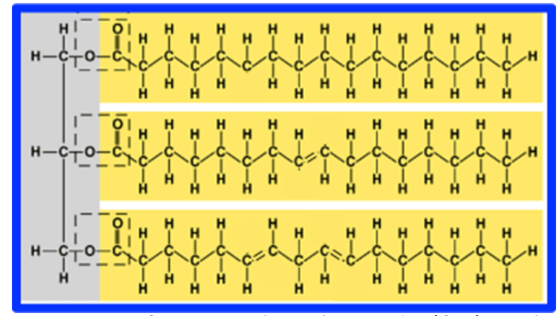
- Each 180^0 pulse produce an echo
- This drastically reduce the scan time
- An effective TE is defined as the time from RF excitation to the echo which has the least phase encoding.
- The number of 180^0 pulses in the train called the *turbo factor* or *train length*
- E.g. if in conventional SE 256 phase matrix and 1 NEX is used, the scan time is 256TR
- In FSE if the turbo factor is 16, the scan time is 256TR/16 =16TR

Parameters

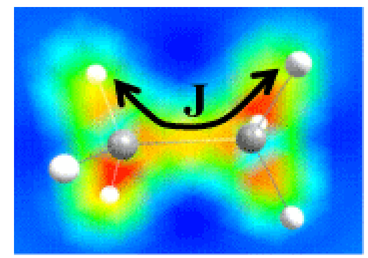
- T1 weighting
  - Short effective TE less than 20ms
  - Short TR 300 – 700 ms
  - Turbo factor 2-6
  - Typical scan time 30s to 1 min
- T2 weighting
  - Long effective TE 100 ms
  - Long TR 4000 ms+
  - Turbo factor 8-30
  - Typical scan time 2 min
- PD weighting
  - Minimum effective TE <20 ms
  - Long TR 4000 ms+
  - Turbo factor 2-6
  - Typical scan time 3-4 min

Bright Fat on FSE





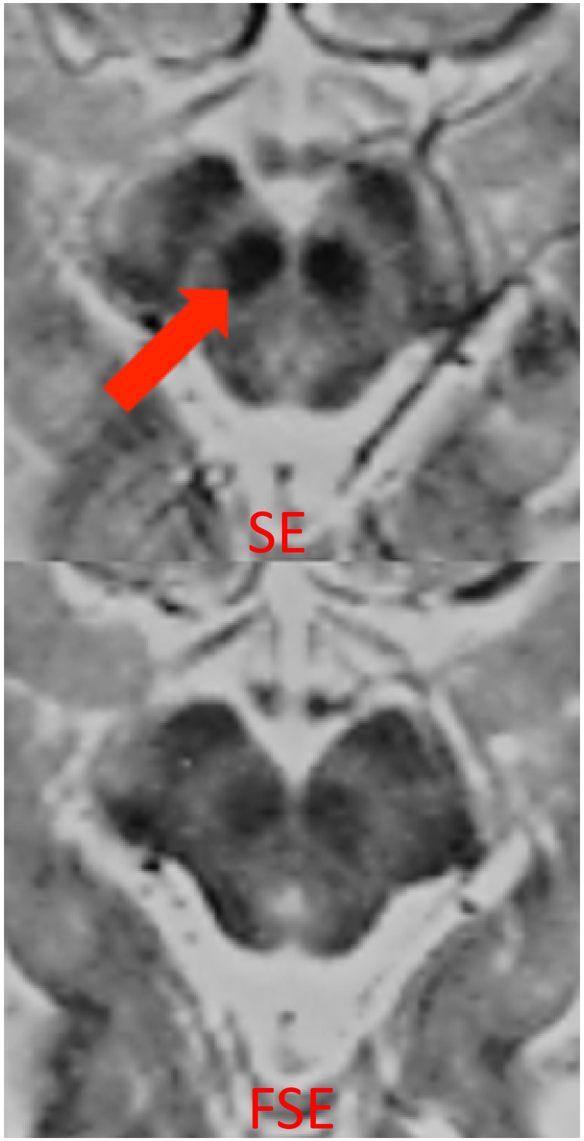
Structure of a typical triglyceride (fat) molecule



J-coupling interaction between neighboring protons is a quantum-derived effect mediated through distortions of electron clouds

- The strength of the *J*-coupling interaction is quantified by the factor *J*, a resonance frequency offset that for lipid protons has values in the range of 6 to 8 Hz. This small frequency shift means that various protons in the lipid will precess at slightly different frequencies. The first out-of-phase interference will occur at *TE= 1/2J*, or at approximately 60-80 ms.
- Multiple 180°-pulses, when applied at intervals shorter than 1/*J (e.g. every 10ms)*, render all *J*-coupled spins chemically "equivalent." The resultant signal is the no longer modulated by the coupling. Hence, the fat on FSE imaging appears brighter than that seen on CSE images.
- In a sense, therefore, it might be said that fat on T2-weighted CSE imaging is abnormally dark, rather than the fat on FSE being abnormally bright.

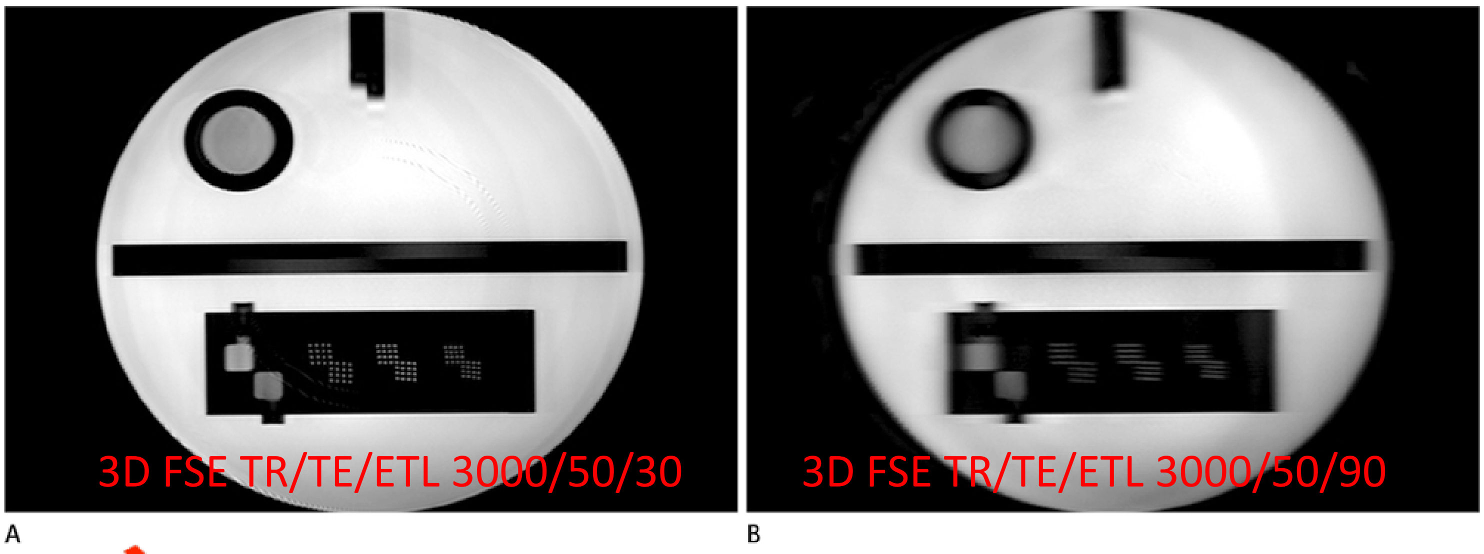
Decreased sensitivity to susceptibility

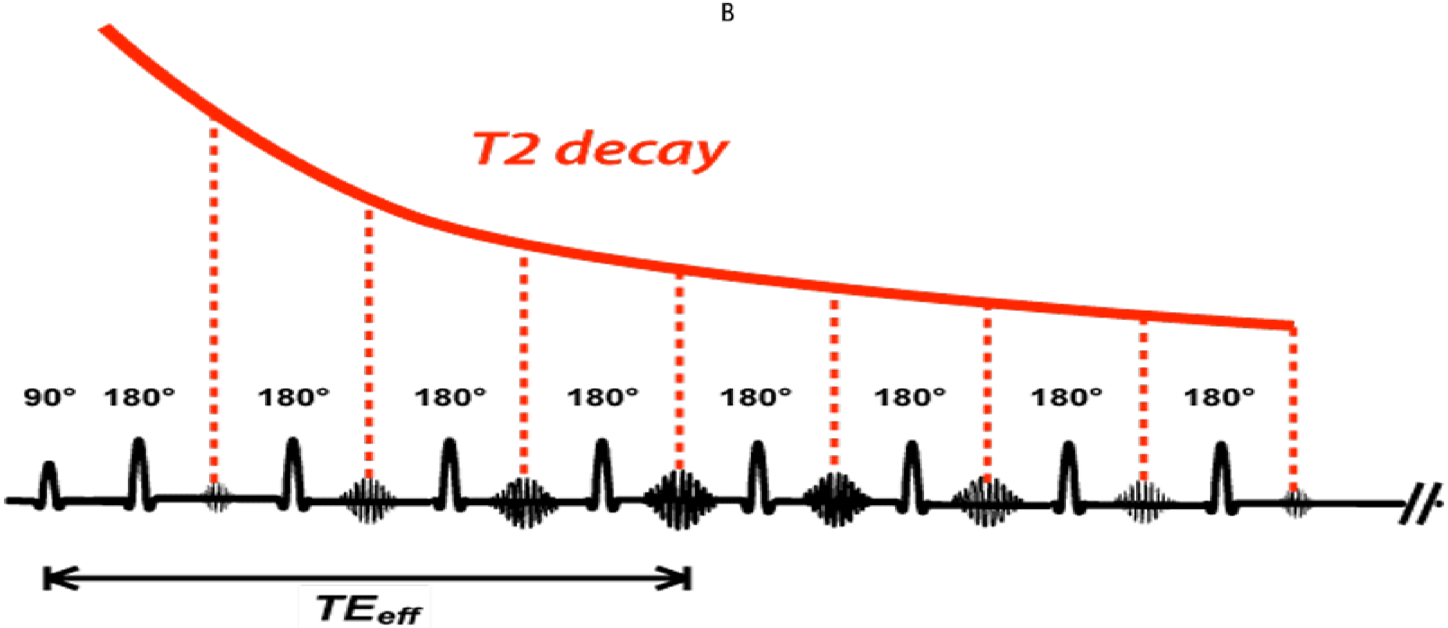


TR/TE(eff)=3000/80

- Microscopic iron deposits cause local distortions of the magnetic field, known as ***magnetic susceptibility gradients***.
- When water molecules diffuse through these gradients, accelerated spin dephasing and T2*- shortening occurs, reducing the MR signal.
- The degree of signal loss depends on the time diffusing water spends in the inhomogeneous fields before refocusing by 180°-pulses. In CSE, the time for refocusing is determined by TE, which may be 50 ms or longer. In FSE, however, 180°-refocusing pulses occur at very short intervals, determined by ESP (typically 5-10 ms), allowing much less time for susceptibility-induced dephasing.

FSE Image Blurring

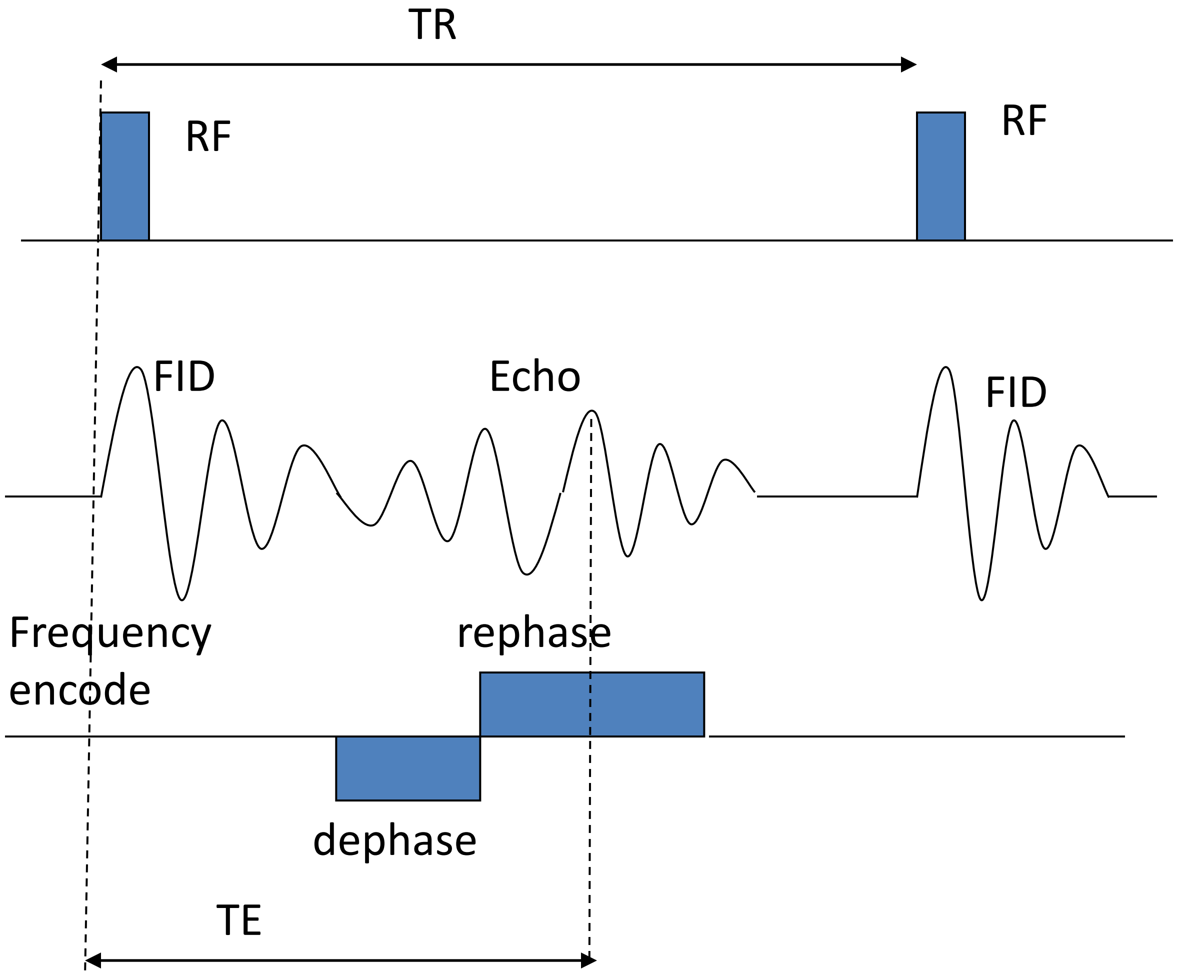




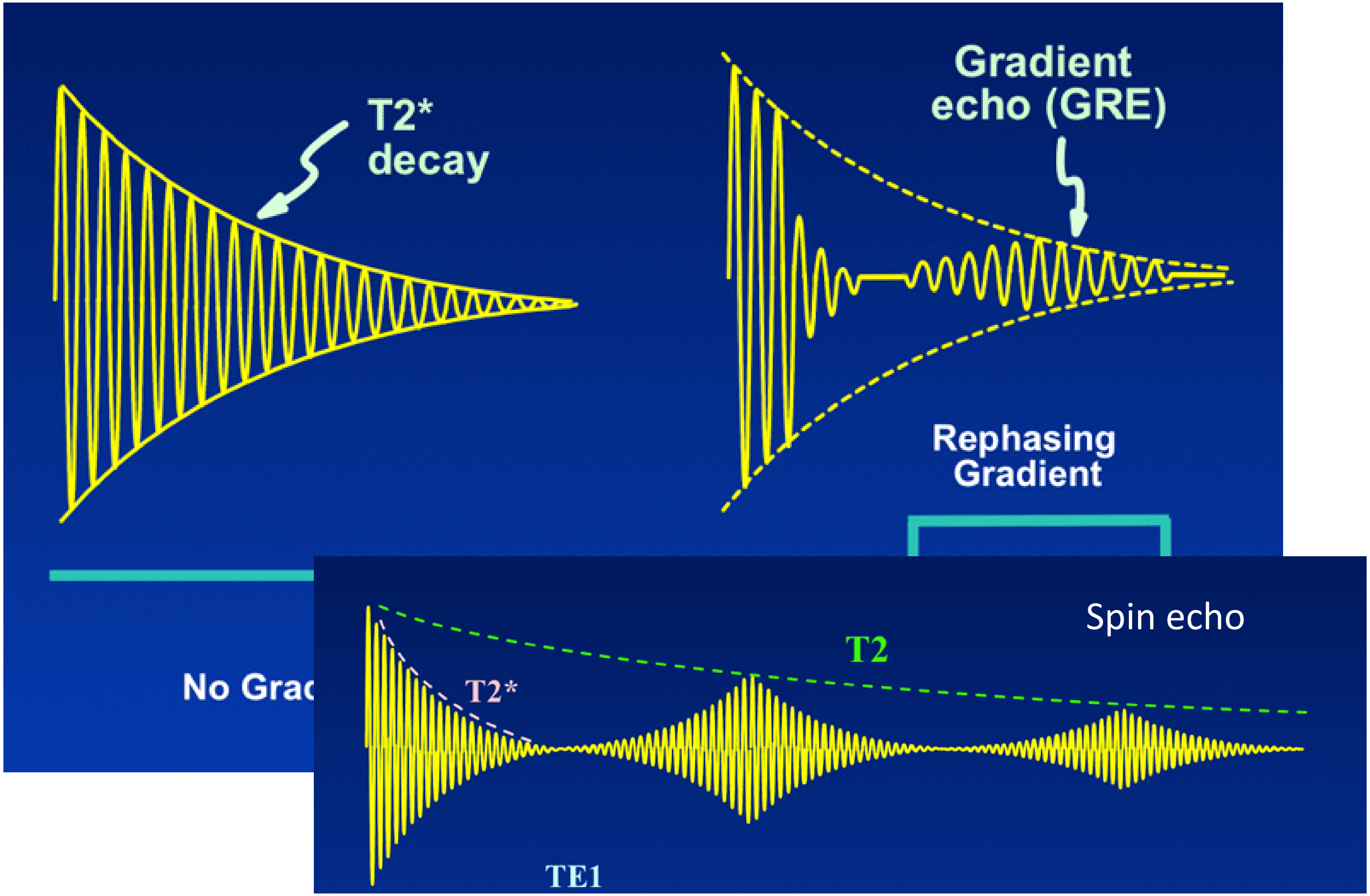
Advantages & Disadvantages

- Advantages
  - Decreased scan times
  - Heavy T2 weighting
  - Versatile – can be used for all weighting in all body regions/parts
  - Long TR's (good for T2 weighted imaging)
- Disadvantages
  - Edge blurring (due to the long echo train)
  - Bright fat on T2 weighted imaging
  - Long TR's (bad for T1 weighted imaging)

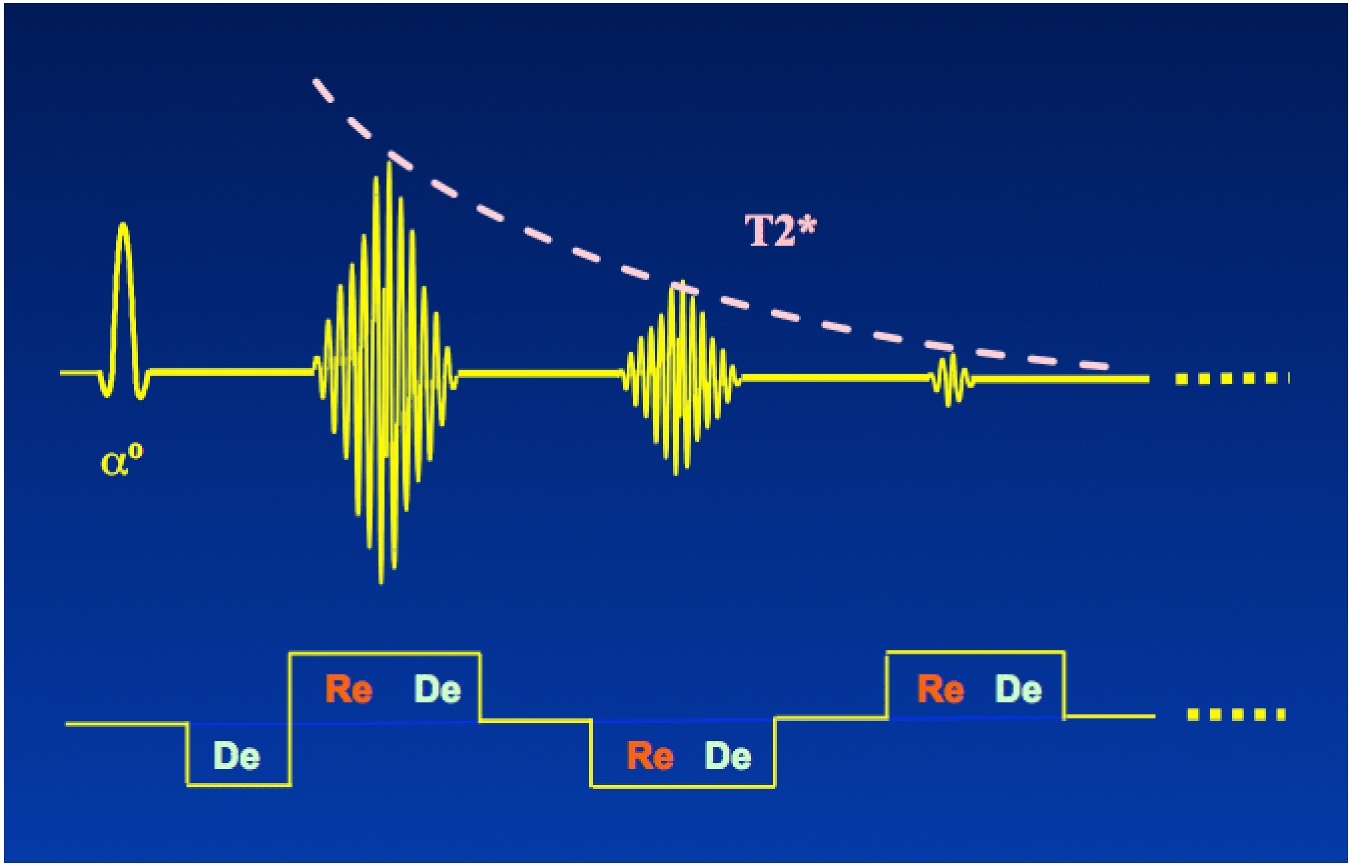
Conventional gradient echo



Conventional gradient echo

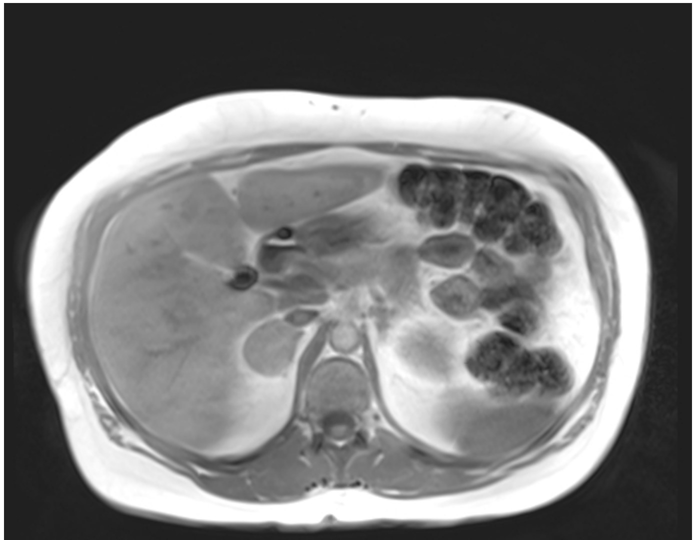


Dual/Multi-echo GRE

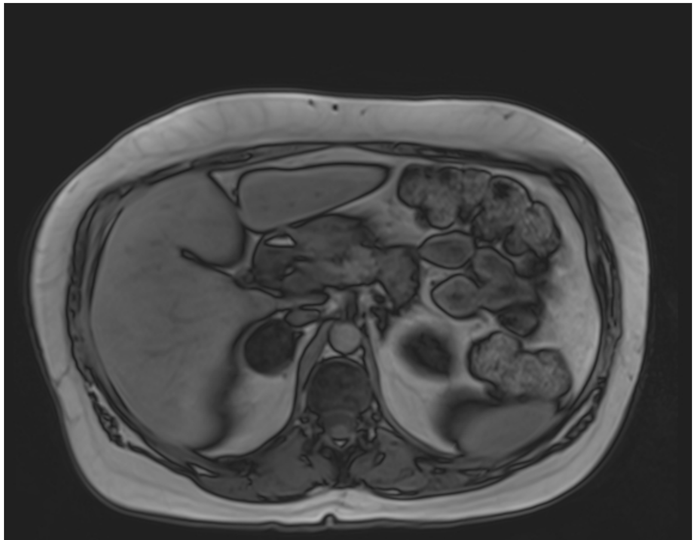


because of T2*-decay, the maximum usable number of echoes is only 3-4 in most cases

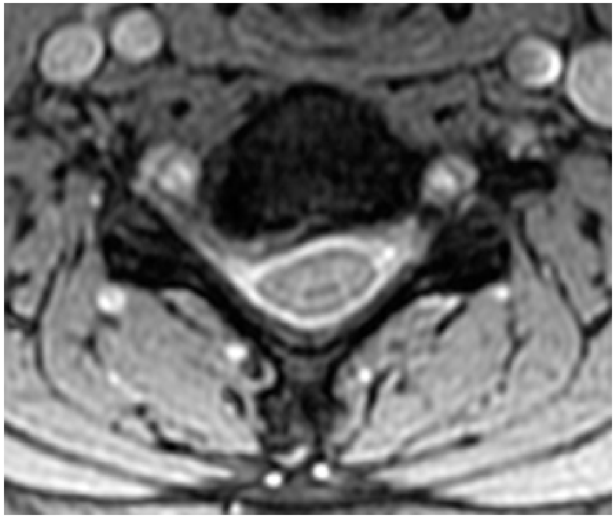
Dual/Multi-echo GRE



In-phase GRE image, TE=4.4



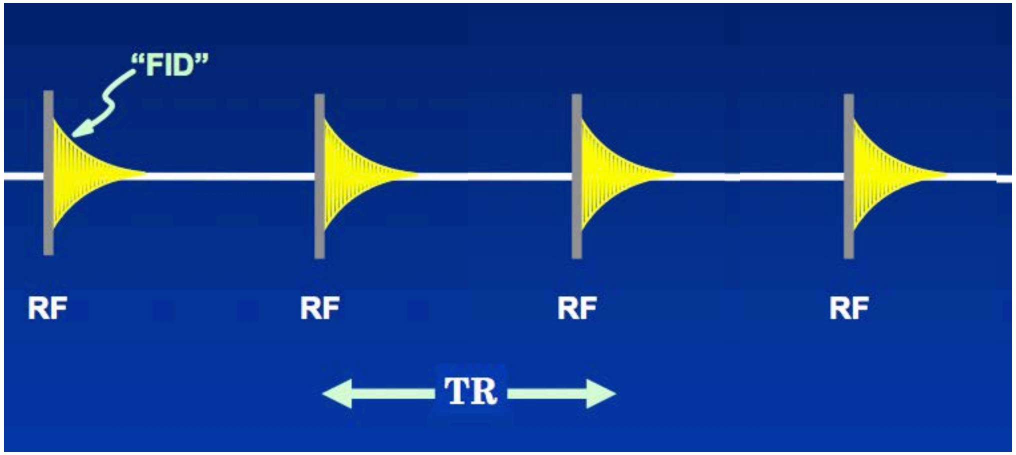
Out-of-phase GRE image, TE=2.2



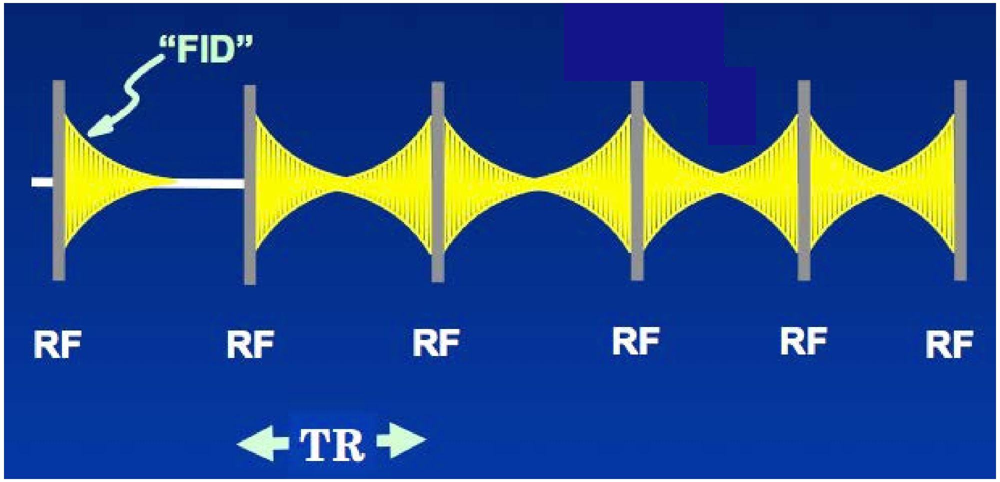
MERGE (GE) /MEDIC (Siemens) C-spine image

GRE sequences

Spoiled GRE sequences: complete disruption of transverse coherences

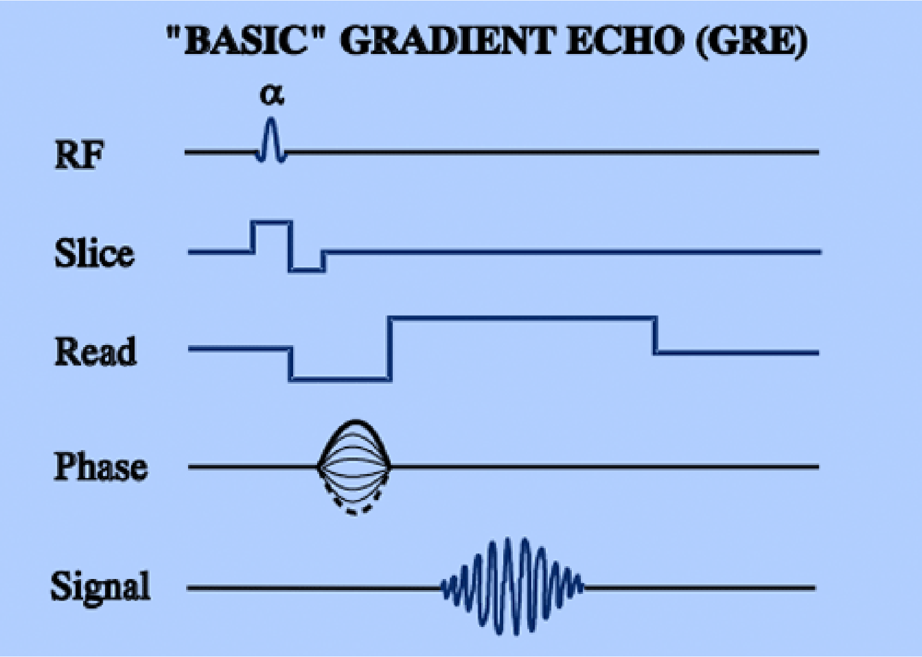


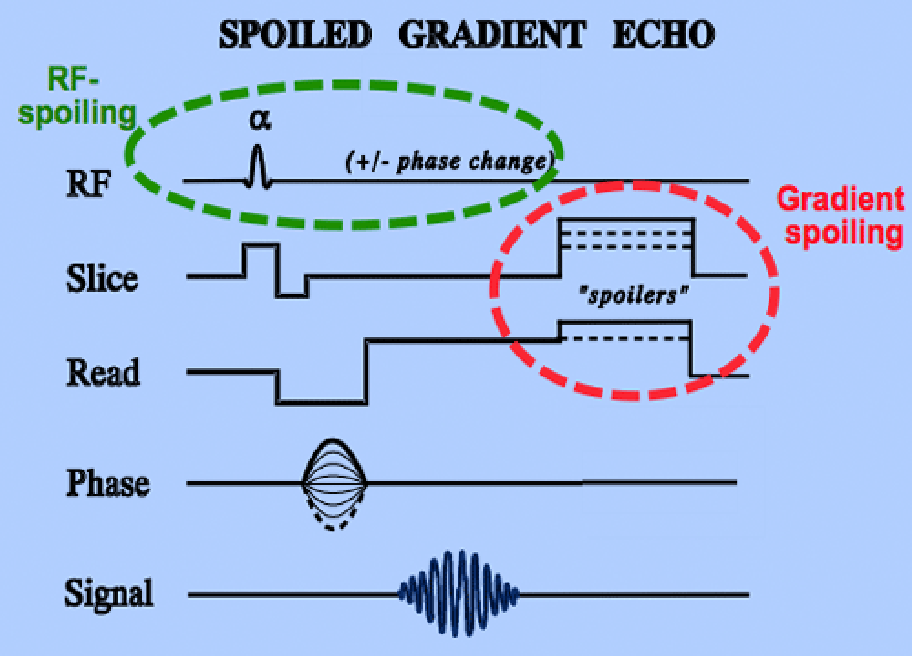
Coherent GRE sequences: preservation of transverse coherences



The transverse signal never completely disappears and the result is called a ***steady-state free precession (SSFP)***.

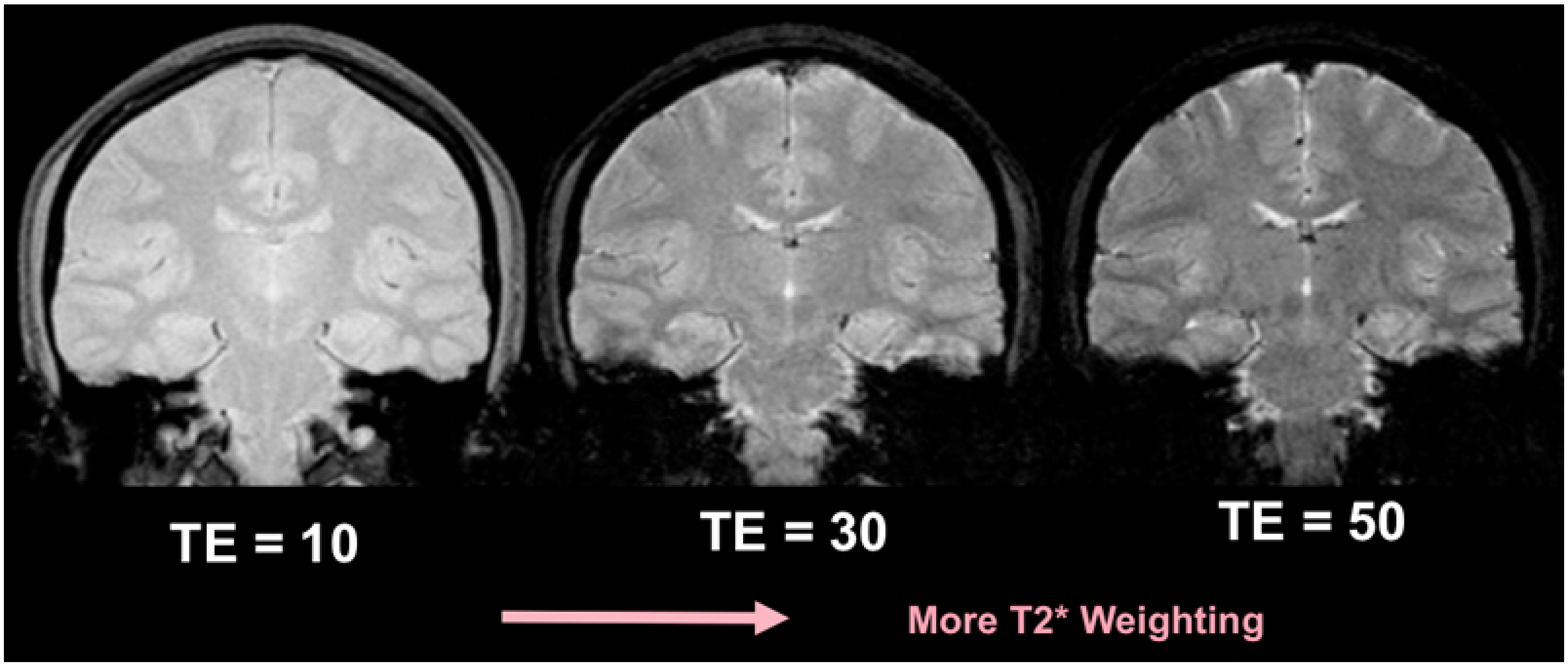
Spoiled GRE sequences





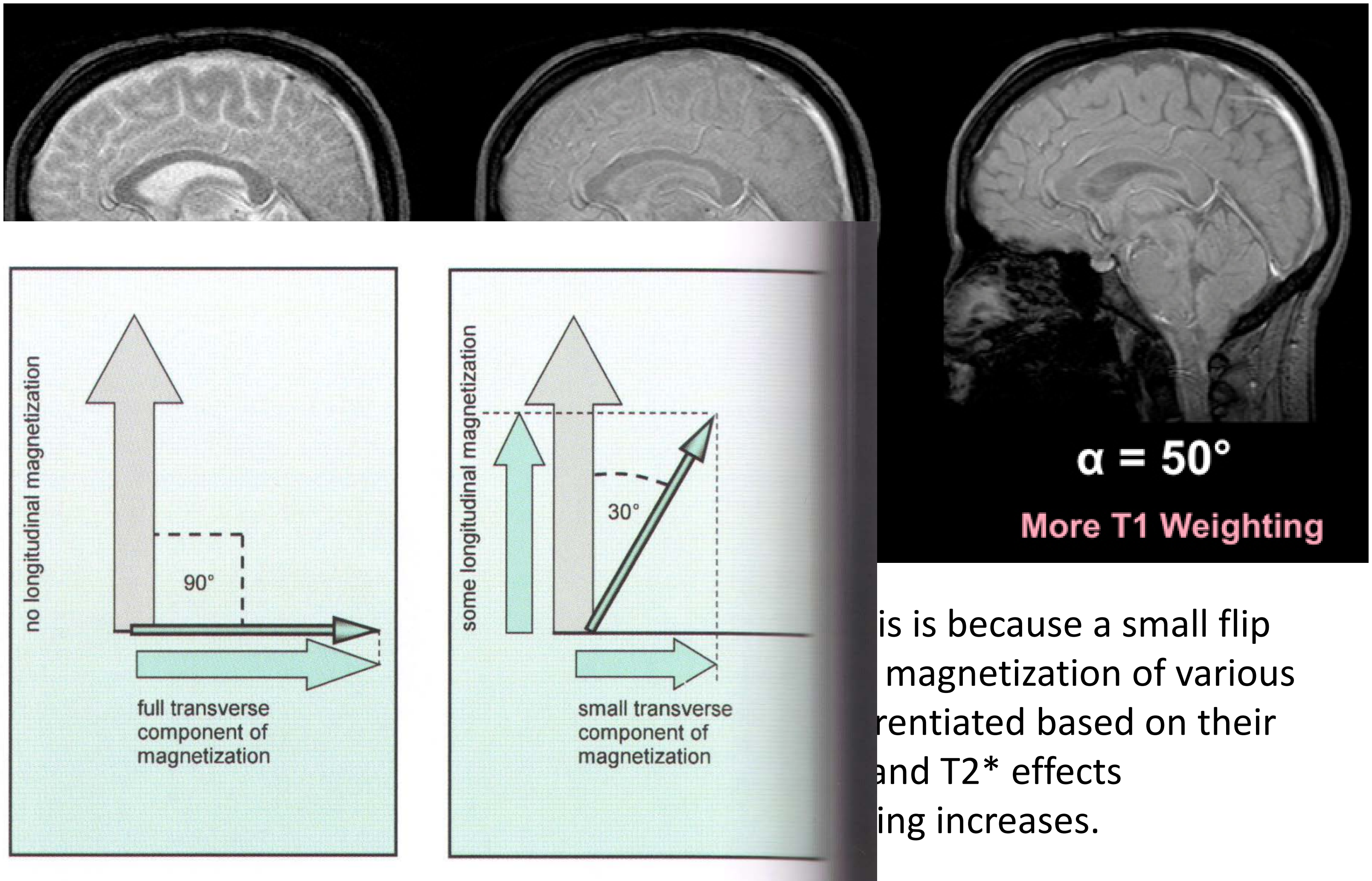
1. Long TR spoiling
2. Gradient spoiling
3. RF-spoiling (FLASH, SPGR, VIBE, LAVA)

Spoiled GRE sequences



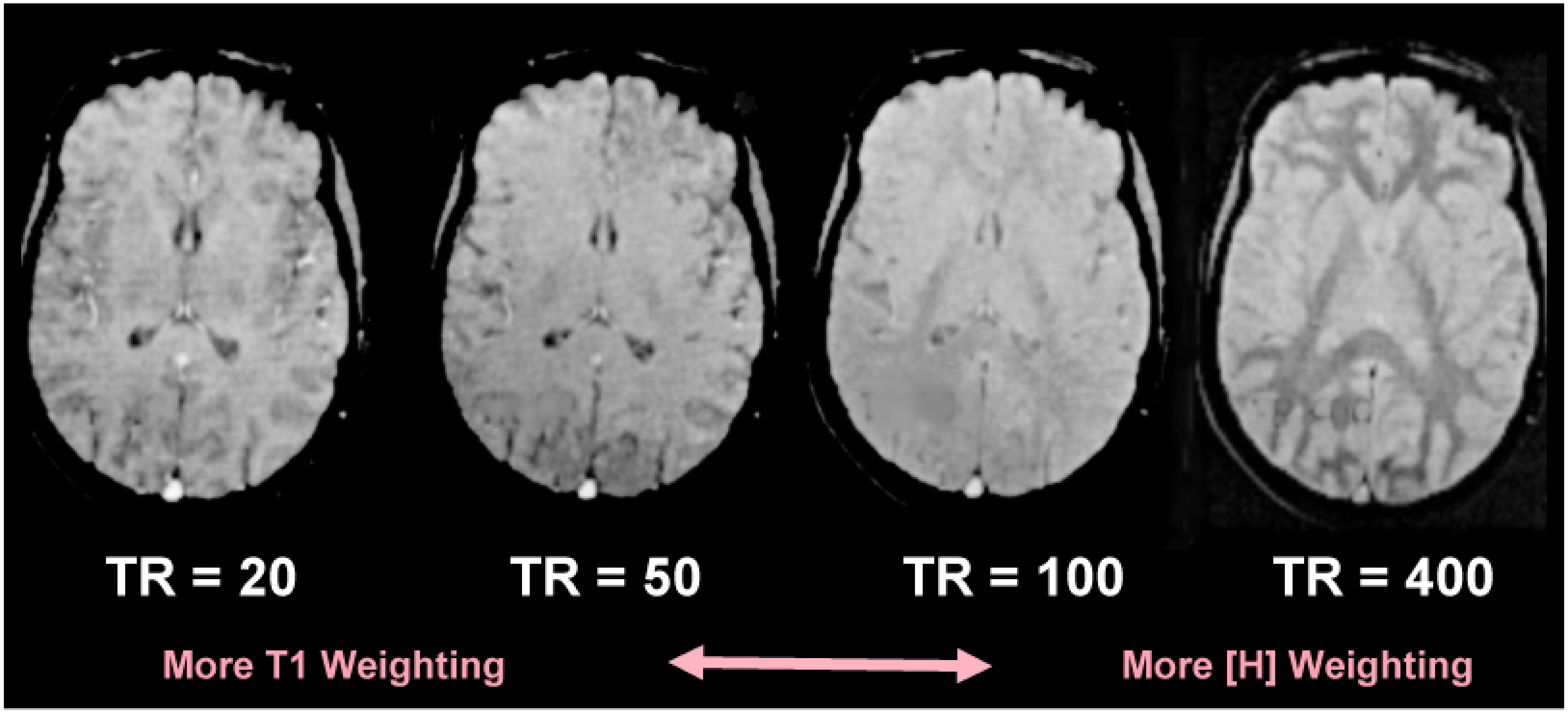
T2*-weighting increases as *TE* is prolonged. This is because a longer *TE* allows more time for dephasing before echo formation.

Spoiled GRE sequences



is is because a small flip
magnetization of various
rentiated based on their
and T2* effects
ing increases.

Spoiled GRE sequences

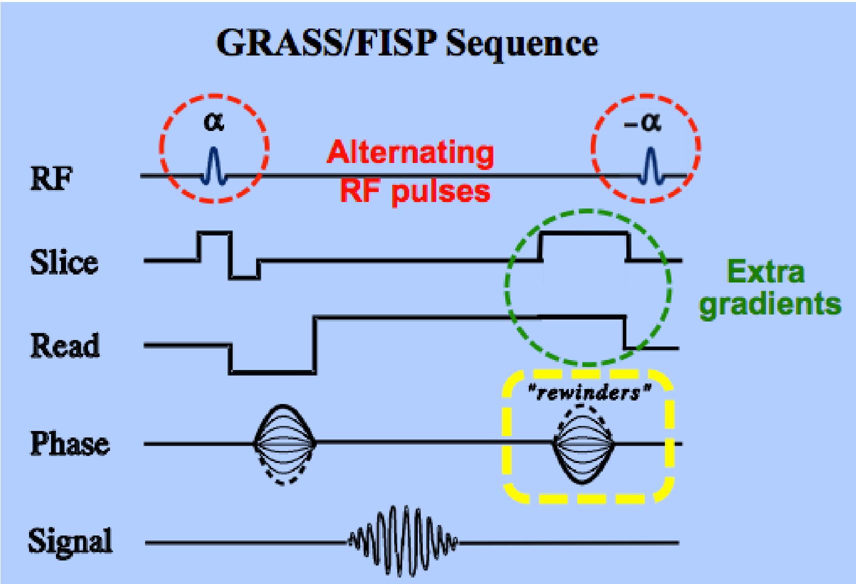


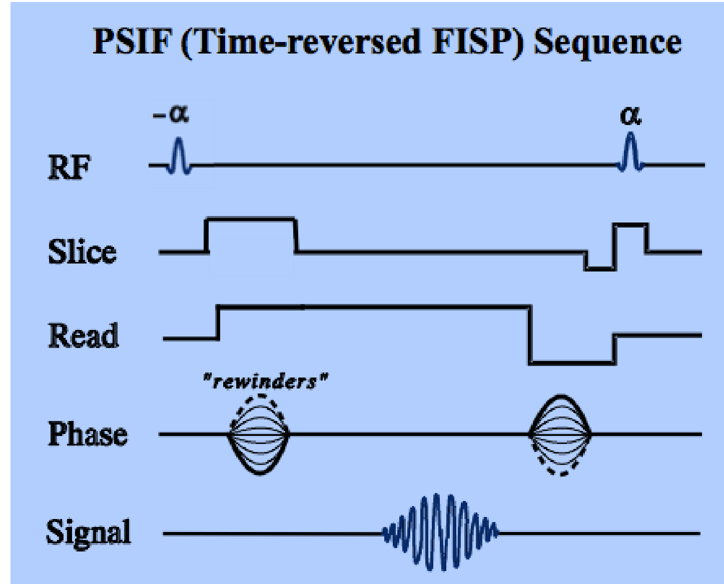
Short *TRs* accentuate T1 effects. Long *TRs* minimize T1 effects, allowing [H]-and T2*-weighting to become dominant.

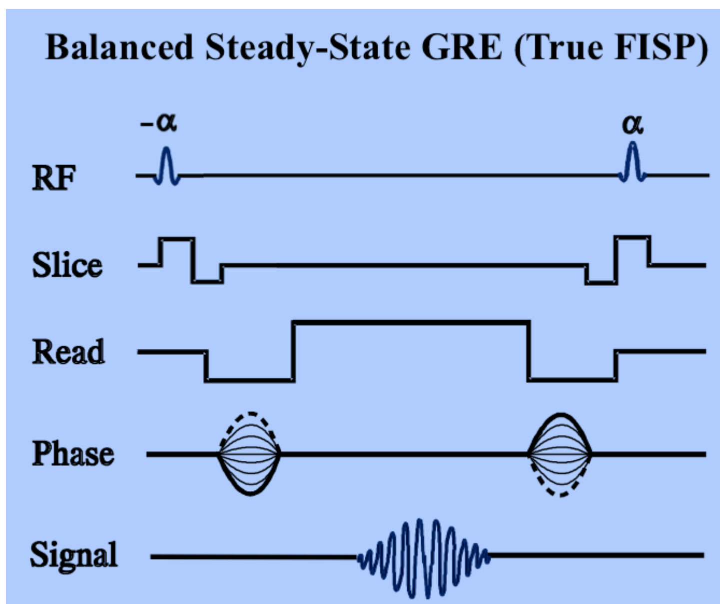
Typical spoiled GRE-parameters to achieve different contrast weightings applicable for 1.5T

Desired Image Contrast	Parameter Selection	Reason
T1-Weighting	Short TR (5-10 ms) Short TE (2-5 ms) Intermediate α (30-50°)	T1 contrast would theoretically be better with α = 60-90°, but signal would be weak because far from Ernst angle; α = 30-50° is compromise for good signal and T1-weighting at short TR values
[H]-Weighting	Long TR (100-400 ms) Short TE (2-5ms) Small α (5-20°)	Long TR and small α minimize T1 weighting; short TE minimizes T2* effects
T2*-Weighting	Long TR (200-800 ms) Long TE (20-50 ms) Small α (5-20°)	Long TR and small α minimize T1 weighting; long TE maximizes T2* effects.

Coherent GRE sequences





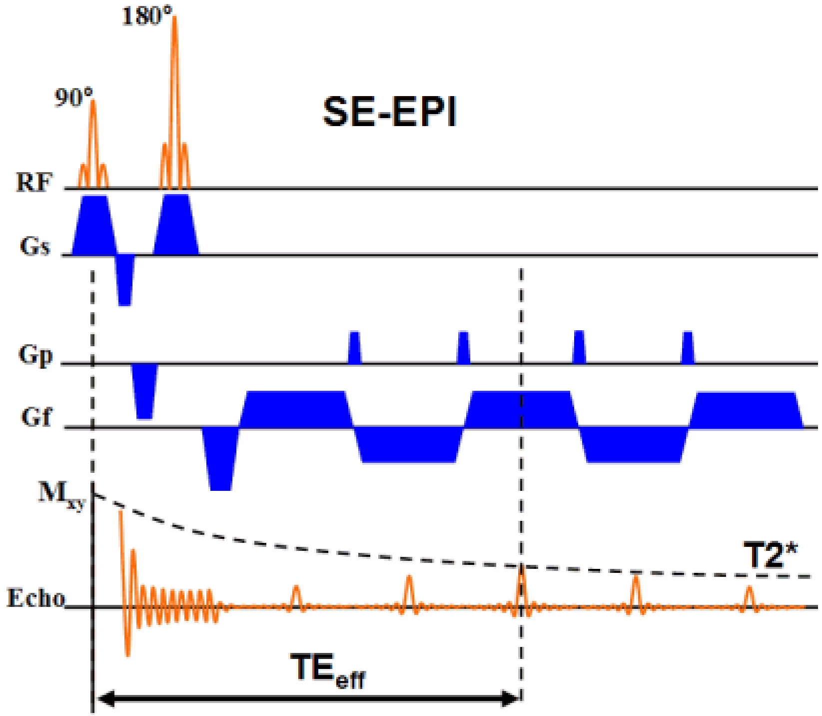


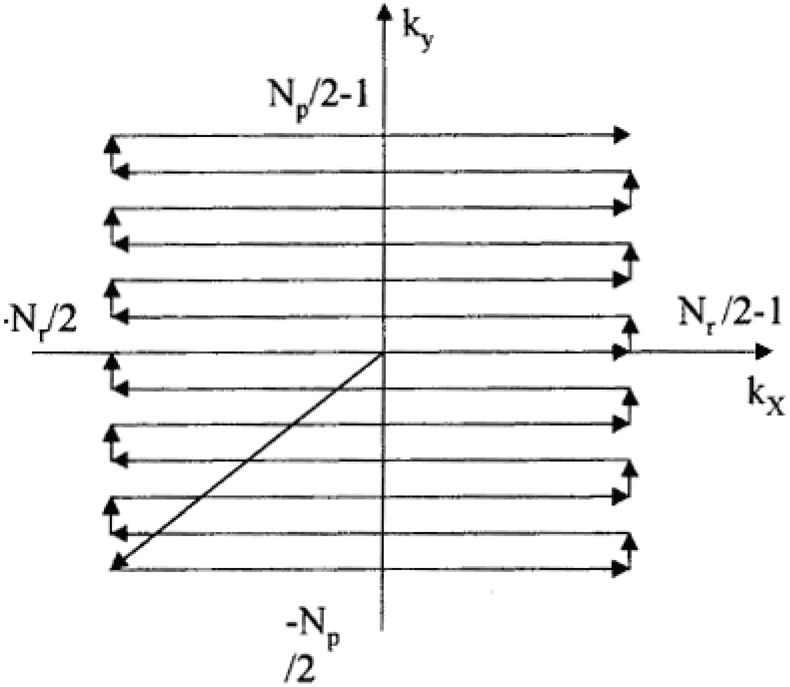
Sequence	Siemens	GE	Philips
Generic Gradient Echo	GRE	GRE	FFE
RF-Spoiled GRE	FLASH	SPGR	T1-FFE
Coherent GRE with “FID” Refocusing	FISP	GRASS	FFE
Coherent GRE with “Echo” Refocusing	PSIF	SSFP	T2-FFE
Coherent GRE with Balanced “FID/Echo” Refocusing	True FISP	FIESTA	Balanced FFE
Coherent Balanced GRE using Dual-excitation	CISS	FIESTA-C	---
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
Spoiled 3D GRE Variants	VIBE	FAME/LAVA	THRIVE
GRE Plus SE with Combined Signal	TGSE	---	GRASE

Echo planer imaging(EPI)

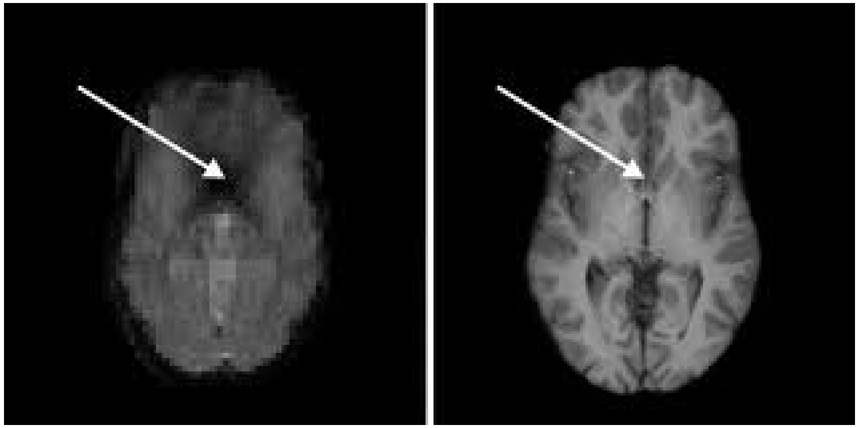
- Fills all the lines of k-space during one TR
- Uses a single echo train
- Multiple echoes are generated and each is phase encoded by a different slope of gradient to fill all the required lines of k space.
- EPI readout can be added to a spin echo (SE-EPI) or gradient echo (GE-EPI) pulse sequence.
- Very sensitive to image artifacts and distortions
- Used in diffusion weighted imaging (DWI) and DSC (dynamic susceptibility contrast) imaging

Echo planer imaging(EPI)



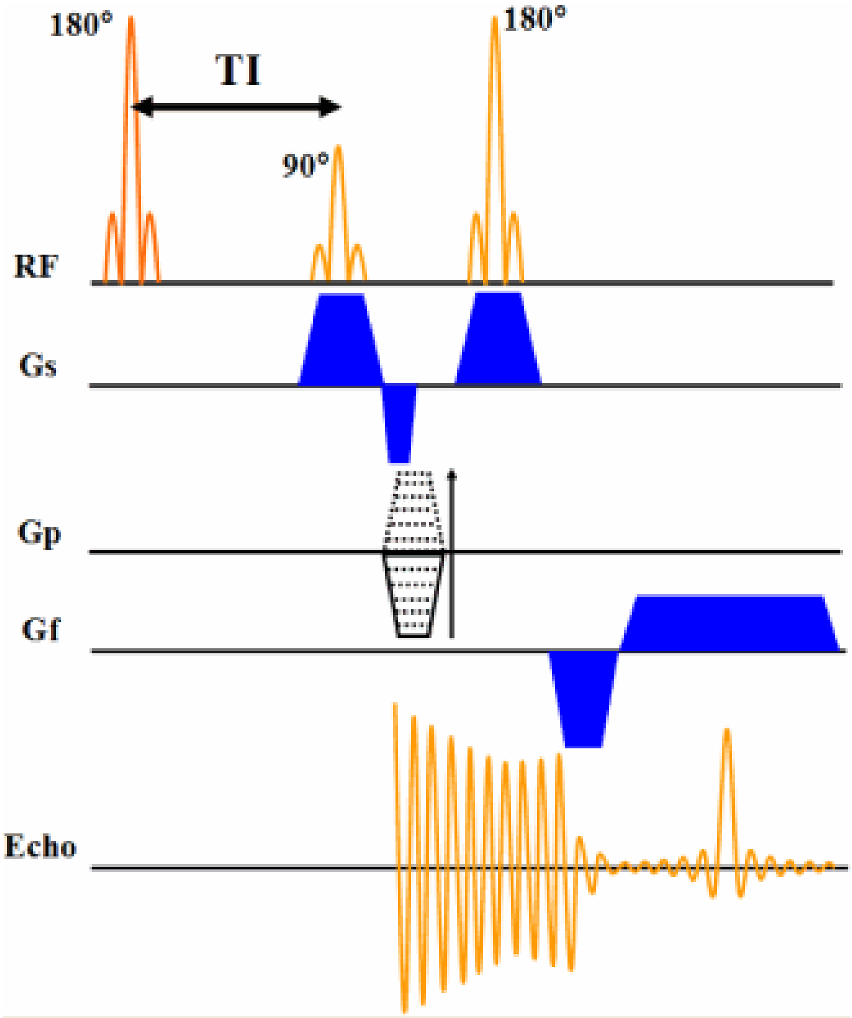


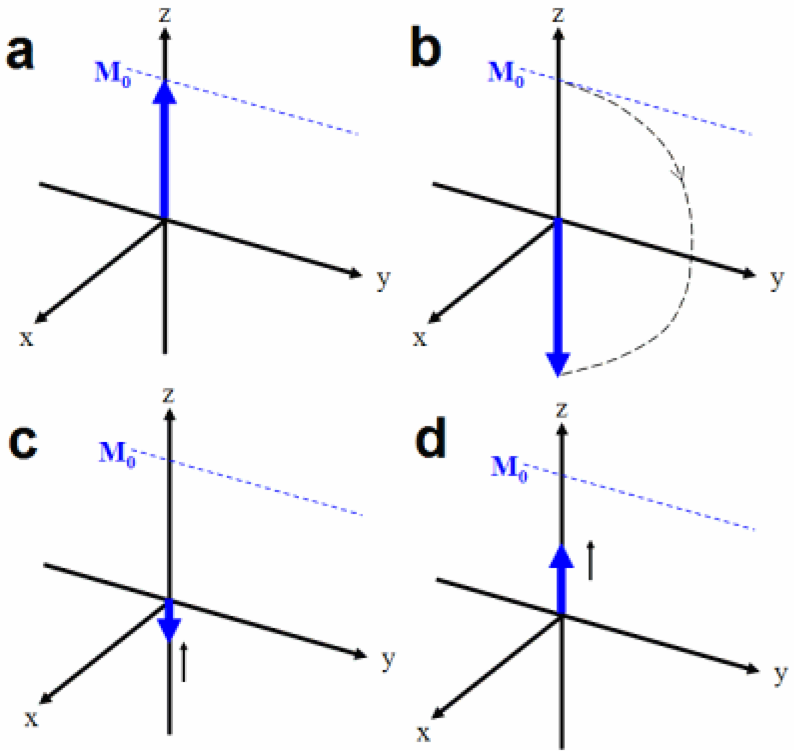
EPI



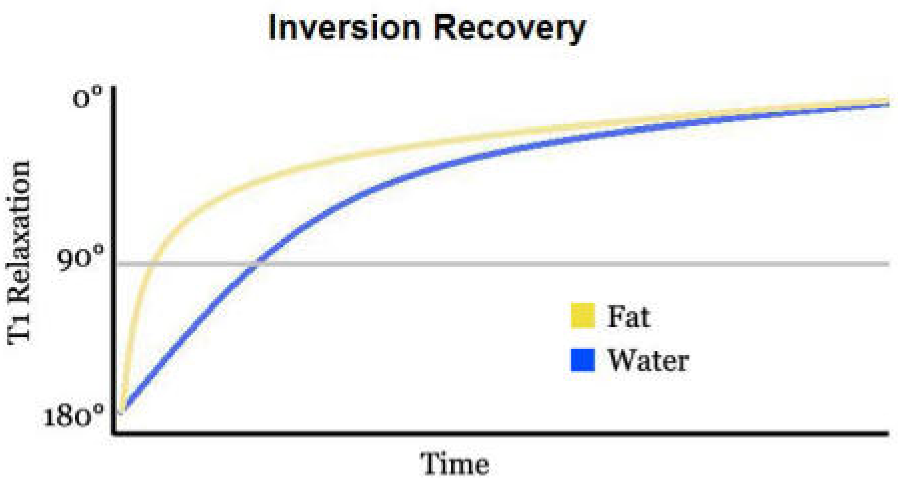
GRE

Inversion Recovery



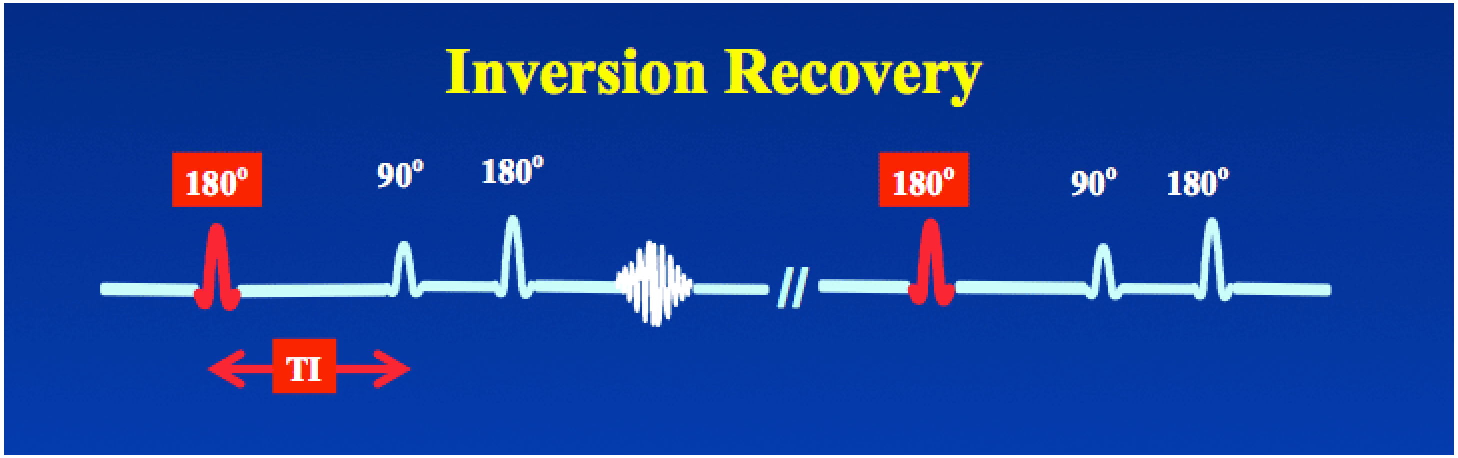


Inversion Recovery

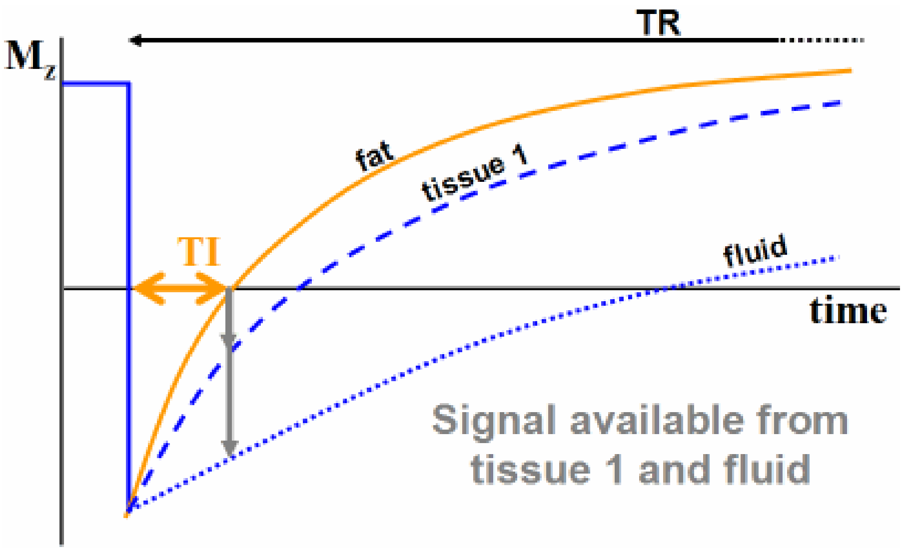


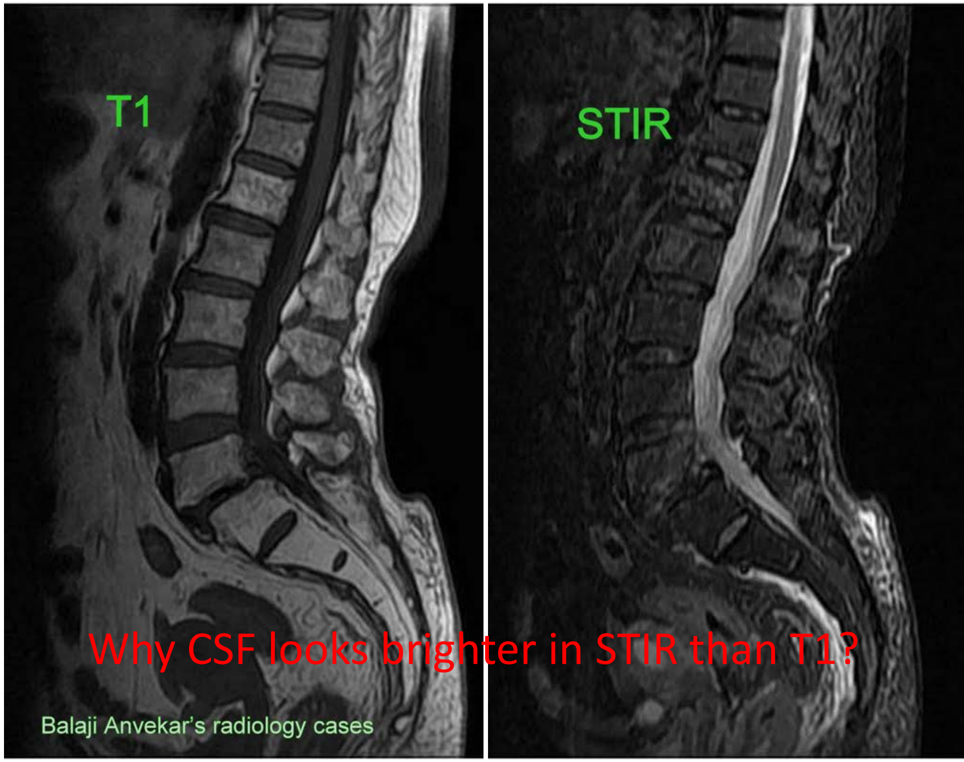
- Starts with a 180^0 inversion pulse.
- This inverts NMV through 180^0 into full saturation.
- When inverting pulse removed NMV begins to relax back to B_0

- A 90^0 excitation pulse is then applied at a time TI (Time from Inversion) from the 180^0 inversion pulse
- TI determines the weighting & contrast
- conventionally used to produce heavily T1 weighted images to demonstrate anatomy & in contrast enhanced imaging
- TR is the time between each 180^0 inverting pulse



STIR (short TI inversion recovery)



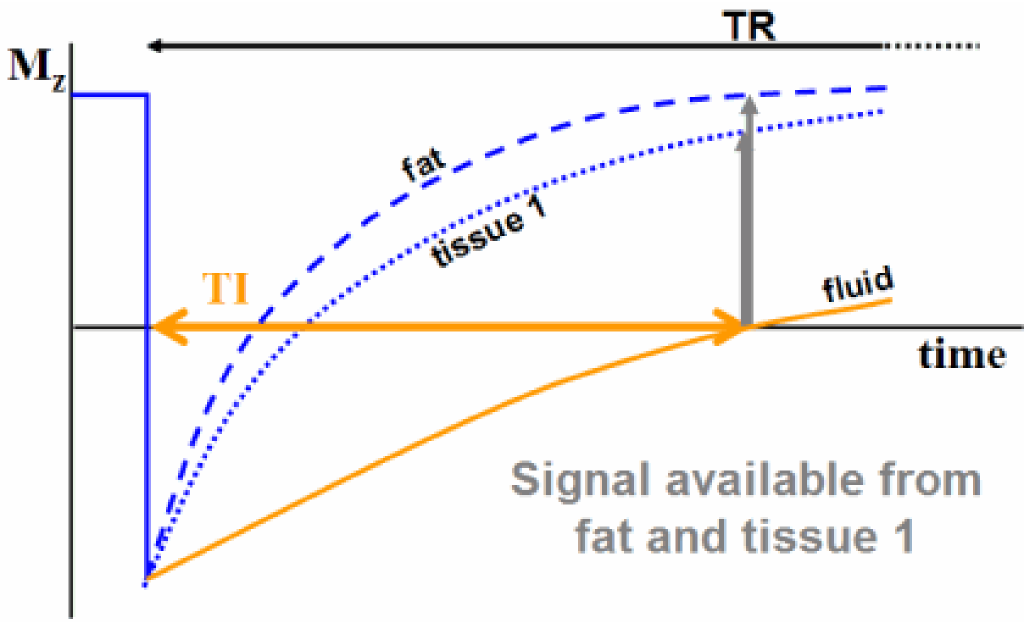


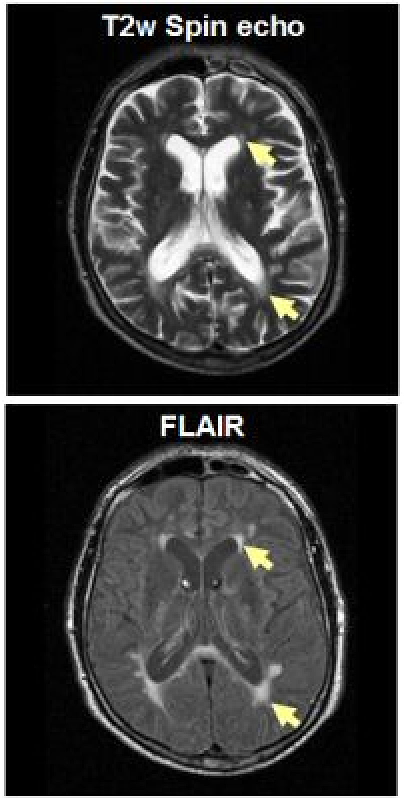
- Uses TI that corresponds to the time it takes fat to recover from full inversion to the transverse plane so that there is no longitudinal magnetization corresponding to fat.
- As a result the signal from fat is nulled.

Parameters

• Short TI (tau)	150 – 175 ms (to suppress fat depending on field strength)
• Long TE	50ms+ (to enhance signal from pathology)
• Long TR	4000ms+ (to allow full recovery)
• Long turbo factor	16-20 (to enhance signal from pathology)
• Average scan time	5-15min

FLAIR (Fluid attenuated inversion Recovery)





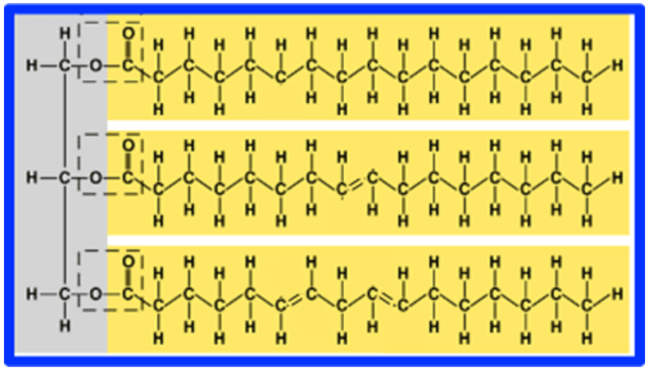
- The signal from CSF is nulled by selecting a TI corresponding to the time of recovery of CSF from 180 to the transverse plane and there is no longitudinal magnetization present.
- Used to suppress signal from CSF in T2 weighted images

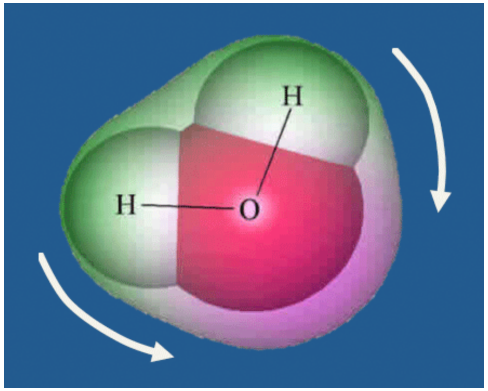
Parameters

• Long TI (tau)	1700 – 2200 ms (to suppress CSF depending on field strength)
• Long TE	70ms+ (to enhance signal from pathology)
• Long TR	6000ms+ (to allow full recovery)
• Long turbo factor	16-20 (to enhance signal from pathology)
• Average scan time	7-20min

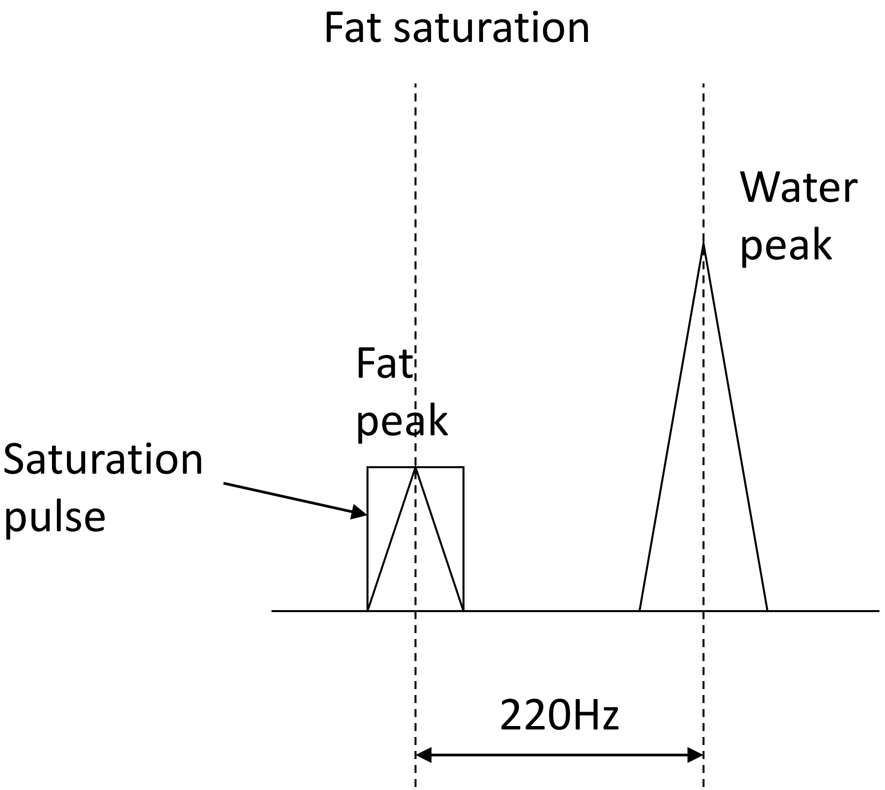
Fat saturation

- STIR can be used, but spectral difference between fat and water can also be used to saturate fat.
- In fat hydrogen is linked to carbon and in water it is linked to oxygen. Therefore the precessional frequency of hydrogen in water and fat are different.
- AT 1.5T field strength this difference is 220 Hz (less in fat).
- To saturate fat signal, a 90^0 pre-saturation pulse must be applied at the precessional frequency of fat to the whole FOV.
- A spoiler gradient is applied to destroy the transverse plane fat signal.





Fat saturation pulses

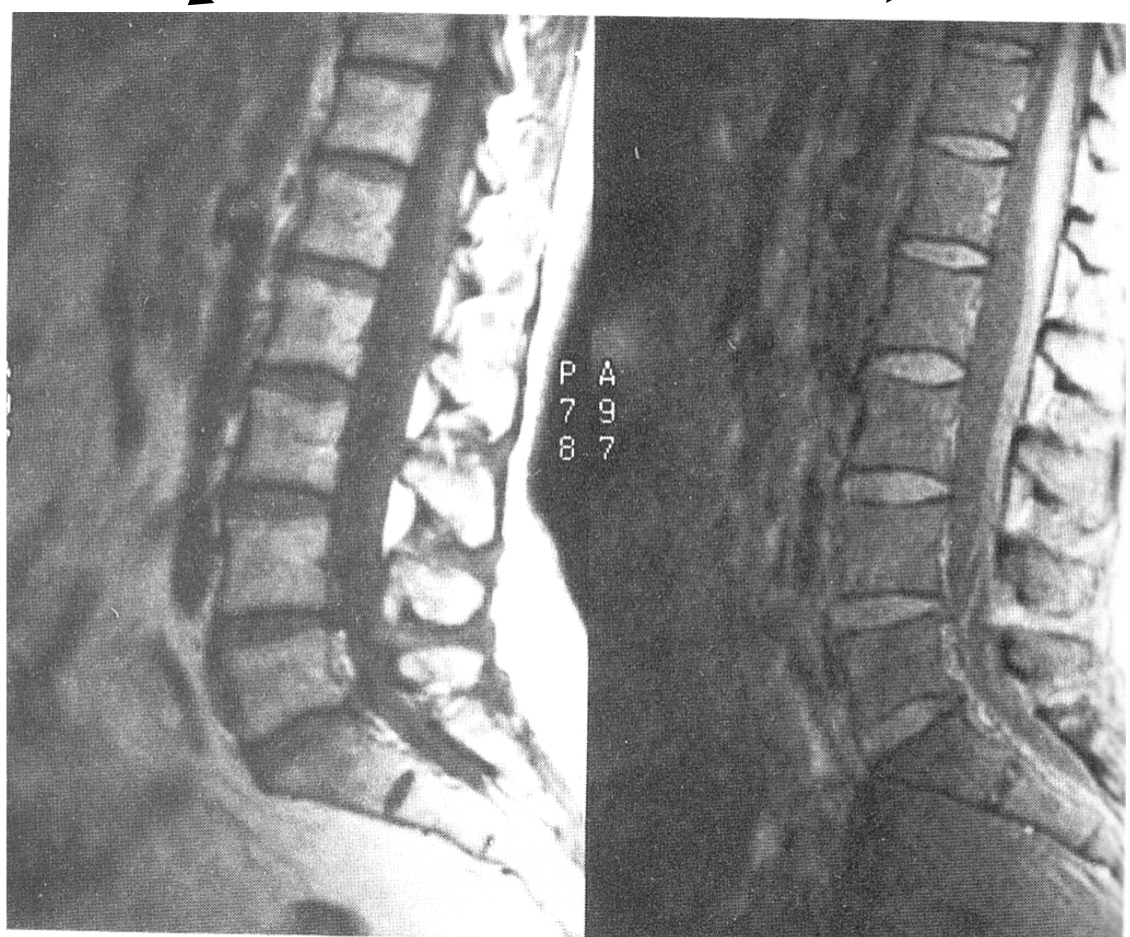


Examples

Sagital T1 weighted images

Without fat saturation

With fat saturation



References

- MRI in practice
- http://mri-q.com

Q1. What's the scan time of an FSE sequence, TR=500ms, phase matrix=128, NEX=2, turbo factor = 4?

- A. 500ms * 128 * 2 = 128s
- B. 500ms * 128 * 2 *4 = 512s
- C. 500ms * 128 * 2 / 4 = 32s
- D. 500ms * 128 / 2 / 4 = 8s

Q2. What TI is used in STIR sequences?

- A. short TI to null water
- B. long TI to null water
- C. short TI to null fat
- D. long TI to null fat

Q3. Which sequence is the fastest?

- A. Spin echo
- B. Fast spin echo
- C. Gradient echo
- D. EPI

Q4. What's the TE_{eff} in a FSE/EPI sequence?

- A. RF excitation pulse to the 1st echo
- B. RF excitation pulse to the last echo
- C. RF excitation pulse to the echo which has the least phase encoding
- D. RF excitation pulse to the middle of the acquisition window