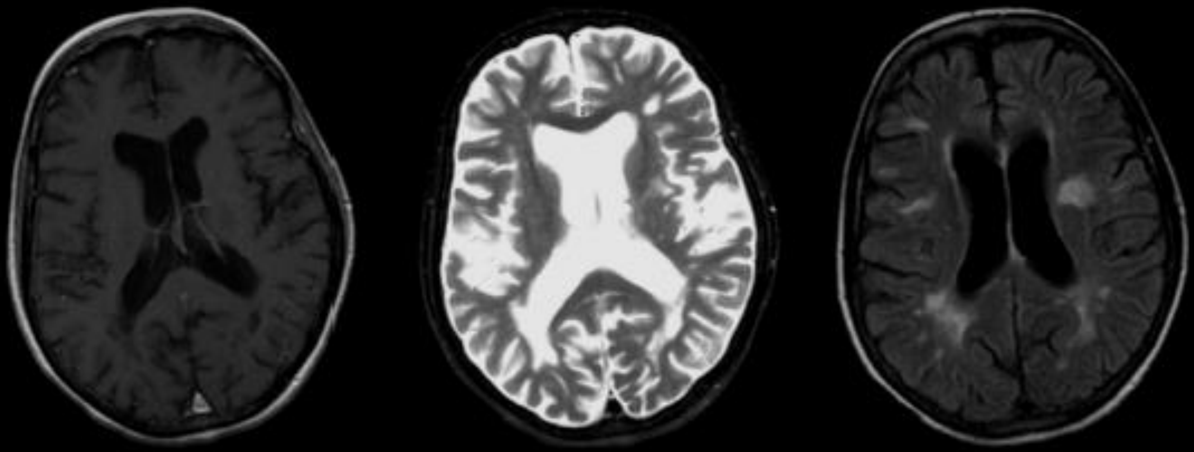
MRI:

T1 vs. T2 Weighting
Spin Echo
Gradient Echo
Inversion Recovery



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Medical Imaging Modalities

Overview

Review:

- Resonance
- T1 & T2
- Spatial Encoding

Spin Echo

- Sequence
- Equation

T1 and T2 Weighting

Gradient Echo

- Sequence
- Equation

Inversion Recovery

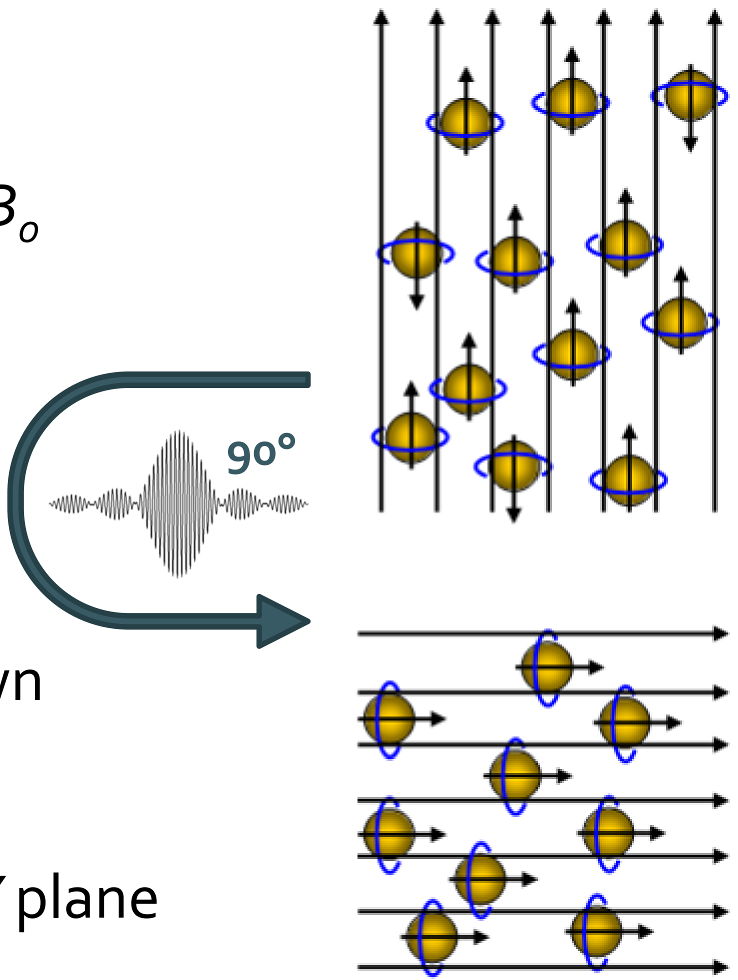
- Sequence
- Equation

Summary

Review: Resonance

Magnetic Field

- Atoms spinning & precessing due to B_o
- Precession f_L proportional to B



Transverse RF Pulse

- 90° RF* pulse "knocks" spin axes down

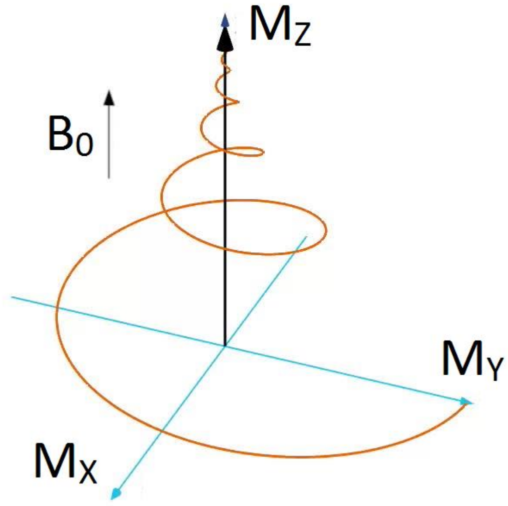
  *(rotating frame of reference)
- Creates net moment M in rotating XY plane

Review: T_1 and T_2

T1

- Rate of recovery of moment in B_o direction: M_Z
- "Spin-Lattice"

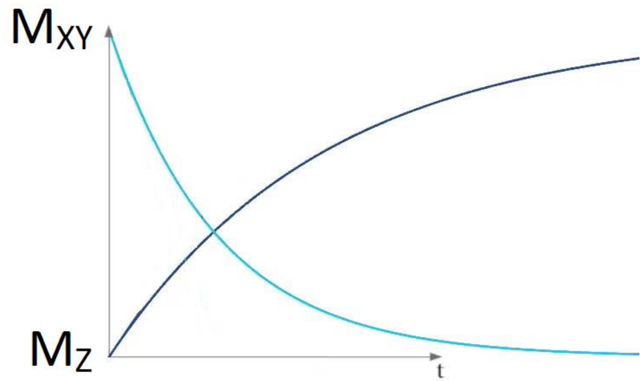
$$Mz = M_0\left(1 - e^{-\left(\frac{t}{T1}\right)}\right)$$



T2

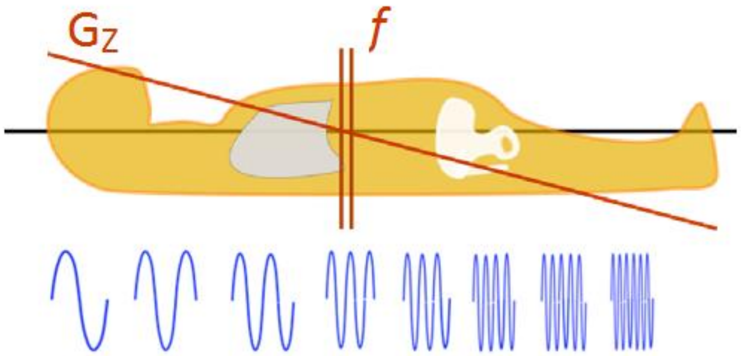
- Rate of decay of moment in B_1 direction: M_{XY}
- "Spin-Spin"

$$Mzy = M_0\left(e^{-\left(\frac{t}{T2}\right)}\right)$$



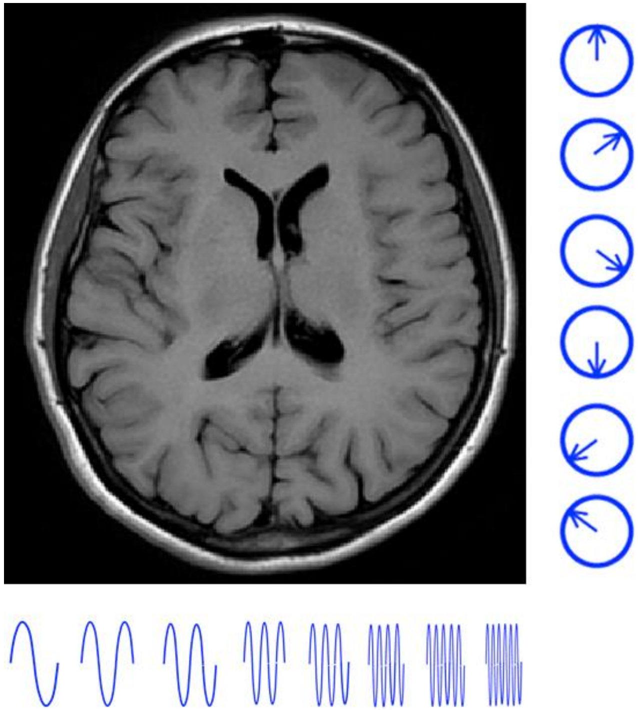
Review: Spatial Encoding

1. Slice Select: During RF
   only excite one plane



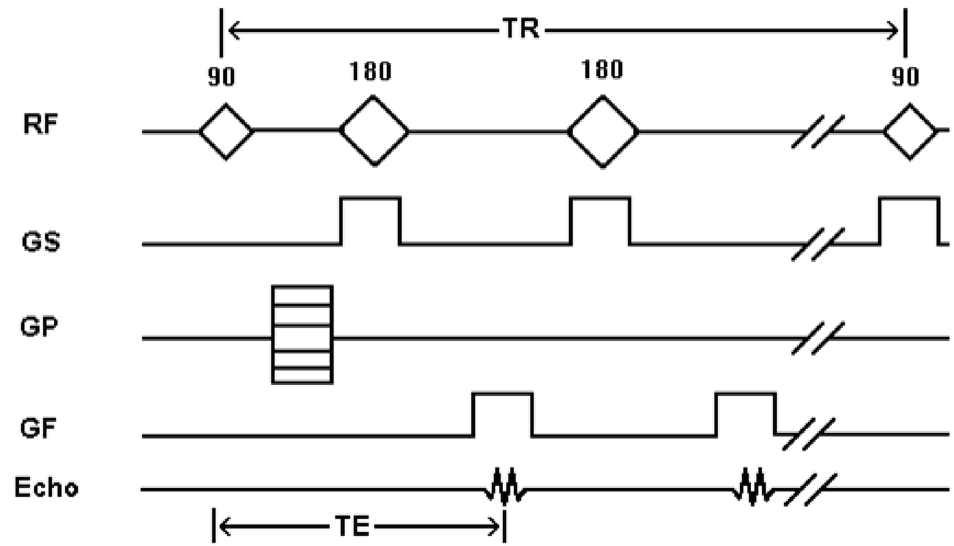
2. Frequency Encode:
   frequency varies across plane

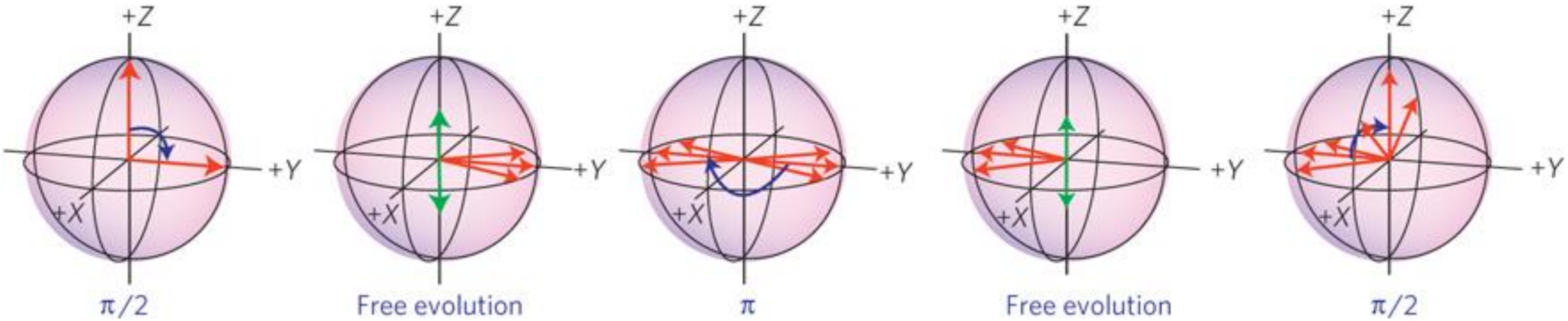
3. Phase Encode:
   phase varies across plane in other direction



Spin Echo Sequence

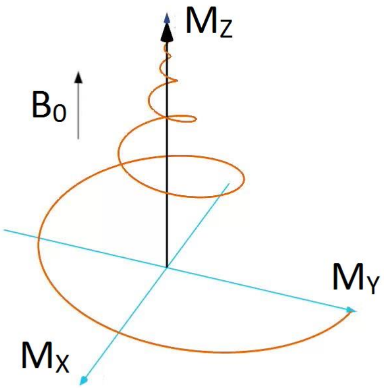
- Refocus M_{XY} using 180 °
- Multiple 180° pulses:
  Multiple echoes
  … Faster Acquisition

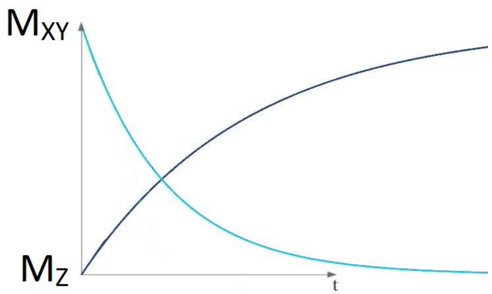




Spin Echo Equation (Signal Magnitude)

$$\Psi_{SE} = \Psi_0 \, e^{-\left(\frac{TE}{T2}\right)} \left(1 - e^{-\left(\frac{TR}{T1}\right)}\right)$$





T1 & TR

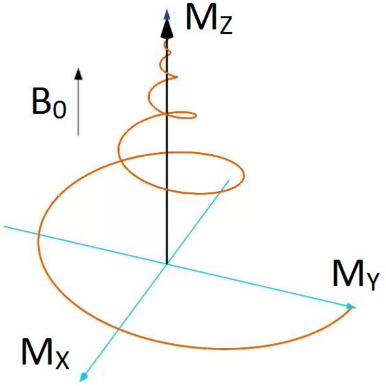
- Long TR: more M_Z recovered for next excitation
- Amount of M_Z recovered depends on tissue T1

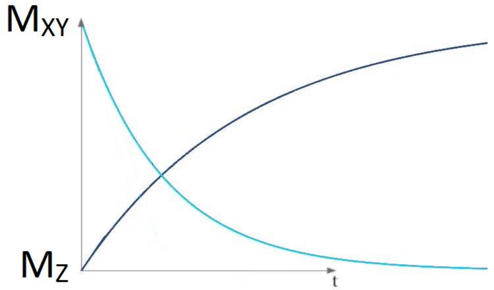
T2 & TE

- Very long TE: signal strength (M_{XY}) decays too much
- Very short TE: tissue T2 has minimal impact

T_1 and T_2 Weighting

$$\Psi_{SE} = \Psi_0\, e^{-\left(\frac{TE}{T2}\right)}\left(1 - e^{-\left(\frac{TR}{T1}\right)}\right)$$





T1-Weighting

- T1 ≈ TR → Emphasize differences in M_Z recovery
- Short TE → Minimize impact of T2

T2-Weighting

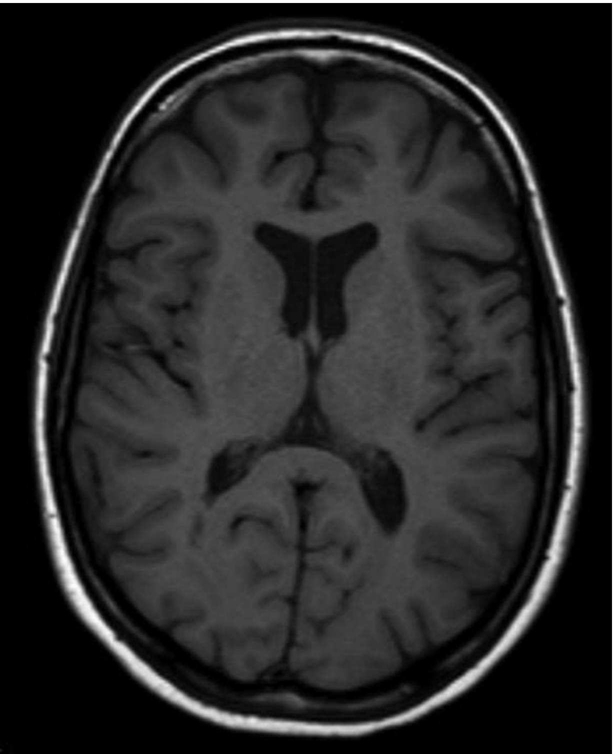
- T2 ≈ TE → Maximize contrast of T2
- Long TR → Allow full M_Z recovery

T_1 and T_2 Weighting

T1-Weighting

- Bright: short T1
- Dark: long T1

$$\Psi_{SE,T_1} \approx \Psi_0 \left(1 - e^{-\left(\frac{TR}{T1}\right)}\right)$$



T2-Weighting

$$\Psi_{SE,T_2} \approx \Psi_0 e^{-\left(\frac{TE}{T2}\right)}$$

- Bright: long T2
- Dark: short T2

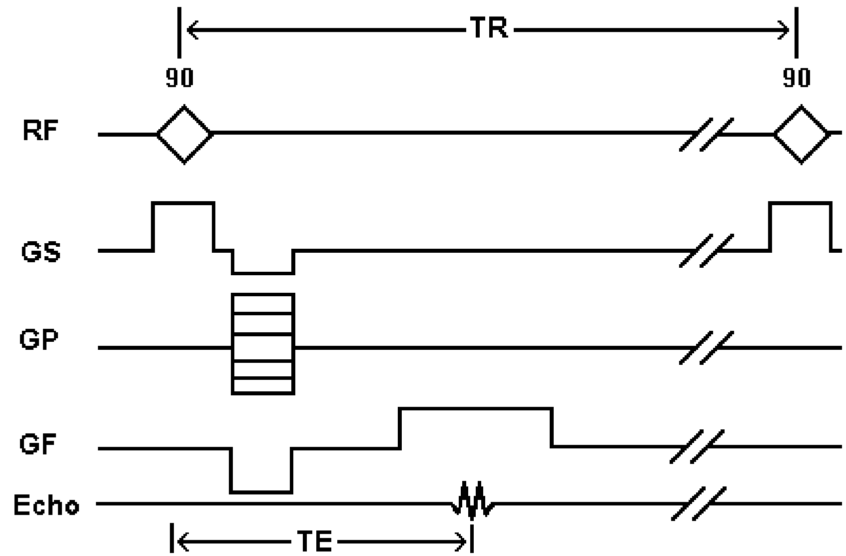
Summary: Spin Echo Weighting

$$\Psi_{\mathrm{SE}} = \Psi_0 \, \mathrm{e}^{-\left(\frac{TE}{T2}\right)} \left(1 - \mathrm{e}^{-\left(\frac{TR}{T1}\right)}\right)$$

$$\{T1, T2\} \sim (x, y)$$

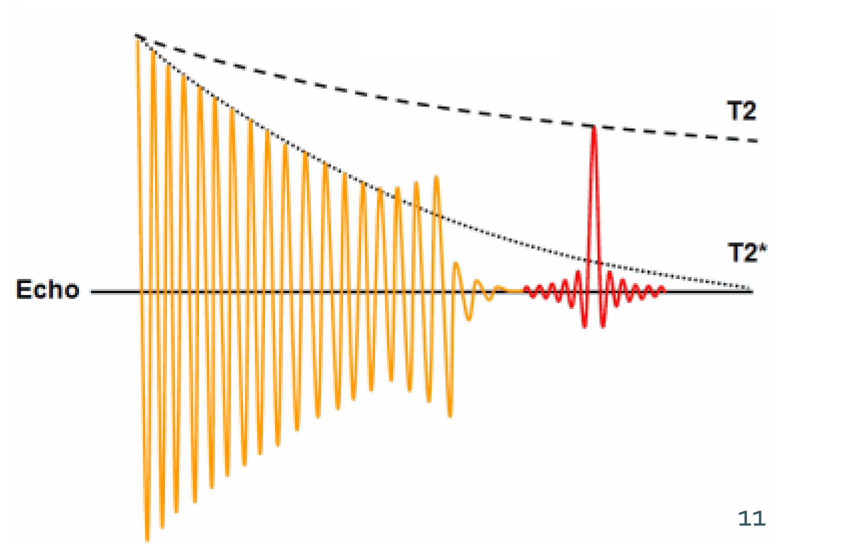
Gradient Echo Sequence

- Another way to refocus M_{XY}: use spatial gradients to de/re-phase spins



- $-0.5\,Gf$ during phase encode
  $+1.0\,Gf$ during readout

- Again, multiple gradients:
  Multiple echoes: “Fast GE”
  … Faster Acquisition



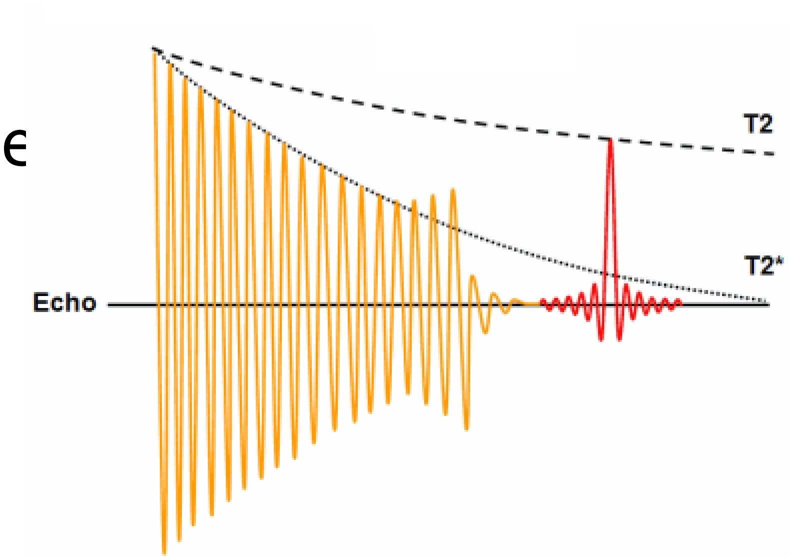
Gradient Echo Equation

$$\Psi_{GE} = \Psi_0 \, e^{-\left(\frac{TE}{T2^*}\right)} \left(1 - e^{-\left(\frac{TR}{T1}\right)}\right) \left(\frac{\sin\theta}{1 - \cos\theta \cdot e^{-\left(\frac{T1}{TR}\right)}}\right)$$

Why θ ≠ 90° ?

- We don't need 180° to act on *XY* plane!
- Faster!

  …Need not wait for M_Z recove
- What if θ = 90° ?



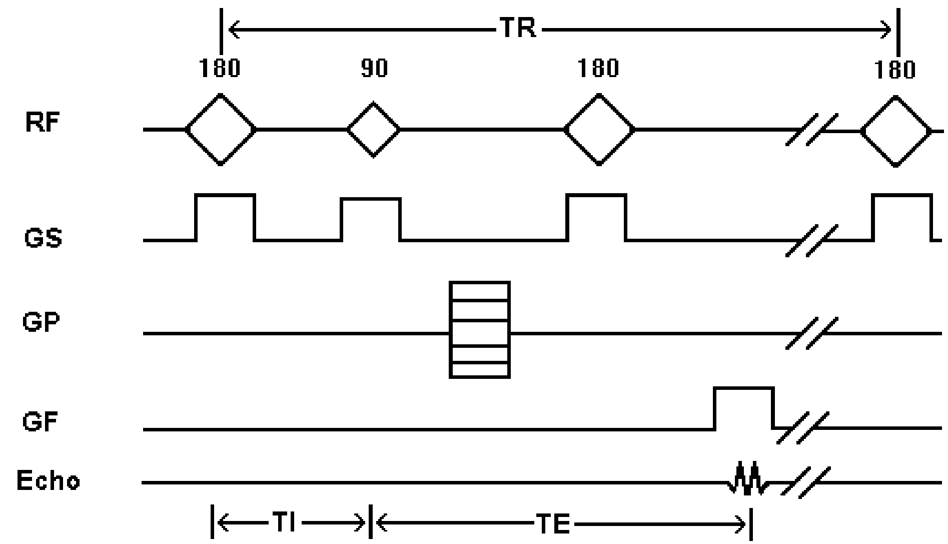
Inversion Recovery Sequence

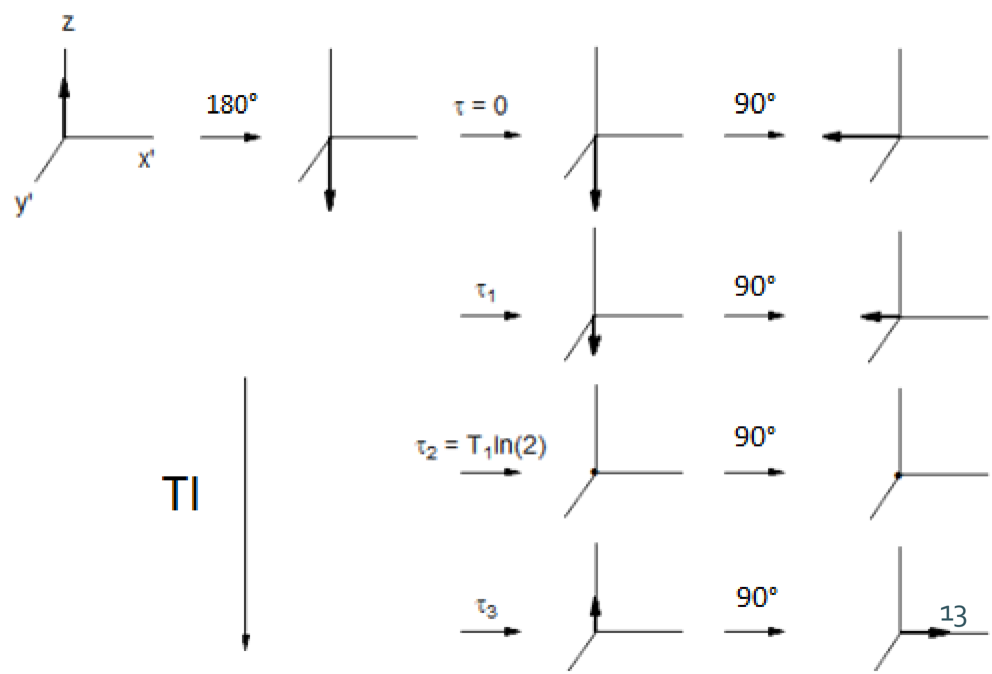
- Want to null the signal from a tissue "*K*".

- Apply 180° *before* 90° pulse so $M_{Z\text{"}K\text{"}}$ is zero when we apply 90°

- Multiple echoes?

  Nope…





Inversion Recovery Equation

$$\Psi_{\mathrm{IR}} = \Psi_0\, e^{-\left(\frac{TE}{T2}\right)} \left(1 + e^{-\left(\frac{TR}{T1}\right)} - 2e^{-\left(\frac{\mathrm{TI}}{\mathrm{T1}}\right)}\right)$$

Selecting TI

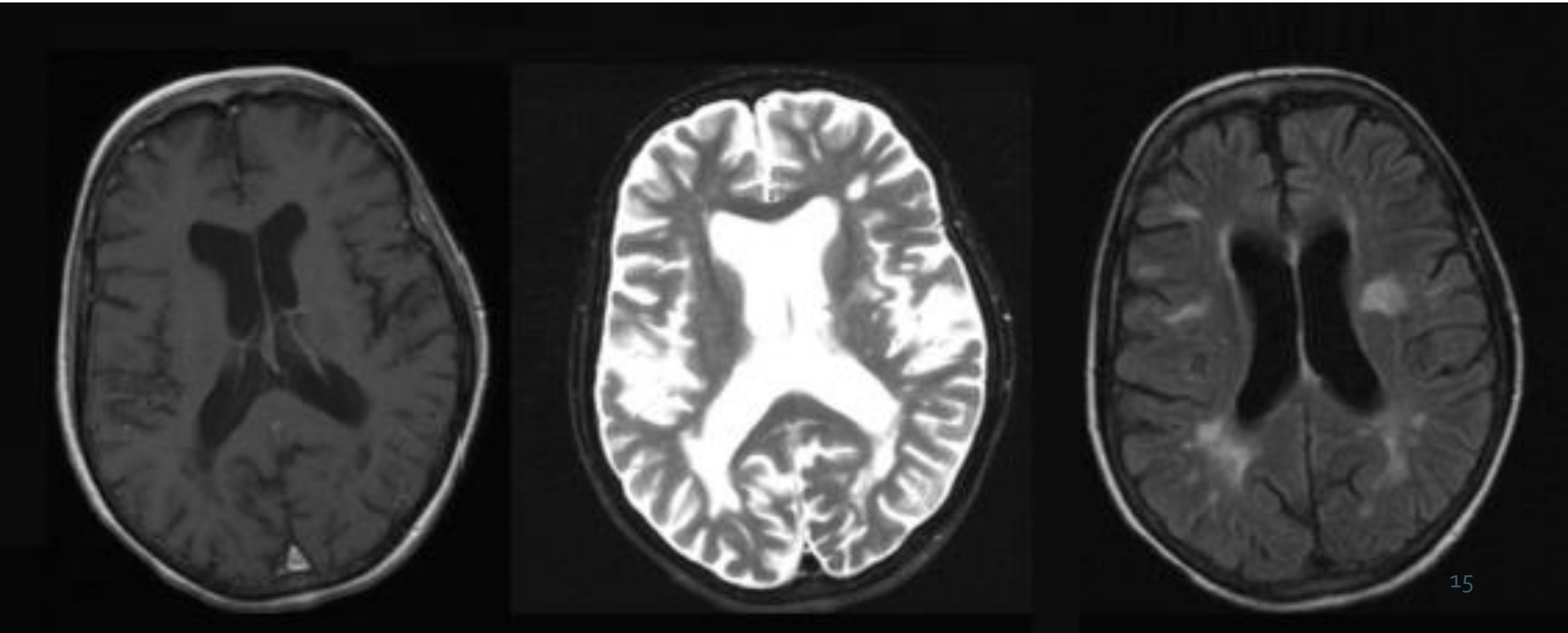
- Not simply (1/2) $T1_K$: these are exponential decays!

$$\mathrm{TI} = \ln(2) \cdot \mathrm{T1}_{\mathrm{K}}$$

- Can null signal from any tissue!
- However: tissues with similar T1 will be affected
- Typically, IR sequences are T2-weighted, e.g. FLAIR

Case Study: White Matter Lesions

- Lesions of MS; correlated with Alzheimer's, stroke risk
- T1: no contrast
- T2: bright, but periventricular uncertainty...
- FLA**IR**: just right!



Summary: SE (T_1 & T_2) vs. GE vs. IR

$$\Psi_{SE} = \Psi_0\, e^{-\left(\frac{TE}{T2}\right)}\left(1 - e^{-\left(\frac{TR}{T1}\right)}\right)$$

180° flip → rephase

$$\Psi_{SE,T_1} \approx \Psi_0\left(1 - e^{-\left(\frac{TR}{T1}\right)}\right)$$

Bright: short T1

$$\Psi_{SE,T_2} \approx \Psi_0 e^{-\left(\frac{TE}{T2}\right)}$$

Bright: long T2

$$\Psi_{GE} = \Psi_0\, e^{-\left(\frac{TE}{T2^*}\right)}\left(1 - e^{-\left(\frac{TR}{T1}\right)}\right)\left(\frac{\sin\theta}{1 - \cos\theta \cdot e^{-\left(\frac{T1}{TR}\right)}}\right)$$

Gradients → rephase

$$\Psi_{IR} = \Psi_0\, e^{-\left(\frac{TE}{T2}\right)}\left(1 + e^{-\left(\frac{TR}{T1}\right)} - 2e^{-\left(\frac{TI}{T1}\right)}\right)$$

Null specific tissue