MRI Physics:

Spin Echo Pulse Sequences

Nicole Seiberlich
Associate Professor, Radiology
Co-Director of MIITT
Pulse Sequences: What do we use?

- Spin Echo
- Gradient Echo
  - Spoiled Gradient Echo
  - Balanced Gradient Echo
- SE / GE + Prep Pulses to boost contrast
Spin Echo Pulse Sequence Diagram

RF

signal

acquisition

90°

180°

TE/2

TE

T_R

echo
Spin Echo MRI Contrast

\[ S = S_0 \left[1 - e^{-\frac{TR}{T1}}\right] e^{-\frac{TE}{T2}} \]

- TR \to very long, then exp \to 0 Image is T2-weighted
- TR \to medium Image is T1-weighted
- TR \to 0 No signal

- TE \to 0, then exp \to 1 Image is T1-weighted
- TE \to medium Image is T2-weighted
- TE \to very long No signal
Spin Echo MR Images

Conventional contrast:

PD-weighted
TR=4000ms
TE=15ms
Spin Echo MRI is SLOOOOW

Spin-Echo ~ minutes

Single-Shot EPI ~ 0.1sec
Spin Echo MRI is just very slow

- SLOW $\Rightarrow$ Long scan duration
  
  Scan time = $TR \times Nyv \times Nave$
  
  Typically $TR$ in range $300\text{ms} \rightarrow 4000\text{ms}$
  
  Given $TR = 2000\text{ms}$, Matrix = 256, $Nave = 1$
  
  Scan time = $2000\text{ms} \times 256 = 512\text{sec} = 8.6\text{ min}$

  For "pure" T2 or PD weighting, $TR > 5\times T1$ to minimize T1 effects
  
  $TR \sim 5000\text{ms} \Rightarrow 21\text{ min for 256 matrix size}$

- Long scan time $\Rightarrow$ artifacts due to motion
Spine Echo Variant: Multiecho SE MRI

T2 relaxation

T2*

90°  180°
Spin Echo Variant: Multiecho SE MRI

- Turbo Spin Echo (TSE)
- Fast Spin Echo (FSE)

- Way faster than Spin Echo
  Turbo Factor/Echo Train Length $\rightarrow 6$
  Number of echoes collected
  Factor by which scan is accelerated
T2 Contrast Determined by Center of k-Space

Center Echo

TE_{eff}
Potential Disadvantages of TSE

- Complex T2 weighting (not all of image data is weighted the same way)

- Some “blur” or “edge-enhancement” occurs since T2-decay and spatial encoding coincide

- Fat exceptionally bright due to funny physics (J-coupling effect)

- High RF power deposited in tissue (high SAR) due to multiple 180° pulses
  → May not be possible at 3T
FSE / TSE MRI - Examples

- **T2wt FSE / TSE**
  - TR=3600ms TE=80ms
  - ETL = 16

- **T2wt FLAIR FSE / TSE**
  - TR=11000 ms TE=125 ms TI=2800 ms
  - ETL = 27

- **IR-prep T1wt FSE / TSE**
  - TR=2100 ms TE=20 ms TI=800 ms
  - ETL = 7
FSE MRI

Single-Shot FSE (ETL~64-128)

Breathhold T2w

MRCP
Spin Echo Pulse Sequences

- TR controls T1 weighting
- TE controls T2 weighting
- Can be combined with “preparation pulses”
- Lack of T2* → fewer distortions/artifacts than other sequences
- Often used in multi-echo format

- Conventional Spin Echo is VERY Slow
- Multi-echo → High SAR due to many 180° pulses
- Multi-slice → Dead time during TR used to scan additional slices
MRI Physics:

Gradient Echo Pulse Sequences

Nicole Seiberlich
Associate Professor, Radiology
Co-Director of MIITT
Gradient Recalled Echo (GRE) Pulse Sequence

Compared to Spin Echo:
1) No 180 pulse   2) Flip angle less than 90   3) Additional gradient to make echo
$T_2^*$ Relaxation Dephases Magnetization (signal loss)
T2* Decay of signal following RF pulse

- Gradient Echo
- Time (~ 2 - 30msec)

Signal

T2*

gradient acts to destroy $M_{xy}$

gradient reversal acts to rebuild $M_{xy}$
GRE Sequence

- T2* Weighting, not T2 (but can be altered)
- Use of small flip angles
- $\rightarrow$ significant residual $M_z$ after RF pulse
  $\rightarrow$ data can be collected at much shorter times
  TR (200ms $\rightarrow$ 2ms) and TE (50ms $\rightarrow$ 0.5ms)
- Signal moves into a “steady state” of low SNR
Very Short TR, Short TE, small flip angle (GRE)
Sub-Classes of GRE

Many sub-classes GRE sequences with very different contrast behavior

- FLASH: Fast Low-Angle Shot (multiple versions Siemens)
- GRASS: Gradient Recalled Acquisition in the Steady State (General Electric)
- FFE: Fast Field Echo (Philips)
- FISP: Fast Imaging w/ Steady Precession (Siemens)
- TrueFISP (Siemens); FIESTA (GE); Balanced FFE (Philips)
- SPGR: Spoiled GRASS; Spoiled FLASH; T1-FFE
- SSFP: Steady-state free precession
- many others …
### Sub-Classes of Gradient Echo Sequences

<table>
<thead>
<tr>
<th>SEQUENCE TYPE</th>
<th>GE</th>
<th>PHILIPS</th>
<th>SIEMENS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient Echo</td>
<td>GRE</td>
<td>FFE</td>
<td>GRE</td>
</tr>
<tr>
<td>Coherent Gradient Echo</td>
<td>GRASS</td>
<td>FE</td>
<td>FISP</td>
</tr>
<tr>
<td>Spoiled Gradient Echo</td>
<td>SPGR</td>
<td>T1-FFE</td>
<td>FLASH</td>
</tr>
<tr>
<td>Steady-State Free Precession</td>
<td>SSFP</td>
<td>T2-FFE</td>
<td>PSIF</td>
</tr>
<tr>
<td>True FISP</td>
<td>FIESTA</td>
<td>Balanced-FFE</td>
<td>TrueFISP</td>
</tr>
<tr>
<td>Fast Gradient Echo</td>
<td>Fast GRE; Fast SPGR</td>
<td>Turbo-FFE; TFE</td>
<td>TurboFLASH</td>
</tr>
<tr>
<td>Fast T1wt 3D GRE</td>
<td>3D FGRE; 3D FSPGR; LAVA</td>
<td>3D TFE; THRIVE</td>
<td>MPRAGE; VIBE</td>
</tr>
</tbody>
</table>

Can have very different contrast behavior (depending on steady-state and sequence settings)
Spoiled Gradient Echo MRI (SPGR and FLASH)

\[ S = \frac{S_0 \left[ 1 - e^{-\frac{TR}{T_1}} \right] \sin(\theta)}{1 - \cos(\theta) e^{-\frac{TR}{T_1}}} e^{-\frac{TE}{T_2}} \]

Control T1 contrast by flip angle and TR (min TE):

- **TR=7 TE=min**
  - T1=50 (1pass Gd in blood)
  - T1=270 (fat)
  - T1=600 (liver)

- **TR=150 TE=min**
  - T1=50 (1pass Gd in blood)
  - T1=270 (fat)
  - T1=600 (liver)
Two options for T1-weighted Imaging (+Gd)

- **2D Spin-Echo**
  - TR = 500 ms
  - TE = 10 ms
  - Duration: 2.1 min

- **3D Spoiled GRE (SPGR)**
  - TR = 10 ms
  - TE = 6 ms
  - Flip = 8°
  - Duration: 2.67 min

Images:
- 256 x 0.5 s
- 2.1 min
- 256 x 0.01 s
- 2.5 sec
- 3D
  - 256 x 64 x 10 ms
  - 2.67 min
Spin Echo vs GRE: Local Signal Dephasing

Spin Echo
less sensitive to local
distortion and signal loss

(Spoiled) GRE
more sensitive to local
distortion and signal loss
due to T2* sensitivity

metal implant
metal implant
Spin-Echo vs EPI: Geometric Distortion and Local Signal Dephasing
Spoiled Gradient Echo

- Very fast, primarily T1-weighted imaging
  - Contrast controlled by FA and TR
- Enables full 3D imaging
  - Great for dynamic imaging or for breathhold scans
- Slower but can be used for T2*-weighted imaging
- Low SNR (can be boosted by using 3D acquisition)
- Signal loss/Distortion around sources of magnetic field inhomogeneities
Fully Balanced Gradient Echo MRI (bSSFP, TrueFISP, FIESTA, bFFE)

\[ S = \frac{S_0 \sin(\theta)}{[1 + \left(\frac{T_1}{T_2}\right)] + [1 - \left(\frac{T_1}{T_2}\right)] \cos(\theta)} \]

NO dependence on TR or TE
BUT
TE must be TR/2
TR short due to “banding artifacts” from magnetic field inhomogeneities

T2/T1 contrast
T1-FFE vs Balanced-FFE

Single-shot locator scans

TR = 8ms
TE = 2.3ms
Flip = 15°
“T1-enhanced” (Spoiled)

TR = 3ms
TE = 1.5ms
Flip = 60°
“Fully Balanced”
Examples Balanced FFE / FIESTA / TrueFISP

3D bFFE
TR=6ms, TE=3ms, flip=45,
0.5mm slices

Note – thin black bands due to Bo inhomogeneity
Balanced Gradient Echo

• bSSFP, FIESTA, TrueFISP, bFFE

• Very fast, T2/T1 contrast
  → Contrast not significantly affected by TR, TE, even flip angle

• High SNR

• TE = TR/2

• Short TR best (2-5 ms)
  → Longer TR leads to “banding” artifacts near at field inhomogeneities