Lecture-9D — Gradient Echo Sequences
RF-Spoiled Sequences and Comparisons

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Learning Objectives

- Explain the motivation and mechanism of RF-spoiling
- Explain the choice of phase-increment in RF spoiling
- Identify spoiling types from different images
- Compare advantages and disadvantages of spoiling methods
Outline: Gradient Echo Sequences

- Gradient Echo = No spin echo!
- Spoiling Types
- Properties

Contrast is based primarily on the end-of-TR action
RF-Spoiled Sequences (FLASH, SPGR, T1-FFE)

Gradient spoiling uses an unbalanced gradient at the end of the TR (Gx and Gz here)

Quadratic Phase Increment to RF
RF Spoiling

- Goal: *Eliminate* transverse magnetization
- Quadratic phase increment + gradient spoiling:
  \[ \phi_k = (0.5)117° k^2 \]
- Shifting, spoiled (averaged) profile
- Transverse magnetization “cancels”
- T1 contrast

*T1-FFE, FLASH, SPGR, Spoiled(!)*
Question 1: Spoiling Increment?

The RF phase is \( \theta \). Why is \( 90^\circ, 180^\circ, 810^\circ (=90^\circ+720) \),… a bad choice?

Periodic (not quadratic) phase

Simply shifts signal in voxel

\[ \phi_k = \left( \frac{0.5}{\theta_k} \right)^2 \]

The use of quadratic phase (RF spoiling) can approximate the case where transverse magnetization is set to 0.

Quadratic Phase RF Spoiling (Rotated to last RF phase)

Explicitly Zeroing $M_{xy}$ prior to RF pulse
Balanced, Gradient-Spoiled and RF-Spoiled

- Gradient-Spoiled
- Constant RF Phase Increment
- Quadratic Phase (Increasing Phase Increment)

Signal Across Voxel, 119° Increment

Perfect Spoiling
SPGR Signal Evolution (Bloch simulation)

In steady state the magnetization is periodic in both time and space.
EPG and RF spoiling

- Same coherence diagram... but almost no spin-echoes or stimulated echoes
Question 2: EPG States and RF Spoiling

How do we know from this steady-state EPG coefficient map that spoiling is working?

No signal can return to $Z_n, F_n > 0$.
RF Spoiling - 120° is a Bad Phase Increment!

- Note Z states, and fluctuations
- Still periodic in time and space

The phase increment is chosen to avoid fluctuations
RF-Spoiled Contrast-Enhanced MR

Pre-Contrast SPGR

Post-Contrast SPGR

Courtesy Lewis Shin
RF Spoiling: Summary

- Gradient spoiling + Quadratic phase RF
- “Eliminates” transverse magnetization
  - Lower signal than GRE or balanced SSFP
  - Pure $T_1$ contrast

*T1-FFE, FLASH, SPGR, Spoiled(!)*
Contrast Example

- Contrast based **solely** on end-of-TR action

- RF-Spoiled T1-weighted
- Gradient-Spoiled
- Balanced $T_2/T_1$ Weighted
Question 3: Which Gradient-Echo Sequence?

An RF-Spoiled and balanced SSFP image are shown. Which is on the right?

1) RF-Spoiled
2) Balanced SSFP

bSSFP: Bright fluid, Opposed-phase, dark bands
Gradient Echo: Flip Angle

RF-Spoiled

Gradient Spoiled

Balanced SSFP

Best?
### Gradient Echo Sequence Comparison

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Balanced SSFP</th>
<th>Gradient Echo</th>
<th>RF-Spoiled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoiling</td>
<td>None</td>
<td>Gradient</td>
<td>RF + Gradient</td>
</tr>
<tr>
<td>Transverse Magnetization</td>
<td>Retained</td>
<td>Averaged</td>
<td>Cancelled</td>
</tr>
<tr>
<td>Contrast</td>
<td>$T_2/T_1$</td>
<td>$T_2/T_1$</td>
<td>$T_1$</td>
</tr>
<tr>
<td>SNR</td>
<td>High (but Banding)</td>
<td>Moderate</td>
<td>Lower</td>
</tr>
</tbody>
</table>
Echo Time Considerations

**Magnitude:** \( S = S_0 e^{-\frac{TE}{T2^*}} \)

**Phase:** \( \phi = \Delta fTE \)

**Blood-Oxygen Level Dependent (BOLD)**

(Courtesy of Karla Miller)

**Ultrashort TE**
*(Short TE - Long TE)*

(Courtesy of Jiang Du)

Choice of TE influences T2* contrast, and relative phase

Water  Fat
Flip Angle Selection

All 3 sequences have the same signal at the Ernst Angle ($\alpha = \cos^{-1}(E_1)$)
Question 2: Flip Angle Selection?

The best flip angle to use is found by:

- A. Maximizing the image SNR
- B. Maximizing contrast between certain tissues
- C. Both A and B

C is correct - there is usually a trade-off.
Summary

- Long TR ~ Simple Dynamics
- Short TR ~ Steady States
  - Balanced, Gradient-Spoiled, RF-Spoiled
  - Contrast variations (T1, T2/T1)
  - Magnetization preparation often used
- Tools
  - Bloch Equations
  - Extended Phase Graphs
  - Intuition!

Acronyms primarily at mr-tip.com
Rad229 – MRI Signals and Sequences

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