Rad229 – MRI Signals and Sequences

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Lecture-9C — Gradient-Echo Sequences
Gradient-Spoiled Sequences

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Learning Objectives

• Explain the gradient-spoiled signal relative to bSSFP
• Explain reversed gradient-spoiling and double-echo in steady-state
• Use EPG simulations to calculate gradient-spoiled signals
Outline: Gradient Echo Sequences

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

Contrast is based primarily on the end-of-TR action
Gradient-Spoiled Sequences (GRE, FFE, FISP, GRASS…)

Gradient spoiling uses an unbalanced gradient at the end of the TR (Gx and Gz here)
Question 1: Constant Gradient vs Off-Resonance?

The gradient is like static \( \Delta B_0 \) induces linearly-increasing \( \Delta f \) or \( \Delta \phi \) across voxel:

If we keep area constant a discrete gradient has a similar effect

\[
\Delta f = \left( \frac{\gamma}{2\pi} \right) G z
\]
Gradient Spoiling

The gradient spoiler does NOT eliminate transverse magnetization, in the steady-state.

Signal is NOT eliminated at the end of TR!
Gradient Spoiling (GRE, FFE, FISP, GRASS)

Precession across voxel dominated by spoiler:
- Each spin has a different precession
- Average of balanced SSFP at start of TR!
- Perhaps some $T_2$ decay to TE

Gradient spoiling averages the bSSFP signal over frequency
Gradient-Spoiled Signal

- Lower signal than balanced SSFP
- Flat signal vs. frequency profile
- No dark band artifacts!
- GRE, FFE, FISP, GRASS

The signal is the complex average of the bSSFP signal just after the RF pulse.
Question 2: Gradient Spoiling and EPG

What does the coherence-pathway diagram for gradient spoiling look like (starting from equilibrium)?
EPG Signal Calculation

- Simulate RF, relaxation, gradient
- Can plot signal evolution and coherence pathways

```matlab
% epg_gradspoil.m: Core loop
% for n=1:N
P = epg_rf(P,flipangle,pi/2); % RF excitation
s(n) = P(1,1); % Signal is F0 state.
P = epg_grelax(P,T1,T2,TR,1,0,1,1); % Spoiler, relaxation
end;
```

![Graph of Gradient-Spoiled Signal vs TR time](image1.png)

- 30° flip angle

![Graph of F and Z states vs time](image2.png)

- Considerable M_z storage

EPG coherence pathways reach a steady state epg_gradspoil.m
EPG Steady-State Gradient-Spoiled Signal

Steady-state EPG states at TE=0 - advancing by 1 gradient shows states at end of TR

Before RF:

After RF:

M_z storage
Gradient Spoiled vs Balanced SSFP

Balanced SSFP

Gradient-Spoiled

(Courtesy of Suba Srinivasan, Stanford)

bSSFP has higher signal, but some artifacts, compared to gradient spoiling
Reversed Gradient Spoiling

Same as gradient-spoiling, but

- Precession **before** imaging
  \[(bSSFP Signal at TE=TR)\]
- Some \(T_2\) contrast

The spoiler gradient still has the effect of inducing off-resonance across the voxel
Reversed Gradient Spoiled Signal

• Almost identical signal to gradient-spoiled imaging
• Flat signal vs. frequency profile, and more T2 contrast than GRE
• PSIF, CE-FAST, T2-FFE

Sampling after the spoiler gradient leads to a similar signal, with more T2 contrast
Double Echo Imaging: DESS/FADE

Double-Echo in steady state samples both before and after the spoiler
Question 3: Split-Spoiling

What if we split the spoiler into two and sample mid-way between?

No signal!

Averaging the “TE=TR/2” bSSFP state -- sign flip with every band

GRE and reversed GRE average bSSFP states just after and just before the RF pulses.
Question 3: (cont)
Gradient Spoiling: Summary

- Gradient spoiling averages the bSSFP magnetization
- Reduce sensitivity to off-resonance
- Can do reversed gradient spoiling or double-echo
- GRE gives $T_2/T_1$ contrast, lower signal than bSSFP

FFE, FISP, GRASS, GRE, FAST, Field Echo, T2-FFE, PSIF, CE-FAST, SSFP(!) FADE, DESS
Is there a way to get pure T1 contrast with gradient-echo imaging?