Bioengineering 278
Magnetic Resonance Imaging

Winter 2010
Lecture 3

Echoes
Spin Echo Formation
CPMG
Coherence Diagrams
Gradient Echo Imaging
Spoiled
Unspoiled steady state
Totally refocused

The Hahn Spin Echo

E. Hahn, 1950
The CPMG Spin Echo

Hahn

\[ Y \]
\[ Z \]

Echo 1

160°
dephase
rephase
dephase
160°
rephase

CPMG

\[ Y \]
\[ Z \]

dephase
160°
rephase
dephase
160°
rephase

Echo 1
Echo 2

Coherence Pathways

RF pulses operating on M:

\[
T_0 = \begin{bmatrix}
1 & 0 & 0 \\
0 & \cos(\alpha) & -\sin(\alpha) \\
0 & \sin(\alpha) & \cos(\alpha)
\end{bmatrix}
\]

A + B = 1
A - B = \cos(\alpha)
A = \frac{1 + \cos(\alpha)}{2} = \cos^2(\alpha/2)
B = \frac{1 - \cos(\alpha)}{2} = \sin^2(\alpha/2)

RF pulses operating on F/Z:

\[
T_1 = \begin{bmatrix}
\cos^2(\alpha/2) & e^{i\phi} \sin^2(\alpha/2) & -ie^{i\phi} \sin(\alpha) \\
e^{-i\phi} \sin^2(\alpha/2) & \cos^2(\alpha/2) & ie^{-i\phi} \sin(\alpha) \\
-i/2 e^{i\phi} \sin(\alpha) & i/2 e^{i\phi} \sin(\alpha) & \cos(\alpha)
\end{bmatrix}
\]

Scheffler 1999: PDF on class web site
also Hennig 1991
Spoiled gradient echo sequence

RF

G_z(t)

G_x(t)

G_y(t)

→ TR ←

• Spoiled FLASH, Spoiled GRASS
• RF phase pseudo-randomized
• Signal comes from FIDs only
• No echo pathways build up

I(x,y) = \rho(x,y) \frac{1 - e^{-TR/T_1(x,y)}}{1 - e^{-TR/T_1(x,y)}} \sin \alpha \cos \alpha \exp(-TE / T_2^*)

Signal intensity is maximized at the Ernst Angle

\alpha_E = \cos^{-1}(\exp(-TR/T_1))

Spoiled gradient echo equation assumes no coherence from shot to shot. In practice this is achieved with RF spoiling.
\[ \alpha_E = \cos^{-1}\left(\exp\left(-\frac{TR}{T_1}\right)\right) \]

Spoiled gradient echo sequence

- Spoiled FLASH, Spoiled GRASS
- RF phase pseudo-randomized
- Signal comes from FIDs only
- No echo pathways build up
Unspoiled gradient echo sequence

- $G_X(t)$
- $G_Y(t)$
- $G_Z(t)$

- RF phase uniform
- Signal comes from FIDs and Echoes
- Signal depends on $\alpha$, TE, TR, $T_1$, $T_2$, $T_2^*$

Echo-only gradient echo sequence

- $G_X(t)$
- $G_Y(t)$
- $G_Z(t)$

- RF phase uniform
- Signal comes from echoes only
- Signal depends on $\alpha$, TE, TR, $T_1$, $T_2$
Fully refocussed gradient echo sequence

- FISP, FIESTA, balanced SSFP
- RF phase alternates
- No net gradient per TR
- No dephasing -> no echoes
- VERY frequency sensitive
  - Zeros separated by 1/TR
- Large signal
- Signal depends on $\alpha$, TE, TR, $T_1$, $T_2$

Nayak et al MRM 2007