E. Wong, BE278, UCSD Winter 2011

Bioengineering 278
Magnetic Resonance Imaging

Winter 2011
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

Echo 1

160° X

dehase

rephase
dehase

160° X

rephase

Echo 2

160° Y

dehase

rephase
dehase

160° Y

rephase

Coherence Pathways

RF\(_x\) pulse 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\(_x\) pulse operating on F/Z:

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

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

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

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

Signal intensity is maximized at the Ernst Angle

\[ \alpha_E = \cos^{-1} \left( \exp(-TR/T_1) \right) \]

Spoiled gradient echo equation assumes no coherence from shot to shot. In practice this is achieved with RF spoiling.
$E = \cos^{-1}(\exp(-TR/T_1))$

Spoiled gradient echo sequence

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

$G_Z(t)$

$G_X(t)$

$G_Y(t)$

RF

TR
Unspoiled gradient echo sequence

- FLASH, GRASS
- 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

- CE-FAST, SSFP
- 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, $T_1$, $T_2$

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