Clinical MRI Education Lecture 2 will start at 7am Tue. 1/27

Thanks for arriving early. You may want to get a cup of coffee and relax ... 😊

MR Signal and Contrast

Spin, Polarization, RF, Excitation, FA, Signal, Frequency/Phase, Relaxation, T1/T2/T2*, Saturation, Echo

RF Frequency = Larmor Frequency → Resonance & Excitation

Any question?

Lecture 2
Pulse Sequence Components and Parameters
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Where is the MR signal coming from?
**Spatially-varying Magnetic Field (i.e. Gradient)**

- The spatial variation is typically linear, i.e. constant gradient (Max. of 40 mT/M for Siemens Avanto)
- The direction of \( \mathbf{B}(x) \) is in the same direction as \( \mathbf{B}_0 \).
- Establishes a relationship between magnetic field and spatial coordinate, i.e. precession frequency depends on spatial location.

\[
\mathbf{B}(x) = \mathbf{B}_0 + xG\mathbf{Z}
\]

**Gradient Pulse**

- Slew rate i.e. Max. slew rate of 200T/M/s for Siemens Avanto
- Amplitude
- Length
- Area = Amplitude x Length (~ Phase Shift)

Create different phase shift along the direction of gradient.

**Method 1: Selective Excitation**

- Selective Excitation of a Slice of Thickness \( \Delta Z \)

**Slice/Slab Thickness and Offset**

- \( f(z) = y(B_0 + zG_z) \)

**RF with Finite Bandwidth (SINC Pulse)**

\[
sinc(x) = \begin{cases} 
1 & \text{for } x = 0 \\
\frac{\sin(x)}{x} & \text{for } x < 0
\end{cases}
\]

\[
\mathcal{F}(x) = \begin{cases} 
0 & \text{for } |x| > \frac{1}{2} \\
\frac{1}{2} & \text{for } |x| = \frac{1}{2} \\
1 & \text{for } |x| < \frac{1}{2}.
\end{cases}
\]

**Truncated SINC pulse and Slice Profile**
**Slice “Cross-talk”**

- Gap
- Thickness

**Slice/Slab Selective Excitation Module**

- SINC RF Pulse
- Trapezoid Gradient Pulse

**Method 2: Frequency Encoding**

- Time domain signal
- Projection

**Frequency Encoding**

- Rx Frequency
- Rx Band Width (RBW)
- FOV (in Freq. Encode Direction)

**Sampling and Digitization**

- Unable to resolve different frequencies when maximum frequency exceeds twice of the sampling frequency. (Nyquist Theorem)

**Aliasing in Frequency Direction**

- Right arm
- Left arm
- Higher than $f_{\text{Max}}$
- Lower than $-f_{\text{Max}}$
- Allassed to lower frequencies
- Allassed to higher frequencies
Chemical Shift Artifact

- Fat Signal
- Water Signal

220Hz @ 1.5T

Mis-registration in frequency encoding & slice selection directions

Chemical Shift Artifact Solutions

1. Increase receiver bandwidth to reduce mis-registration in frequency encoding direction.
2. Increase transmission bandwidth to reduce mis-registration in slice selection direction.
3. Use fat suppression (FS) or water excitation (WE) techniques to reduce fat signal.

- What about changing the field strength?
- Different kind of artifacts due to chemical shift also occurs in GRE, EPI and MRS.

Frequency Encoding Module

Signal

Echo

Trapezoid Gradient Pulse

Method 3: Phase Encoding

Phase Shift

Net phase is determined by vector sum of signals with different phase shifts:

\[ M_\varphi = \int M_\varphi(y) \exp(-i\pi G_y y) dy \]

- To figure out the intensity of signal at each location along the phase encoding direction, multiple measurements of various degree of phase shifts (multiple G_y steps) are needed. Similar to using multiple linear equations to solve for multiple variables.

Phase Encoding Module

Trapezoid Gradient Pulses of Different Amplitude
Aliasing in Phase Encoding Direction

FOV = 26x26 cm
FOV = 40x40 cm
FOV = 48x48 cm

Unable to distinguish different phases if phase accumulation exceeds 2π.

Aliasing in Slice Direction

Slice from 3D data set
Slice from 2D data set

Aliasing Solutions

- Use anti-aliasing filter for frequency encoding (always applied and adjusted according to RBW).
- Increase FOV.
- Swap frequency and phase encoding directions.
- Add phase and/or slice over-sampling.
- Apply spatial saturation.
- Choose/activate appropriate coil(s).
- Cover with RF blanket.

2D Imaging with Frequency & Phase Encoding

Frequency Encoded Points (Xres = 8)

Slice-selective versus Non-selective

Slice selective
- RF pulse with SINC modulation + gradient.
- Longer pulse length.

Non selective
- RF pulse with simple on/off and no gradient.
- Shorter pulse length.
- Scalable

Slice/Slab Selective Refocusing Module

RF
Gz

180° SINC RF Pulse

Trapezoid Gradient Pulse
Echo Condition

- The directions of magnetic moments in the transverse plane are re-aligned to generate a signal peak.
- Therefore, the time integral of gradient pulses from excitation to echo, i.e. the total phase accumulation ($\theta \sim y G_y \tau$), must be zero.
- No necessary for all three axis at the same time.

Spatial Resolution Related Parameters

- Slice/slab orientation, thickness, gap, offset and number; acquisition order; transmission bandwidth.
- Frequency encoding direction, receiver bandwidth/sampling frequency, sampling points.
- Phase encoding direction, number of steps.
- FOV, PFOV, Matrix sizes.
- RF and gradient pulse waveform and length.

The Anatomy of Basic MR Pulse Sequences

- Magnetization Preparation Section
  - CPMG, CPMG, Inversion Recovery
  - Spatial Selective Saturation
  - Magnetization Transfer (MT)
  - CHESS water suppression
  - Inversion Recovery (IR)

- Data Acquisition Section
  - Slice/Slab Selective Excitation
  - Phase Encoding(s)
  - Echo Generation
  - Spin Echo (SE), Fast/Turbo SE (TSE), Single-shot FSE (HASTE)
  - Gradient Recalled Echo (GRE), Fast GRE, Single-shot GRE (EPI)
  - Diffusion Weighting (DWI/DTI) and Gradient Moment Nulling (GMN)
  - Frequency Encoding
  - Filling of K-space

- Magnetization Recovery Section
  - Spoiling
  - Driven Equilibrium

Thank you!

Please send your additional questions and comments to: clin1@iupui.edu