Pulse Sequencing

- Spin Echo 自旋回音 (SE)
- Fast Spin Echo 快速自旋回音 (FSE)
- Gradient Echo 梯度回音 (GRE)
- Echo Planer Imaging 回音平面造影 (EPI)

Pulse Sequence Diagram, PSD

- The sheet music (樂譜) of MRI
  - Arranging the tone, timing, and duration for each component.
- The instruments (樂器) in MRI are...
  - Transmitting RF coil (transmit RF pulse)
  - Slice-selective gradient coil
  - Phase-encoding gradient coil
  - Frequency-encoding gradient coil
  - Receiving RF coil (receive echoes)

The goal of PSD

- Just like that the sheet music aims to form a beautiful melody for the concert.
- PSD aims to fill out a full K-space for MR imaging!
**K-Space properties**

- Each of the signals has its maximum signal amplitude in the center column.
- The maximum amplitude occurs in the center row because this line is obtained without additional dephasing.

1 K-Space matrix → 1 MR image

**Image of K-Space**

- Conventional way

**The Question now is ...**

- How to fill out the K-space matrix...
  - Control frequency-encoding gradient for the x-axis (columns) of K space.
  - Control phase-encoding gradient for the y-axis (rows) of K space.
  - The image contrast is determined by TR, TE, and flip angle.

**Spin-echo pulse sequence diagram**

- An echo is acquired per TR.
Multi-echo spin echo

- Fill each echo into the distinct k-space.
- For an eight-echo train, we get eight different images.

Fast spin echo (FSE)

- We will only have one k-space. We'll fill this k-space eight lines (eight-echo train) at a time with eight different phase-encoding strengths.

Fast spin echo

- In FSE, before each 180° pulse, we place a different value of the phase-encoding gradient.
- For the 180° pulse before the echo we choose as the TE_{eff} (in this case, 102 msec), we use a phase-encoding gradient with the lowest strength.
**Fast spin echo**

- In FSE, before each 180° pulse, we place a different value of the phase-encoding gradient.

- For the 180° pulse before the echo we choose as the $T_{E_{eff}}$ (in this case, 102 msec), we use a phase-encoding gradient with the lowest strength.

**Multi-slice & multi-echo spin echo**

- Multi-echo procedure doesn't increase the phase-encoding steps.

**Phase-encoding step**

- Please compare to the conventional spin echo.

- Depends on both ETL and slice number in a TR.

**The purpose of Gradient Echo**

- $Scan\ time = (TR)(N_p)(NEX)$

- Number of excitation (SNR)

- Number of phase encoding (spatial resolution)

- Repetition time: can be controlled to minimize the scan time.
GRE Pulse Sequence Diagram

- Three operator-controlled parameters that affect the tissue contrast.

Bi-lobed Readout Gradient

- Intentionally dephase the FID and rephase (or recall) it at time of TE.
- The maximum of echo occurs at the midpoint of the positive (rephasing) lobe.

Properties of GRE

- A smaller flip angle is used instead of the 90° RF pulse
  - A shorter TR is demanded for full recovery of M₂
- Instead of 180° RF pulse, a bi-lobed readout gradient is used to obtain an echo.
  - Quicker to apply than a 180° RF pulse → reduce minimum TE
- T₂* weighting is presented due to the absence of 180° RF pulse.

Tissue contrast in GRE

<table>
<thead>
<tr>
<th></th>
<th>T₁ weighting</th>
<th>Proton density</th>
<th>T₂* weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flip angle</td>
<td>Large (70°~110°)</td>
<td>Small (5°~20°)</td>
<td>Small (5°~20°)</td>
</tr>
<tr>
<td>TR</td>
<td>Short (&lt; 50 ms)</td>
<td>Long (&gt; 200 ms)</td>
<td>Long (&gt; 200 ms)</td>
</tr>
<tr>
<td>TE</td>
<td>Short (1~5 ms)</td>
<td>Short (5~10 ms)</td>
<td>Long (15~25 ms)</td>
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In conventional gradient echo the TR does not always affect image contrast. Once a certain value of TR has been exceeded, the M₂ recovers fully. Under these circumstances the flip angle and TE control the degree of saturation and dephasing respectively.
The Purpose of EPI

• Even the GRE can shorten TR, we still need several TRs to fill out one K space matrix.

• Can we fill out one K space matrix within a TR?
  • To do so, we need to manipulate the phase-encoding and frequency-encoding gradient.

Single-shot EPI

• The phase-encode gradient is subsequently applied briefly during the time when the readout gradient was zero (200 μsec).

Multi-shot EPI

• Also called segmental EPI
  • The readout is divided into multiple shots or segment ($N_y$)
    • $N_y = N_x \times ETL$
Contrast in EPI

- Contrast in EPI depends on the "root" pulsing sequence
- SE-EPI (90°-180°-EPI)
- GRE-EPI (α°-EPI)
- IR-EPI (180°-90°-180°-EPI)
  - inversion-recovery (IR)

Artifacts in EPI

- Signal Dropout
- Distortion
- Ghosting
- Chemical shift (must add fat sat when using EPI)

THE END

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