本週課程內容

- Echo Planar Imaging (EPI)
- 組織壓抑技術(Tissue suppression imaging)

Echo Planar Imaging, EPI

- EPI: the fastest MRI technique
  - Diffusion tensor imaging, perfusion imaging, functional MRI
- Single-shot EPI, multi-shot EPI
- Constant phase encoding, blipped phase encoding
Hardware requirements in EPI

- High performance gradients
  - Rapid on/off switching of the gradients
  - Gradient strength of 20~100 mT/m
  - Gradient rise time of less than 300μsec
- Fast computers
  - Fast digital manipulations and signal processing
- Fast-sampling ADC
  \[
  \frac{T_s}{N_x} = \frac{1}{BW} \quad T_s \downarrow \Rightarrow BW \uparrow \quad \text{(in MHz)} \Rightarrow \text{SNR} \downarrow
  \]

Single-shot EPI

- Readout gradient: reversed rapidly from maximum positive to negative Ny/2 times

Multi-shot EPI

- Also called segmental EPI
  - The readout is divided into multiple shots or segment (Ns)
    \[ Ny = Ns \times \text{ETL} \]

A zigzag coverage of k-space
A spiral coverage (using oscillating Gx and Gy)
An interleaved coverage of k-space
Multi-shot vs. single-shot EPI

Advantages
• Less stress on the gradients (fewer duty cycles \(\Rightarrow\) better cooling)
• Less time to build up phase errors \(\Rightarrow\) reducing susceptibility artifacts

Disadvantages
• Longer scan time
• More susceptible to motion artifacts

Scan time
• \(T(\text{single-shot EPI}) = \text{ESP} \times N_y \times N_{EX}\)
• \(T(\text{multi-shot EPI}) = TR \times N_s \times N_{EX} = TR \times N_y/ETL \times N_{EX}\)

Contrast in EPI

• SE-EPI (90\(^\circ\)-180\(^\circ\)-EPI)
  • eliminate \(\Delta B_{\text{ext}}\)
  • \(T_1\) and \(T_2\) weighting
  • Diffusion-weighted imaging
• GRE-EPI (\(\alpha\)-EPI)
  • \(T_2^*\) weighting
  • Faster imaging speed
  • Perfusion imaging
• IR-EPI (180\(^\circ\)-90\(^\circ\)-180\(^\circ\)-EPI)
  • Heavy \(T_1\) weighting

Diffusion weighted imaging, DWI

• Apply a pair of diffusion gradients before and after the 180\(^\circ\) RF pulse (SE-EPI)

For a “fixed-position” proton, this pair of gradients won’t cause dephasing.
Diffusion weighted imaging, DWI

Abscess, tumor at high cell density

(a) Dephasing
(b) Diffusion gradients
(c) Rephasing

Axon bundles (perpendicular to axons)

(a) Dephasing
(b) Diffusion gradients
(c) Rephasing

Axon bundles (parallel with axons)

(a) Dephasing
(b) Diffusion gradients
(c) Rephasing

Diffusion is defined as the process of random molecular thermal motion (Brownian motion)
- High (free) diffusion along gradients → low signal
- Low (restricted) diffusion along gradients → high signal

DW-MRI aims at highlighting the differences in water molecule mobility, irrespective of their direction of displacement.
- Applying diffusion gradients in at least 3 spatial directions
- Diffusion magnitude (trace image)
- T2-weighted image
Diffusion weighted imaging, DWI

- Diffusional signal loss by the gradient application
  \[ \frac{S}{S_0} = e^{-rG^2\gamma^2(\Delta-\frac{\delta}{2})D} = e^{-bD} \]
  - \( S_0 \) is the signal intensity with out the diffusion weighting (no gradient application)
  - \( S \) is the signal with the gradient application
  - \( D \) is a diffusion constant
  - \( \gamma \) is the gyromagnetic ratio
  - \( G \) is the gradient strength
  - \( \delta \) is the gradient duration
  - \( \Delta \) is the time interval between dephasing and rephasing gradients

Diffusion tensor imaging

- Perform diffusion-weighted acquisitions in at least 6 directions
- We can reconstruct the diffusion tensor

Advantages of EPI

- Scan time is approximately 100 msec or less (32~50 msec).
- Cardiac and respiratory motion won’t pose problems.
- PD, T1, and T2 weighted images free of motion artifacts can be achieved.
- It allows the functional studies rather than the mere depiction of anatomy.
- Resolution can be improved due to fast scanning speed.

Disadvantages of EPI

- Fat suppression with presaturation techniques is always required (to cancel fat-water chemical shift artifacts).
- Rapid on/off switching of the gradients \( \Rightarrow \) possible “electric shock” in the subject
- Potential for phase error (less effect for multi-shot EPI)
- Intrinsic non-uniformities in B0 and susceptibility effects (less effect for multi-shot EPI)
### Artifacts in EPI

- **Signal Dropout**
- **Distortion**
- **Ghosting**
- **Chemical shift**

### Suppression techniques

- Two common targets (tissues): fat and water
- Suppression techniques
  - Inversion recovery (IR) techniques
  - Chemical/spectral saturation or frequency-selective presaturation
  - Spatial presaturation in the field of view (FOV)

### Inversion recovery, IR

- After the 180° RF pulse, the magnetization starts to recover from \(-M_0\) instead of zero.
- \(TI(null) = \frac{\ln(2)}{T_1} \approx 0.693 \times T_1 \)
Tissue Suppression: STIR & FLAIR

- **STIR**: Short TI inversion recovery, fat suppression
  - At 1.5T, TI = 0.693 x 200 = 138.6 msec
- **FLAIR**: Fluid attenuated inversion recovery, water suppression
  - At 1.5T, TI = 0.693 x 3600 = 2494.8 msec
- **Fast FLAIR**: IR for water + fast spin echo (FSE)

Fast FLAIR: an example

- Two slabs of 15 slices each
- Multi-slice + FSE (ETL = 8, FSE takes 8 x 17 = 136 msec)
- The maximum # of slice in one TR is usually limited by TI

Advantages/Disadvantages of IR

- **Advantage**
  - No variability caused by magnetic field inhomogeneities
- **Disadvantages**
  - Tissues with similar T1 values are all suppressed.
  - Long acquisition times caused by long TRs
  - Low SNR

Chemical/spectral presaturation

- A frequency-selective presaturation pulse is applied before the RF excitation pulse.
- We select appropriate frequency (based on the Larmor equation) to suppress fat or water.
- At 1.5T, water protons precess 220 Hz faster than fat protons.
### Chemical/spectral presaturation

**Advantages**
- Resolves tissues with similar T1 values (fat and Gd-enhanced tumors)
- No influence on the signal from other tissues (in contrast, IR affects the contrast of all tissues)

**Disadvantages**
- Suffers from sensitivity to magnetic field inhomogeneities (e.g. metallic susceptibility artifacts).
- Cause extra RF heating
- May lengthen TR, thus increasing the scan time (5~8 ms)

### Spatial presaturation

**Advantages**
- Minimize phase ghosts
- Minimize flow artifacts

**Disadvantages**
- May cause signal suppression in the reminder of the FOV
- May lengthen TR, thus increasing the scan time (5~8 ms)

### Magnetization transfer, MT

**To suppress protein-bound water**
- Protons in protein-bound water exhibit a resonant frequency that is approximately 500 to 2500 Hz away from that of bulk water protons.
Magnetization transfer, MT

- MT is similar to spectral fat suppression techniques except that here, the off-resonant frequency is up to 2000 Hz as opposed to 220 Hz in the case of fat suppression.
- Used in time of flight (TOF) MR angiography to suppress the background brain tissue and enhance visualization of smaller vessels.
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<td>TSE</td>
<td>Turbo-spin echo</td>
<td>SE using multiple phase-encoded echoes for faster filling of k-space</td>
<td>PSE, RARE</td>
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<tr>
<td>TFE</td>
<td>Turbo-field echo</td>
<td>TFE with inversion or saturation pulse preceding the whole measurement in order to establish T₁, weighting, or for the noting of the signal of a specific tissue</td>
<td>TFI, FSPGR</td>
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<tr>
<td>TFL</td>
<td>Turbo-field low-angle shot</td>
<td>FLASH with inversion or saturation pulse preceding the whole measurement in order to establish T₁, weighting, or for the noting of the signal of a specific tissue</td>
<td>TFF, FSPGR</td>
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<td>VIBE</td>
<td>Volume-interpolated breath-hold examination</td>
<td>3D GRE with low flip angle excitation and &quot;spoiling&quot; after data acquisition of a single k-space line and Fou- rier interpolation in the direction of partition encoding</td>
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