Echo Planar Imaging Techniques and Applications

Chen Lin
Indiana University School of Medicine & Indiana University Health

Outlines

• EPI Technique
  – EPI pulse sequence
  – Characteristics of EPI
  – Common artifacts associated with EPI
  – Variants of EPI
• Applications of EPI
  – DWI, DTI, DSC, ASL, fMRI
  – Challenges and requirements
  – Why choose EPI

Disclosure

• Research funding provided by Siemens Healthcare.

Multi-echo (ME) Spoiled GRE

Single-shot GRE (GRE/FID-EPI)

K-space sampling with EPI
**Spin Echo EPI (SE-EPI)**

- **Gslice**: TE/2
- **Gread**: 180°
- **Gphase**: ~90°

$T_2$ weighted contrast with SE-EPI instead of $T_2^*$ weighted for GRE-EPI
Reduced off-resonance artifacts

**CHARACTERISTICS OF EPI**

- Fast and efficient scan.
  - "freeze" motion
  - Low SAR compared with SS-FSE.
- Artifact prone
  - More severe @ higher field strength
  - Requires high performance and well calibrated hardware.
- Limited spatial resolution
- $T2w$ for SE-EPI; $T2^w$ for GRE-EPI.

**ULTRA-FAST MRI SEQUENCES**

- Conventional Spin Echo Sequence (67 sec)
- Fast Spin Echo Sequence (53 sec)
- Spoiled Gradient Echo Sequence (21 sec)
- Balanced SSFP (bSSFP, TrueFISP, FIEASTA) (14 sec)
- Single-shot FSE (SS-FSE, HASTE) (8.8 sec)
- Single-shot Echo Planar Imaging (EPI)
  - Spin Echo EPI (SE-EPI) (8.6 sec)
  - Gradient Echo EPI (GRE-EPI, EPI-FID) (5.9 sec)

**EPI ARTIFACTS**

- Nyquist (N/2) Ghosting
- Different phase shifts in odd and even frequency encoding lines
- Correct by:
  - Gradient calibration and/or eddy current compensation
  - Reference scan (w/o phase encoding or shifting one phase step)

**NYQUIST (N/2) GHOSTING**

$N/2$ Ghosting in $k$-space (Dimension)

**CHEMICAL SHIFT DISTORTION**

Distortion due to chemical shift

**FOV/2**
**Chemical Shift Artifact in EPI**
- Low bandwidth \(\rightarrow\) Large chemical shift in phase direction
- Inversely proportional to Echo SPacing (ESP)

<table>
<thead>
<tr>
<th>Without Fat Suppression</th>
<th>With Fat Suppression</th>
</tr>
</thead>
</table>

**Geometric Distortion in EPI**
- \(B_0\) inhomogeneity introduces local gradients
- Phase error accumulates in the echo train.
- Minimized with fewer echoes (ETL) and/or less echo spacing (ESP)
- Retrospective correction with measured \(B_0\) map

**How to reduce Echo SPacing (ESP)**
- High rBW (Faster sampling rate)
- Lower read resolution (Less frequency encoding points)
- Ramp Sampling

**How to reduce echo train length (ETL)**
- Reduce phase resolution or phase FOV (Less phase encoding steps)
- Partial Phase Fourier
- Parallel Imaging

**Examples with varying ESP & ETL**

**Skip Echo EPI and Circular EPI**
Multi-shot EPI (MS-EPI)

Single-shot EPI (SS-EPI) with low resolution in Y direction

Multi-shot EPI (MS-EPI) with higher resolution

SS-EPI versus MS-EPI

Multi-shot -> Less echoes per shot -> reduced susceptibility artifacts

Other Multi-shot EPI k-space Trajectories

Other Artifact in EPI

“Blurring”
- Due to T2* induced signal modulation in k-space.
- May not be obvious due to low spatial resolution and other artifacts.

“Dark Spots”
- Intra-voxel de-phasing due to off resonance.
- Reduce voxel size, i.e. slice thickness.
- SE-EPI.

EPI based Applications

1. Diffusion Weighted Imaging (DWI)
   - Intra Voxel Incoherent Motion (IVIM)
   - Diffusion Tensor Imaging (DTI)
2. BOLD functional MRI (fMRI)
3. Perfusion Weighted Imaging (PWI)
   - Dynamic Susceptibility Contrast (DSC)
   - Arterial Spin Labeling (ASL)
4. Magnetic Resonance Spectroscopic Imaging (MRSI)
5. Real-time cardiac Imaging
6. ...

Restricted Water Diffusion in Tissue

Chen Lin, PhD DABR 3/11

Chen Lin, PhD DABR 3/11

Chen Lin, PhD DABR 3/11

Chen Lin, PhD DABR 3/11

Chen Lin, PhD DABR 3/11

Chen Lin, PhD DABR 3/11

Chen Lin, PhD DABR 3/11

Chen Lin, PhD DABR 3/11

Chen Lin, PhD DABR 3/11

Chen Lin, PhD DABR 3/11

Chen Lin, PhD DABR 3/11
ADC and Tissue Properties

- Large extra-cellular space
- High ADC
- High cellular fraction
- Small extra-cellular space
- Low ADC

Motion Dependent Phase Difference

G

Diffusion at Different Stage of Tumor

ADC

Diffusion Weighted SE-EPI

\[ S_2 - S_1 = e^{-b \cdot ADC} \]

ADC Map Calculation

ADC = \[ \frac{\ln(S1) - \ln(S2)}{b1 - b2} \]

Acute Ischemic Stroke vs Infarction

- Interruption of blood flow to brain tissue
- Cell swelling
- Reduction in ADC
Body Diffusion Applications

- Breast
- Liver
- Pancreas
- Kidney
- Prostate
- Screening of Metastasis

Typical Body DWI Protocol

- 2D SS-EPI sequence with TR > 1500 ms, TE = min.
- Matrix: 128x128 - 192 x 192
- Suppress fat signal.
- Average multiple acquisitions, if possible.
- Control physiological motion (e.g. Breath hold, Respiratory triggering)
- Use high rBW (e.g. > 1600 Hz/Px)
- Acquire partial k-space
- Select b-values according to application (e.g. 50 - 1500 sec/mm²)

Getting more from Diffusion Attenuation Curve?

\[ S = S_0 \cdot (1 - f) \cdot e^{-bADC} + f \cdot e^{-bADC^*} \]

Intra Voxel Incoherence Imaging

Diffusion Anisotropy and DTI

DTI based Fiber Tracking / Tractography

Provide information about white matter connectivity
High Angular Resolution Diffusion Imaging (HARDI or Q-ball Imaging)

- 1 dir
- 3 dir
- 6 dir
- 7 dir

Perfusion

- Deliver oxygen and nutrients to the cells
- Affected by pathological and physiological conditions, such as tumor angiogenesis, stroke and infarct, vascular wall changes.

Perfusion Model and Parameters

- Blood Flow (ml of blood / gram of tissue / sec)
- Blood Volume (ml of blood / gram of tissue)
- Mean Transit Time (MTT) (sec)

\[ CBF = \frac{CBV}{MTT} \]

MR Perfusion Imaging Methods

- Dynamic Susceptibility Contrast (DSC) MRI Perfusion
  - GRE-EPI (T2* weighted)
  - SE-EPI (T2 weighted)
- Dynamic Contrast Enhanced (DCE) MRI Perfusion
  - Spoiled Fast Gradient Echo (T1 Weighted)
- Arterial Spin Labeling
- Intra Voxel Incoherence

Typical DSC Perfusion Protocol

- Single-shot GRE-EPI or SE-EPI
- TE = 30 – 60 ms (GRE-EPI) or 50 – 80 ms (SE-EPI)
- TR = min. (< 2 sec depends on number of slices)
- TA = 90 - 120 sec. or ~ 100 time points
- Contrast dose = 0.1 – 0.2 mmol/kg
- Injection rate: 3 – 5 ml/sec with 20 ml saline flush.

DSC Perfusion Imaging
**SE-EPI vs GRE-EPI for DSC PWI**

- SE-EPI signal (T2 dependent) is more specific to microvasculature/perfusion while GRE-EPI signal (T2\* dependent) is also affected by larger vessels.
- GRE-EPI provides greater sensitivity and coverage/temporal resolution (more slices for same TR).

**PWI with Arterial Spinning Labeling**

- Tagged blood flows through vasculature and exchanges with tissue.
- Change total tissue magnetization in slice (1-2%) compared to control.
- "Control" = "Labeled" or CBF

**PICORE PASL**

- IR-SS-GRE EPI, TE = min, TR ~ 2500ms
- Sl Thk = 7mm, FOV = 224mm, Matrix = 64 x 64
- 5-7 slices with 0% gap
- rBW = 2368Hz/px (ESP=0.51ms)
- Parallel Imaging Acceleration = 2
- Fat Suppression
- TI2=1800ms, TI1=700ms, TI1s=1600ms
- 101 volumes in 4:17

**Typical ASL PWI Protocols @ 3T**

- Blood Oxygenation Level Dependent Contrast
  - Deoxy-hemoglobin is paramagnetic (An endogenous contrast agent, like Gd)
  - Oxy-hemoglobin is less so.
  - Blood T2\* depends on oxygenation (Arterial vs venous).

- T2\* difference between activated and rest states
  - Oxyhemoglobin
  - Deoxyhemoglobin

- Signal change ~ 1-2% @ 1.5T
**BOLD fMRI**

- Stimulus (Block Design)
- Measured Response
- Statistical Significance of Correlation

**Typical BOLD fMRI Protocol @ 3T**

- SS-GRE EPI, TE = 30ms, TR = 2000ms
- Sl Thk = 3.5mm, FOV = 224mm, Matrix = 64x64
- 33 slices with 0% gap
- rBW = 2442Hz/px (ESP=0.47ms)
- ETL = 64

- 144 volumes (16/Block) in 4:52 with Prospective Motion Correction

---

**Proton-Echo-Planar-Spectroscopic-Imaging (PEPSI)**

- Courtesy of Dr. Stefan Posse, U. of NM

---

**Advanced Functional MRI Exam**

- High resolution 3D anatomical scan
  - 3D T1MP-RAGE (IR-SPGR)
  - 3D T2 or FLAIR SPACE (CUBE)
- B0 Field Mapping
- fMRI w. different paradigms
- DTI
- DSC or ASL Perfusion
- Spectroscopy scan
- MRA / MRV
- ...

---

Thank You!

www.indiana.edu/~mri