Echo Planar Imaging Techniques and Applications

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Outlines
- What’s EPI and how does it work?
- Characteristics of EPI
- Common artifacts associated with EPI
- Different variations of EPI
- EPI based functional imaging (fMRI)
- EPI based diffusion weighted imaging (DWI)
- EPI based diffusion tensor imaging (DTI)

Ultra-fast Sequences
- Single-shot FSE / TSE (SS-FSE, HASTE)
- Echo Planar Imaging (EPI)
- Interleave of SE and GRE (TGSE, GRASE)
- Balanced SSFP (bSSFP, TrueFISP, FIEASTA)

Multi-echo (ME) Spoiled GRE
Separate images for fat and water separation (DIXON), improve SNR & Contrast (MEDIC); $T_2^*$ Quantification/Mapping

Gradient Recall Echo EPI (GRE-EPI)
Phase Encoding: sum of all previous $G_{\text{phase}}$ areas

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

- \( T_1 \) weighted contrast with SE-EPI instead of \( T_2^* \) weighted for GRE-EPI
- Reduced off-resonance artifacts

**Characteristics of EPI**

- Fast scan.
- \( T_2w \) for SE-EPI; \( T_2^*w \) for GRE-EPI
- Low SAR compared with SS-FSE.
-Artifact prone.
- High performance and well calibrated hardware.
- Low resolution.

**N/2 (Nyquist) Ghosting**

- Different phase shifts in odd and even frequency encoding lines
- Correct by:
  - Gradient calibration and eddy current compensation
  - Reference scan

**Chemical Shift Artifact in EPI**

- Low bandwidth -> Large chemical shift in phase direction
- Displacement \( \approx \) ESP
- Without Fat Suppression
- With Fat Suppression

**Geometric Distortion in EPI**

- Phase error accumulates in the echo train.
- Minimized with less echoes and/or shorter echo spacing
- Retrospective correction with measured \( B_0 \) map

**Other Artifact in EPI**

- Blurring
  - Due to \( T_2^* \) 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.
  - Improve with better shim and/or SE-EPI.
How to reduce the ESP & ETL

• To reduce echo spacing (ESP):
  – High rBW (Faster sampling rate)
  – Lower resolution (Less freq encoding points)
  – Ramp Sampling

• To reduce echo train length (ETL):
  – Lower resolution (Less phase encoding points)
  – Parallel imaging (reduces min. TE as well which compensates for the lost of signal)
  – Partial Fourier

Multi-shot EPI

SS-EPI versus MS-EPI

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

Other Multi-shot EPI k-space Trajectories

GRASE/TGSE Sequence

EPI based Applications

• BOLD functional MRI (fMRI)
• Diffusion Weighted Imaging (DWI)
• Diffusion Tensor Imaging (DTI)
• DSC and ASL Perfusion
• Real-time Imaging
• …
Neuro-activity and Blood Oxygenation

Rest

More deoxygenated Hb

Active

Increase of blood flow and oxygenated Hb

Source: Functional Magnetic Resonance Imaging

BOLD Contrast

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

Resting State

Activated State

- Oxyhemoglobin
- Deoxyhemoglobin

Signal

Signal change ~ 1-2 % @ 1.5T

30ms

TE

Hemo-dynamic Response

Baseline

Peak

Rise

Sustained Response

Undershoot

Neuro Activity

Initial Dip

Response Recording

Stimulus Presentation

Scanner Room

Equipment Room

Console Area

Sync Trigger

Typical fMRI Setup

Neuro Activity and EPI Signal Intensity

- Increase in cerebral blood supply to the region of activation.
- Less increase of local oxygen extraction.
- Net reduction in deoxyhemoglobin concentration.
- Longer T₂*.
- Increase of signal intensity in T₂* weighted images such as EPI.
Stimulus Presentation and Response Recording

- Audio-visual Presentation
  - Instruction/Questions/Prompt -> Motor Skills
  - Music, Word, Numbers
  - Pattern, Image, Animation, Video
- Neurological Activities/Process
  - Word generation / Category generation
- Response Recording
  - Finger switches/Keypads
- Physiological Monitoring
  - Respiratory rate, heart Rate, eye tracking

BOLD fMRI

Scanner QA for fMRI

Typical Clinical fMRI Protocol @ 3T

- SS GRE EPI, TE = 30ms, TR = 2000ms and FA = 80°
- SI Thk = 3.5mm, FOV = 224mm, Matrix = 64 x 64
- 33 slices with 0% gap (whole brain coverage)
- rBW = 2368Hz/px (ESP=0.51ms)
- iPAT = 2
- FATSAT
- 144 volumes in 4:54

fMRI Post processing

Simultaneous Mapping of Multiple Functions
**fMRI Applications**

- Brain function research
- Neuro degenerative diseases
- Surgical planning for tumor resection
- ...

**Diffusion Weighted Single-shot SE-EPI**

\[ s = s_{ext} e^{-bD} \]  
where \( b = \gamma^2 G^2 \Delta^2 / \delta \)

**ADC Map Calculation**

\[ \text{ADC} = \frac{\ln(S_1) - \ln(S_2)}{b_2 - b_1} \]

**Restricted Water Diffusion in Tissue**

- Low cell density
- Large extra-cellular space
- High ADC

- High cell density
- Small extra-cellular space
- Low ADC

**Acute Stroke**

- Interruption of blood flow to brain region
- Ischemic injury, infarction
- Reduction in ADC
Diffusion at Different Stage of Tumor

Body Diffusion Applications
- Breast
- Liver
- Pancreas
- Kidney
- Prostate
- Screening of Metastasis

Body Diffusion Applications

Typical Body DWI Protocol
- 2D single shot EPI sequence with TR > 1500 ms, TE = min.
- FOV: 36 – 40 cm, Matrix: 128x128 - 192 x 192
- Interleave multiple slices.
- Suppress fat signal.
- Average multiple acquisitions, if possible.
- Control physiological motion (e.g. Breath hold, Respiratory triggering)
- Use high receiver bandwidth (e.g. > 1600 Hz/Px)
- Acquire partial k-space (parallel imaging and partial Fourier).
- Use either single and combined gradients for diffusion weighting and select b-values according to application (e.g. 50 - 1500 sec/mm²)

Diffusion Anisotropy

Fractional Anisotropy (FA)

DTI based Fiber Tracking / Tractography

Provide information about white matter connectivity
Comparison of DTI Fiber Tracking with Histology Preparation

S. Mori - JHU

Fiber Tracking Examples

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Tractography

Superior view color fiber maps
Lateral view color fiber maps

Zhang & Laidlaw

Fiber Tracking and Neurosurgical Planning

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Typical Functional MRI Exam

- High resolution structural scan
  - 3D T1 MP-RAGE (IR-SPGR)
  - 3D T2 or FLAIR SPACE (CUBE)
- B0 Field Mapping
- fMRI scans with different paradigms
- DTI scan
- Perfusion scan
- Other routine scans
- fMRI QA

Thank You!

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