Rad229 – MRI Signals and Sequences

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Lecture-10C — Pulse Sequences III
Advanced Echo Planar Imaging (EPI)

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Learning Objectives

• Appreciate several alternatives to single-shot EPI.
• Describe how multiple single-shot EPI can be averaged to mitigate bulk motion artifacts.
• Compare interleaved and segmented EPI approaches.
• Evaluate advantages and disadvantages of various EPI approaches.
EPI – Artifacts

Linear Phase Ghosts in EPI

Distortion in EPI

\[ d_{pe}(\vec{r}) = \frac{\gamma}{2\pi} \Delta B_0(\vec{r}) t_{esp} FOV_{pe} \]

EPI displacement due to off-resonance.

Constant Phase Ghosts in EPI

Object Phase

Fat Aliasing in EPI
Advanced EPI Sequences – Distortion reduction?

- Partial Fourier
  - Shorten TE, ESP, or ETL
- Parallel imaging, C.S., & M.L.
  - Reduce TE, ETL, model $\Delta B_0$
- Segmented EPI
  - Reduce TE, ESP, and ETL, model motion or $\Delta B_0$
- Multi-shot
  - Reduce TE, ESP, and ETL, model motion or $\Delta B_0$

$$d_{pe}(\vec{r}) = \frac{\gamma}{2\pi} \Delta B_0(\vec{r}) t_{esp} FOV_{pe}$$

EPI displacement due to off-resonance.
EPI protocols oftentimes require repeated acquisitions (e.g. DWI/DTI) that are amenable to motion correction.

Repeated acquisition ($N_{EX}$) or “direction”

- **NEX = 1**: No motion correction + averaging
- **NEX = 2**: (Rigid body) motion correction + averaging
- **NEX = 3**: Patient wiggles around

EPI protocols often require repeated acquisitions (e.g. DWI/DTI) that are amenable to motion correction.
Partial Fourier in the phase encode direction EPI can improve image quality.

Partial-Fourier in $k_x$ (fractional echo)
Relative to full-Fourier:
- Shorter echo spacing
- Reduced distortion
- Slightly reduced $T_2^*$ effects
- Slightly reduced minimum TE

Partial-Fourier in $k_y$ (fractional NEX)
Relative to full-Fourier:
- Same echo spacing
- Reduced distortion
- Reduced $T_2^*$ effects
- Reduced minimum TE

(more common)
Other distortion reduction strategies


Reversed Gradient Polarity Method (RGPM)

(+) Estimate $\Delta B_0$ and correct the final image.

(-) Need to acquire two images.
EPI artifacts generally improve with shorter readout durations. The trick is to recover a high quality image!
EPI – Single-Shot vs. Interleaved

- **Single-shot EPI:**
  - Faster, reduces sensitivity to motion (especially for DWI)

- **Interleaved EPI:**
  - Slower, reduces sensitivity to $T_2^*$ and off-resonance

Images courtesy: Catherine Moran

$N_{	ext{interleaves}} = 2 \times \text{P.I.}$
EPI – Interleaved vs. Segmented

Interleaved EPI (relative to full-Fourier):
- Reduced ETL
- Slightly longer echo spacing
- Reduced TE
- Reduced $T_2^*$ effects
- Reduced distortion

Segmented EPI (relative to full-Fourier):
- Reduced ETL
- Same echo spacing
- Shorter TE
- Reduced $T_2^*$ effects
- Reduced distortion
EPI Propeller (Phase-encode)
- Long axis (low $k_y$-res)
  - Note: Same $T_{\text{esp}}$ as EPI!
- Reduced geometric distortion
- Short TE, short ETL
- Motion robust
- Self-navigating (low-res image every blade)
- Each blade corrected for phase and delays


EPI Propeller (Readout)
- Short axis (low $k_x$-res)
  - Shorter $T_{\text{esp}}$
- Reduced geometric distortion
- TE and ETL ~constant
- Motion robust
- Self-navigating
- Each blade corrected…
Interleaved EPI and other “EPI” approaches

Distortion reduction from:

- Reduced effective FOV\(_{pe}\)
- Reduced \(t_{esp}\)
- Reduced \(t_{esp}\)

\[ d_{pe}(\vec{r}) = \frac{\gamma}{2\pi} \Delta B_0(\vec{r}) t_{esp} FOV_{pe} \]

EPI displacement due to off-resonance.
Interleaved EPI and other “EPI” approaches

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<tr>
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<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Interleaved EPI</td>
<td>Easier to implement/reconstruct, not slewing all the time (more efficient)</td>
<td>Motion between interleaves causes ghosting – harder to correct.</td>
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<td>SAP-EPI and RS-EPI</td>
<td>Each ‘segment’ acquired at full FOV → can correct for motion between segments.</td>
<td>Slewing a lot. Residual distortion for each “SAP-EPI segment” combines to give overall image blurring.</td>
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Summary

- Single-shot EPI is very fast, but prone to artifacts.
- Several methods trade-off reducing different artifacts, but may increase acquisition time or decrease SNR.
- Clever combinations of each approach can significantly improve image quality for a range of applications.
Further Learning...