Rad229 – MRI Signals and Sequences

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Lecture-10C — Pulse Sequences III

Advanced Echo Planar Imaging (EPI)

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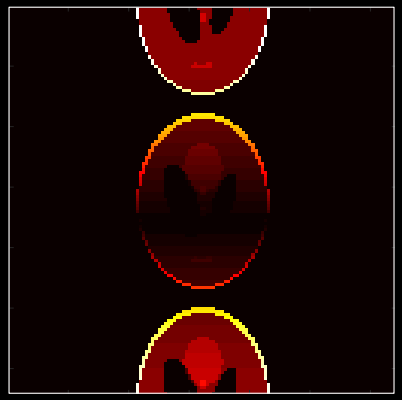
Learning Objectives

- 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

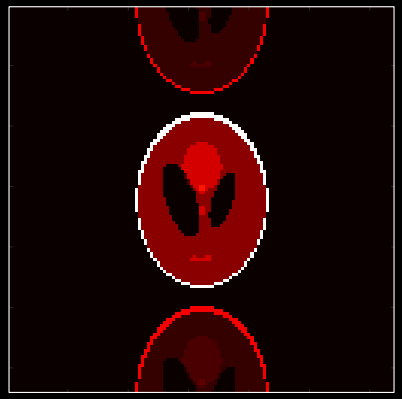


Distortion in EPI

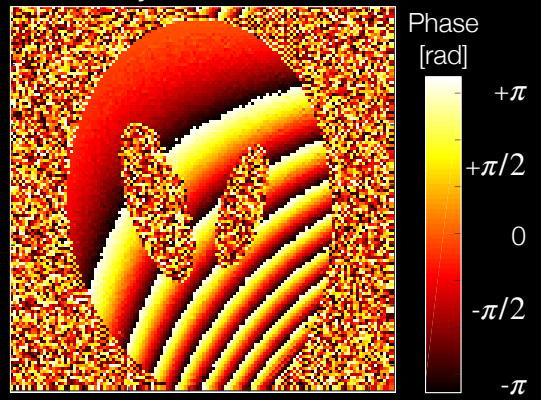
$$d_{pe}(\vec{r}) = \frac{\gamma}{2\pi}\Delta B_0(\vec{r})t_{esp}FOV_{pe}$$

EPI displacement due to off-resonance.

Constant Phase Ghosts in EPI



Object Phase



Fat Aliasing in EPI

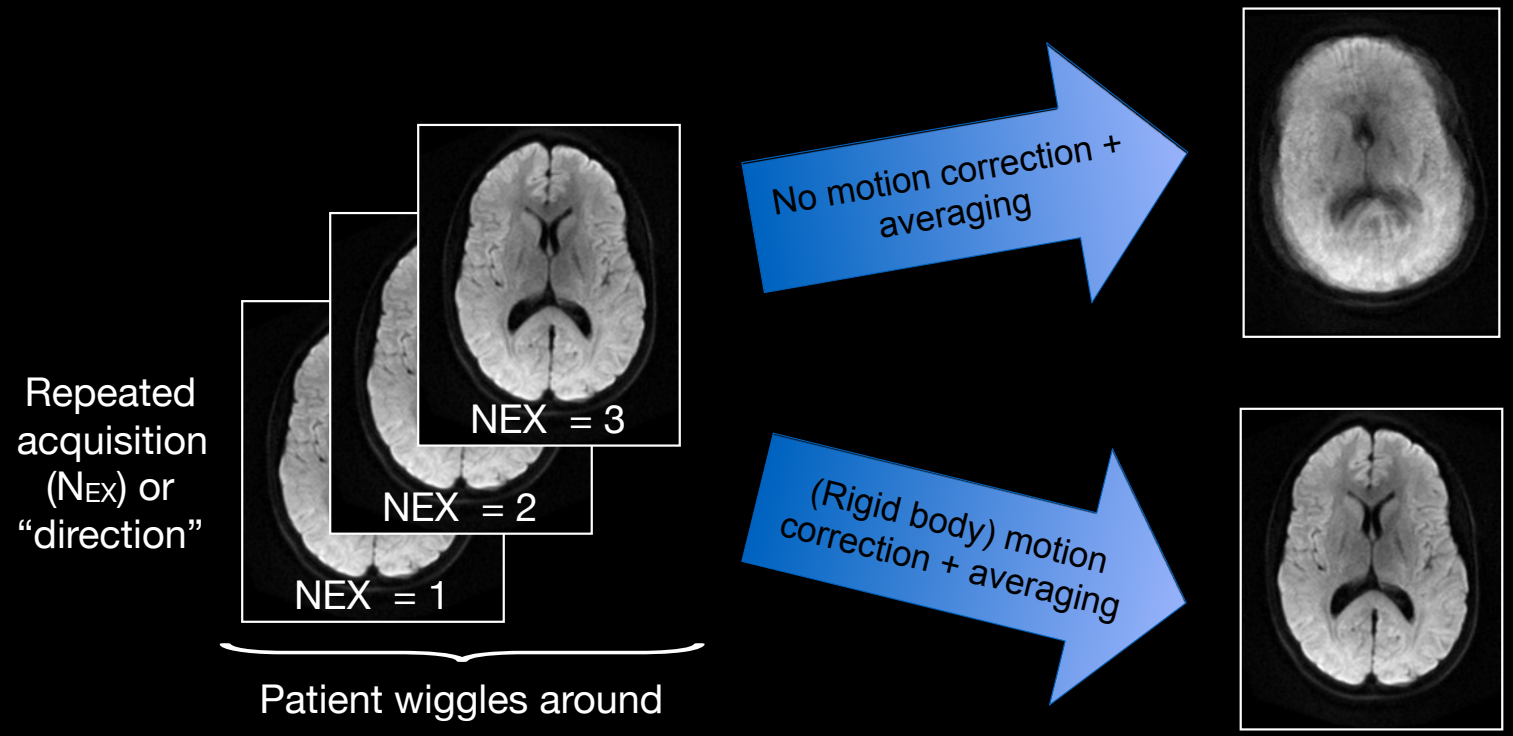
Advanced EPI Sequences – Distortion reduction?

- Partial Fourier
  - Shorten TE, ESP, or ETL
- Parallel imaging, C.S., & M.L.
  - Reduce TE, ETL, model ΔB_0
- Segmented EPI
  - Reduce TE, ESP, and ETL, model motion or ΔB_0
- Multi-shot
  - Reduce TE, ESP, and ETL, model motion or ΔB_0

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

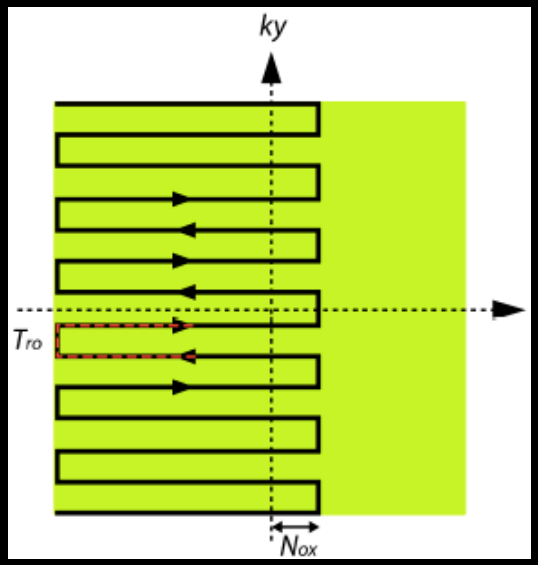
EPI displacement due to off-resonance.

EPI – Motion correction

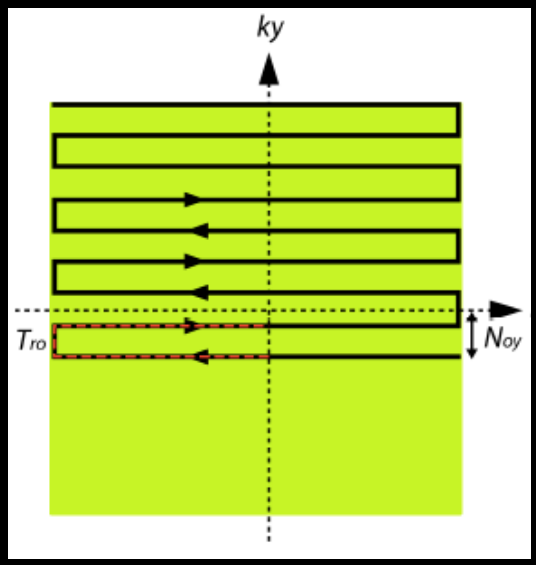


EPI protocols oftentimes require repeated acquisitions (e.g. DWI/DTI) that are amenable to motion correction.

EPI – Partial Fourier



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

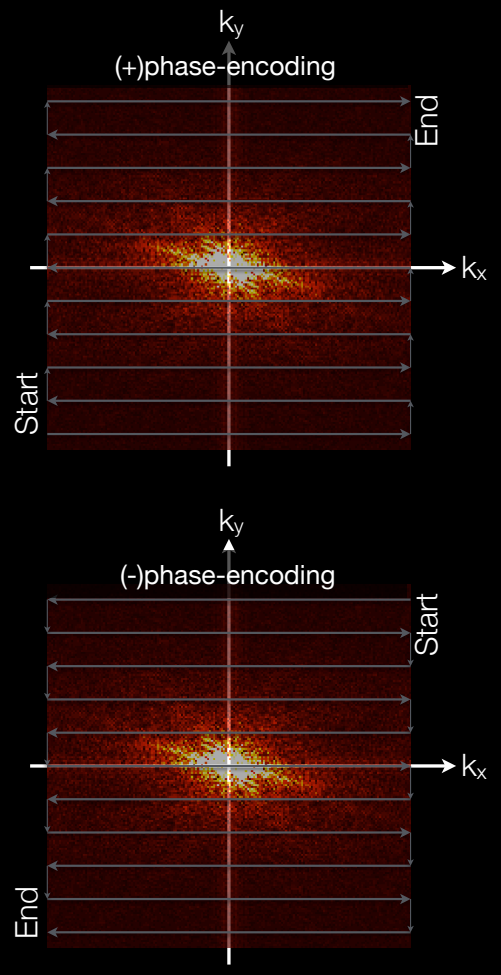


Partial-Fourier in k_y (fractional NEX)
Relative to full-Fourier:
- Same echo spacing
- Reduced distortion
- Reduced T_2* effects
- Reduced minimum TE

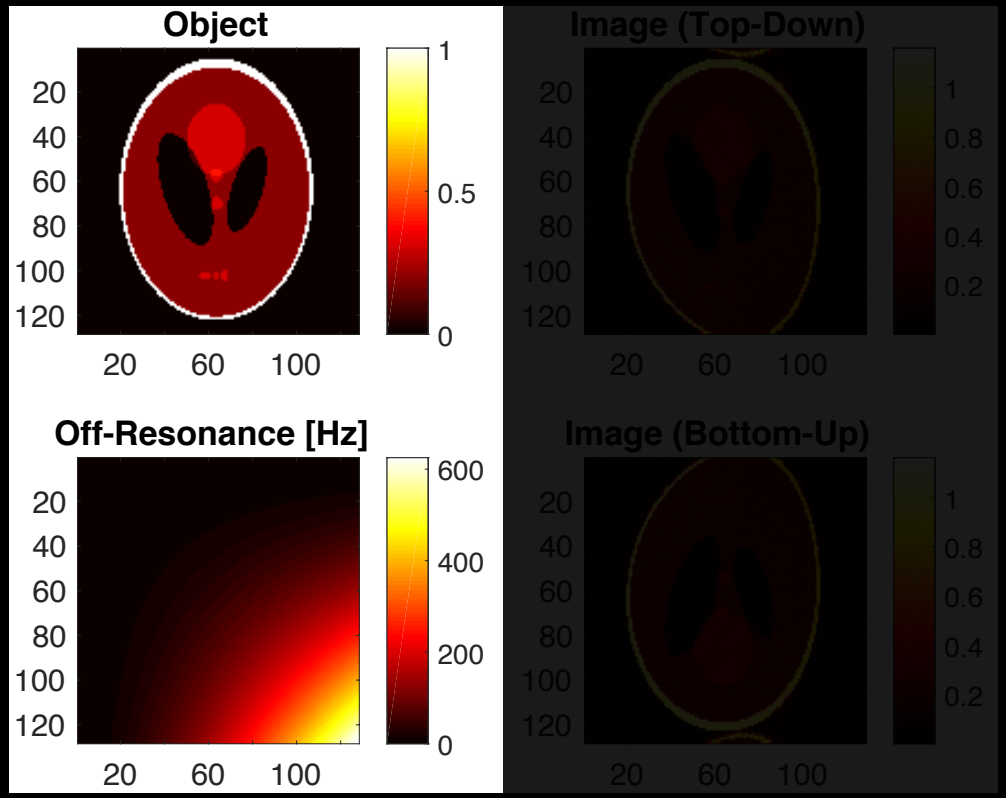
(more common)

Partial Fourier in the phase encode direction EPI can improve image quality.

Other distortion reduction strategies



Reversed Gradient Polarity Method (RGPM[1])

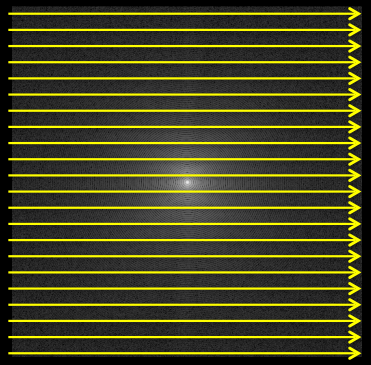


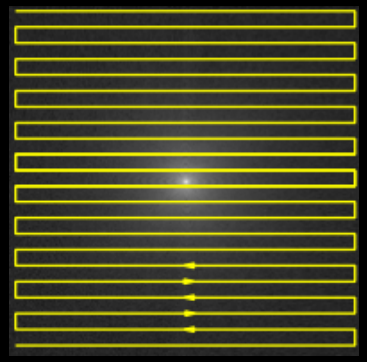
(+) Estimate ΔB_0 and correct the final image.

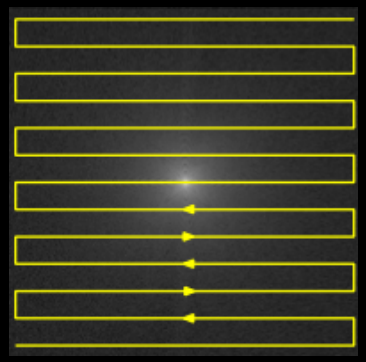
(-) Need to acquire two images.

[1] Chang H, Fitzpatrick J. A technique for accurate magnetic resonance imaging in the presence of field inhomogeneities. IEEE TMI. 1992;11:319–329.

EPI Distortion – Reduction Methods







Any guesses?

FSE (Not distorted)

Single-Shot EPI

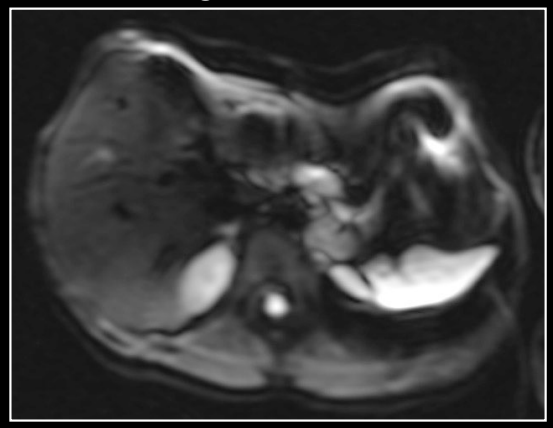
Single-Shot EPI (3x P.I.)

EPI artifacts generally improve with shorter readout durations. The trick is to recover a high quality image!

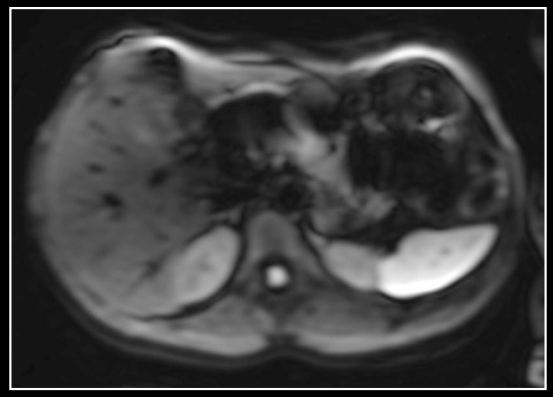
EPI – Single-Shot vs. Interleaved

- Single-shot EPI:
  - Faster, reduces sensitivity to motion (especially for DWI)
- Interleaved EPI:
  - Slower, reduces sensitivity to T_2* and off-resonance

Single-Shot EPI

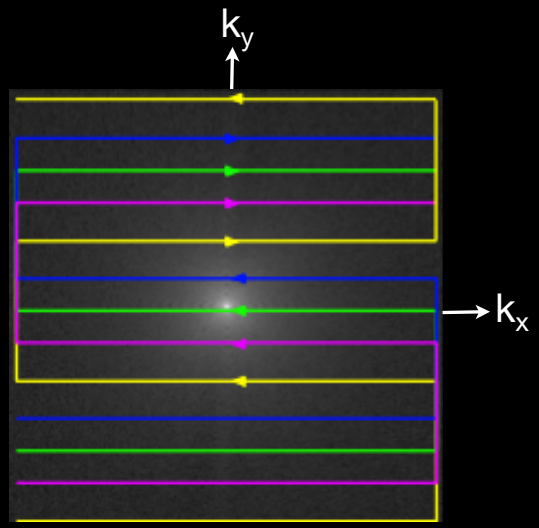


$N_{interleaves}$ = 2x P.I.

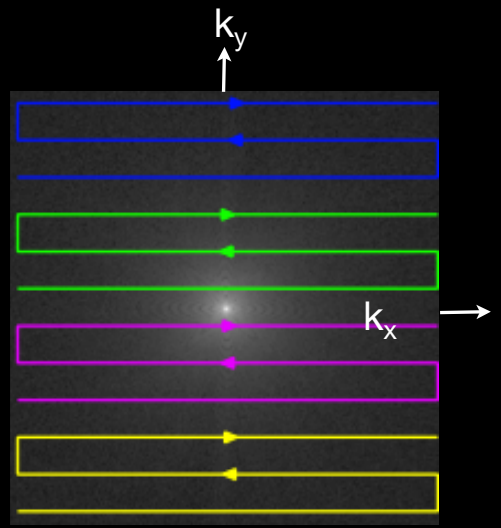


Images courtesy: Catherine Moran

EPI – Interleaved vs. Segmented



Interleaved-EPI



Segmented-EPI

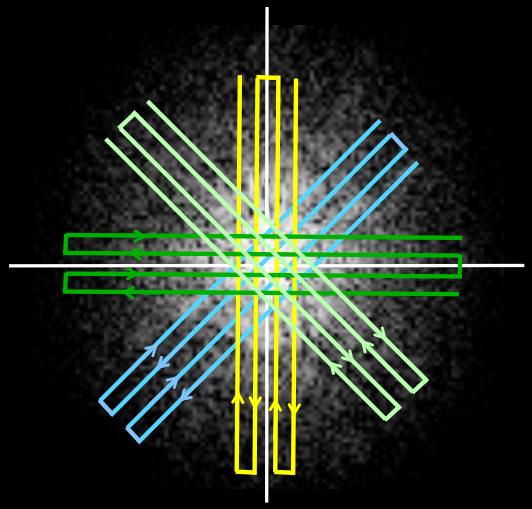
Interleaved EPI (relative to full-Fourier):

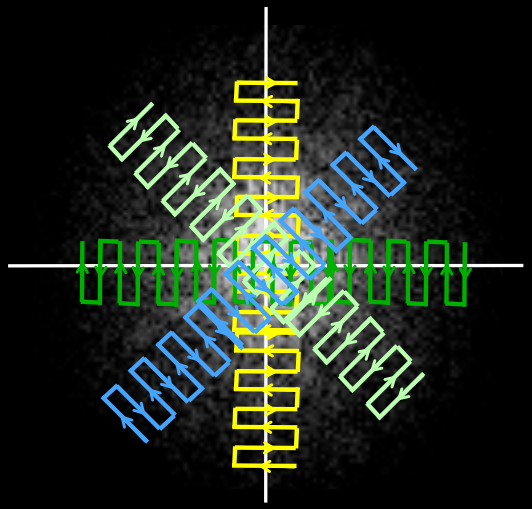
- Reduced ETL
- Slightly longer echo spacing
- Reduced TE
- Reduced T_2^* effects
- Reduced distortion

Segmented EPI (relative to full-Fourier):

- Reduced ETL
- Same echo spacing
- Shorter TE
- Reduced T_2^* effects
- Reduced distortion

Propeller EPI





EPI Propeller (Phase-encode)

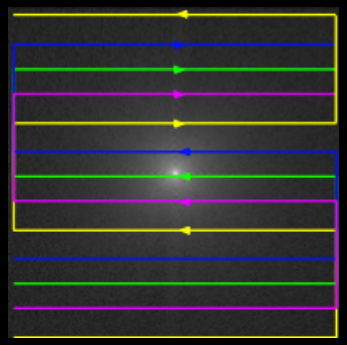
- Long axis (low k_y-res)
  - Note: Same T_{esp} as EPI!
- Reduced geometric distortion
- Short TE, short ETL
- Motion robust
- Self-navigating (low-res image every blade)
- Each blade corrected for phase and delays

EPI Propeller (Readout)

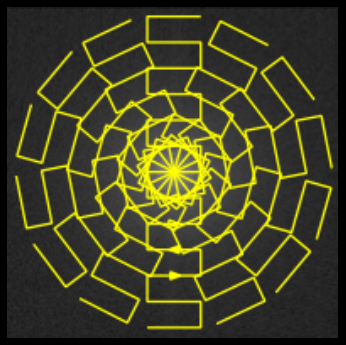
- Short axis (low k_x-res)
  - Shorter T_{esp}
- Reduced geometric distortion
- TE and ETL ~constant
- Motion robust
- Self-navigating
- Each blade corrected…

Wang FN et al. Magn Reson Med. 2005 Nov;54(5):1232-40; Skare S *et al*. Magn Reson Med. 2006 Jun;55(6):1298-307.

Interleaved EPI and other “EPI” approaches

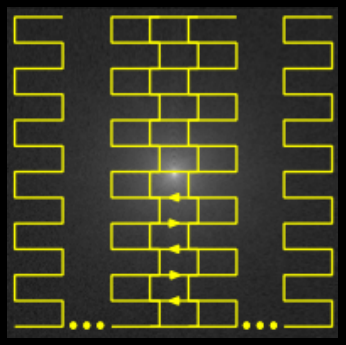


Interleaved-EPI



SAP-EPI

“short-axis propeller EPI”



RS-EPI

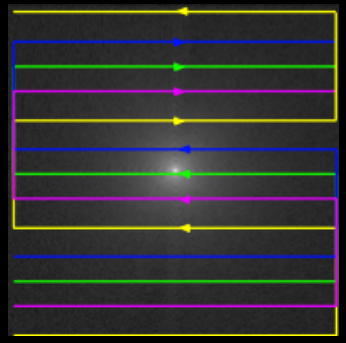
“readout-segmented EPI”

Distortion reduction from:	Reduced effective FOV_{pe}	Reduced t_{esp}	Reduced t_{esp}

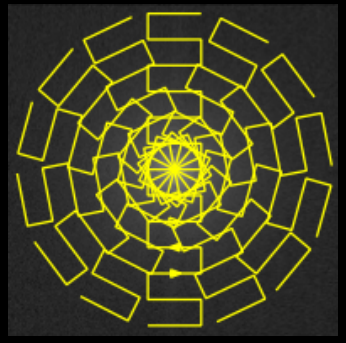
$$d_{pe}(\vec{r}) = \frac{\gamma}{2\pi}\Delta B_0(\vec{r})t_{esp}FOV_{pe}$$ EPI displacement due to off-resonance.

Interleaved EPI and other "EPI" approaches

Interleaved-EPI

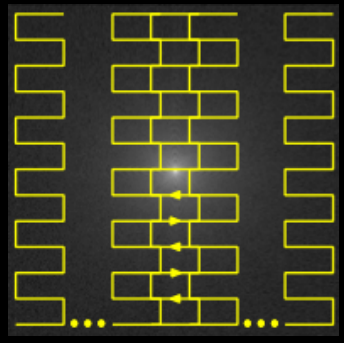


SAP-EPI



"short-axis propeller EPI"

RS-EPI



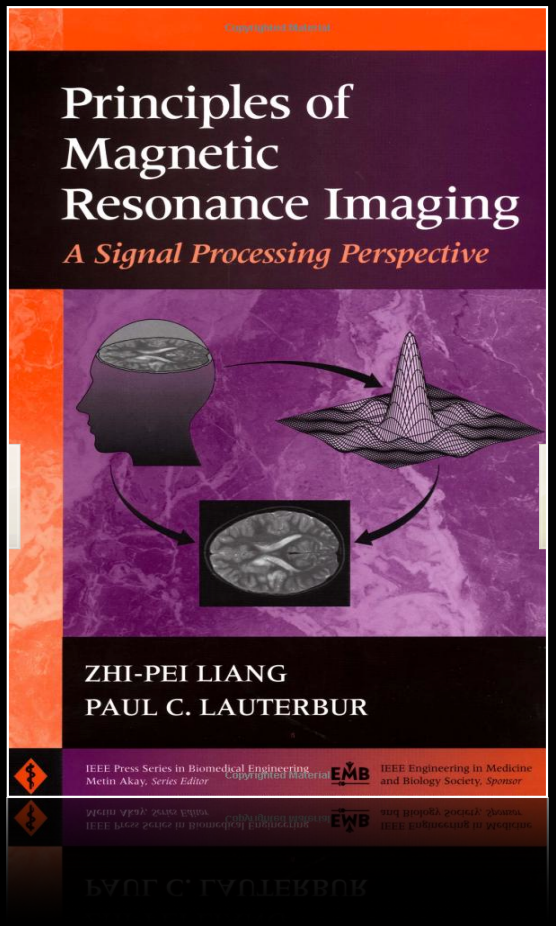
"readout-segmented EPI"

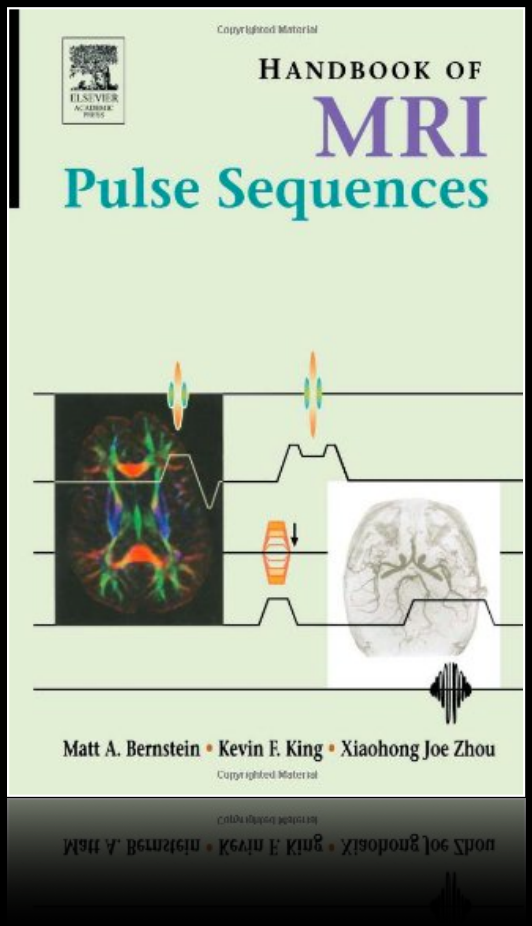
	Advantages	Disadvantages
Interleaved EPI	*Easier to implement/ reconstruct, not slewing all the time (more efficient)*	*Motion between interleaves causes ghosting – harder to correct.*
SAP-EPI and RS-EPI	*Each 'segment' acquired at full FOV → can correct for motion between segments.*	*Slewing a lot. Residual distortion for each "SAP-EPI segment" combines to give overall image blurring.*

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…





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