In vivo 7 T diffusion MRI: High spatio-angular-temporal resolution pursuit

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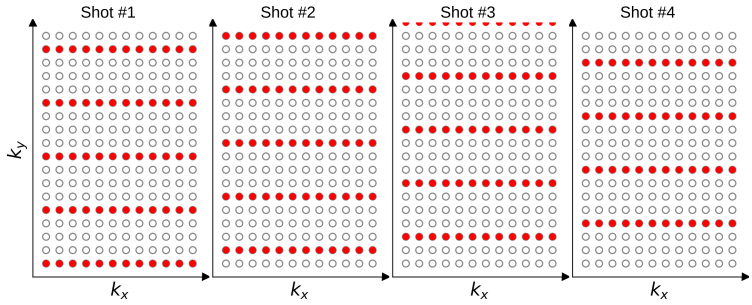
Motivation: In vivo Diffusion MRI at 7 T

MUSE [1] faces challenges in ultra-high field

✓ MUSE: self-gated multi-shot interleaved EPI (iEPI) DWI reconstruction



⋆ requires fully-sampled in-plane acquisition

[1] Chen NK, et al. A robust multi-shot scan strategy for high-resolution diffusion weighted MRI enabled by multiplexed sensitivity-encoding (MUSE). *NeuroImage* (2013). doi: 10.1016/j.neuroimage.2013.01.038

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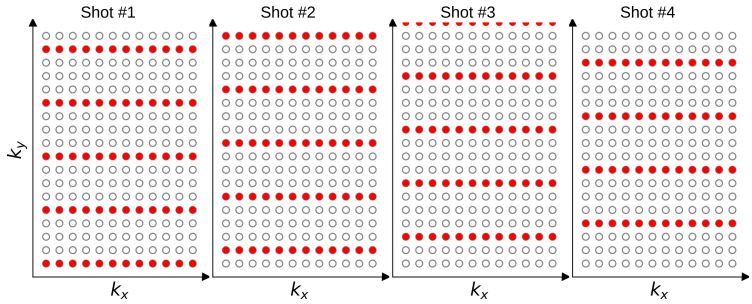

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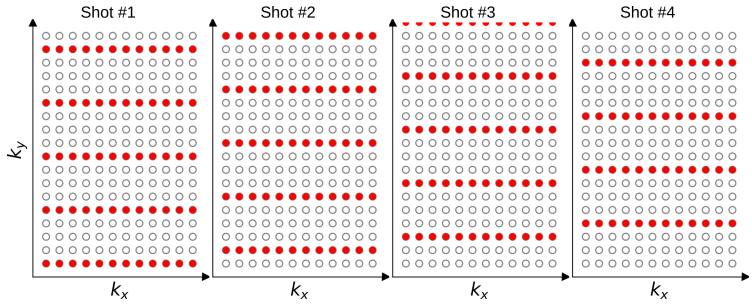

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⋆ increases specific absorption rate (SAR) at ultra-high field

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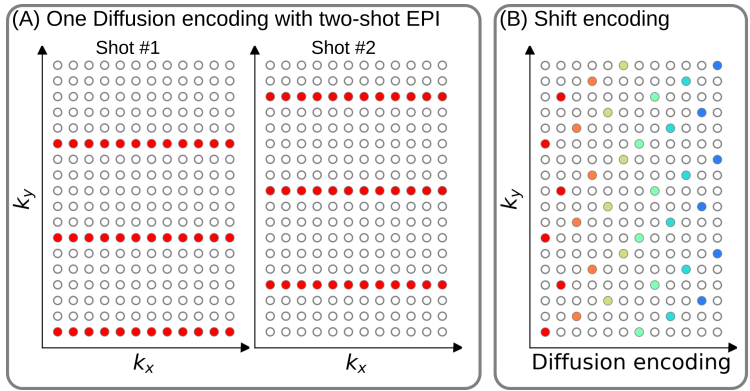
Undersampled iEPI Acquisition and Joint k-q-Space Reconstruction

This work presents preliminary results on

1. undersampled iEPI acquisition to reduce scan time and to reduce SAR
2. joint k-q-space reconstruction to boost SNR

Methods

Undersampled iEPI with Shift Encoding



(A) Given the acceleration along k_y as $R \rightarrow (R \times N_{\mathrm{shot}})$-fold undersampling per shot

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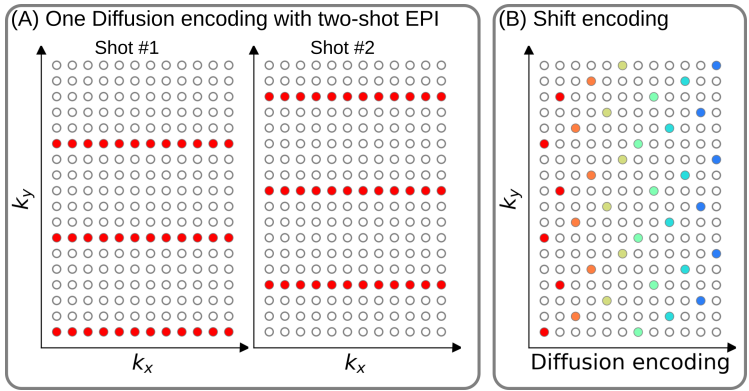
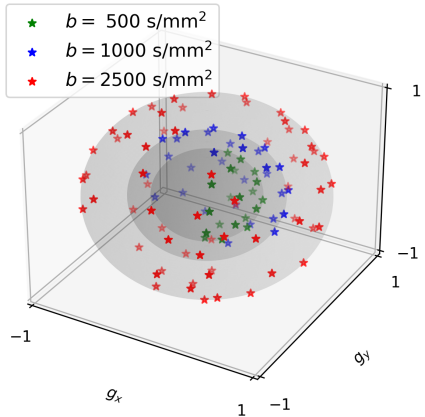


(A) Given the acceleration along k_y as $R \rightarrow (R \times N_{\mathrm{shot}})$-fold undersampling per shot

(B) k_y shift encoding along diffusion encoding $\rightarrow$ complementary k-q-space sampling

In Vivo Acquisition

- three-shell diffusion sampling
- 1.4 mm isotropic resolution and 68 slices
- k_y undersampling $R = 3$, partial Fourier 6/8
- 1- and 2-shot scans



Joint k-q-Space Reconstruction

Shot phase variation informed joint reconstruction:

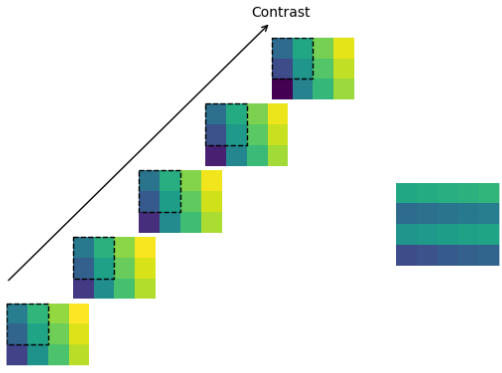
$$\operatorname{argmin}_{\mathbf{x}_q} \left\| \mathbf{y}_{c,q,s} - \mathbf{P}_{q,s}\mathbf{F}\mathbf{S}_c\{e^{i\mathbf{\Phi}_{q,s}}\mathbf{x}_q\} \right\|_2^2 + \lambda \mathbf{R}(\mathbf{x}_q) \tag{1}$$

$$\begin{aligned} \mathbf{x} &: \text{diffusion weight images,} \\ \mathbf{\Phi} &: \text{shot-to-shot phase variation,} \\ \mathbf{S} &: \text{coil sensitivity maps,} \\ \mathbf{F} &: \text{2D Fourier transform,} \\ \mathbf{P} &: \text{sampling mask,} \\ \mathbf{y} &: \text{measured raw data.} \end{aligned} \tag{2}$$

Indices: q - diffusion encoding; s - shot; c - coil

Overlapping Locally Low Rank (LLR) Regularization

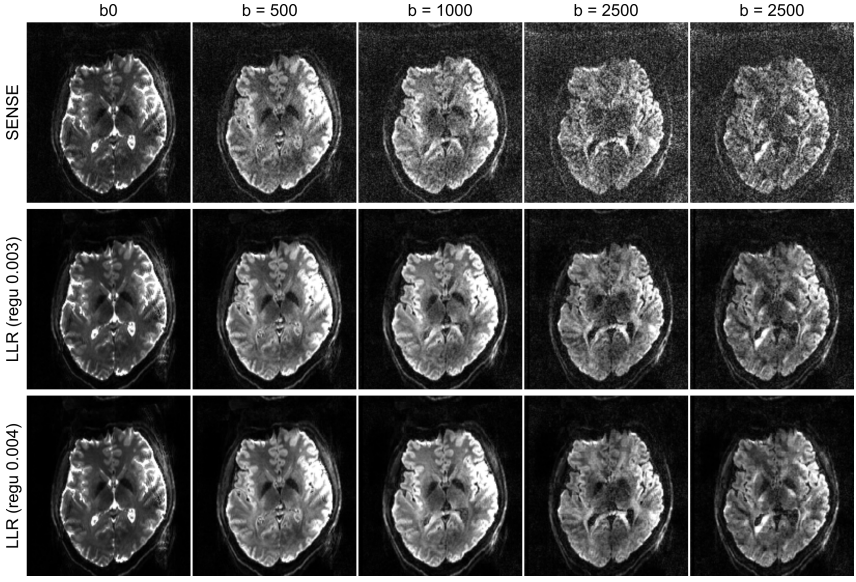
1. Stride set as 1, leading to overlapping local patches
2. Use local patches to create spatial-contrast (diffusion) matrices
3. singular value thresholding (SVT) [a] on these matrices
4. Backpass (adjoint) the SVT matrices back to full image matrices



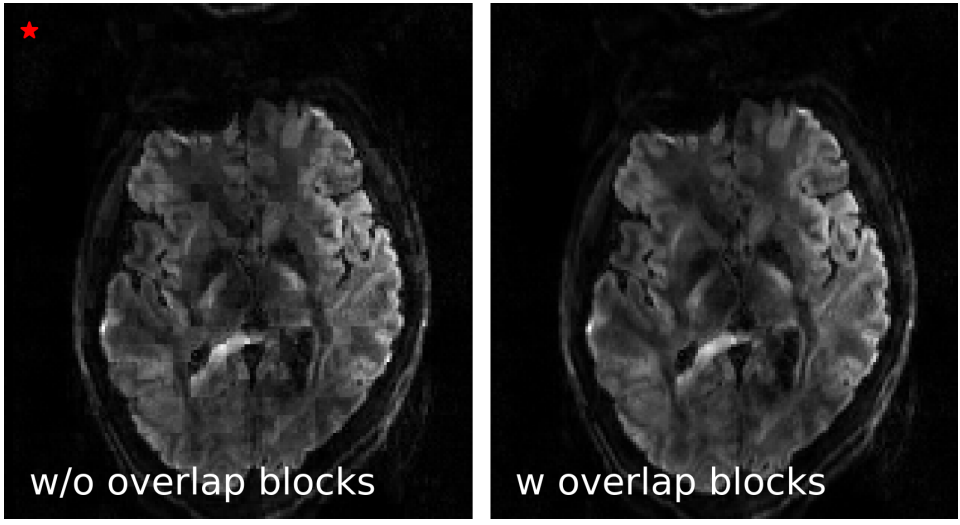
[a] Cai JF, Candes EJ, Shen Z. A singular value thresholding algorithm for matrix completion. *SIAM J Optim* (2010). doi: 10.1137/080738970

Results

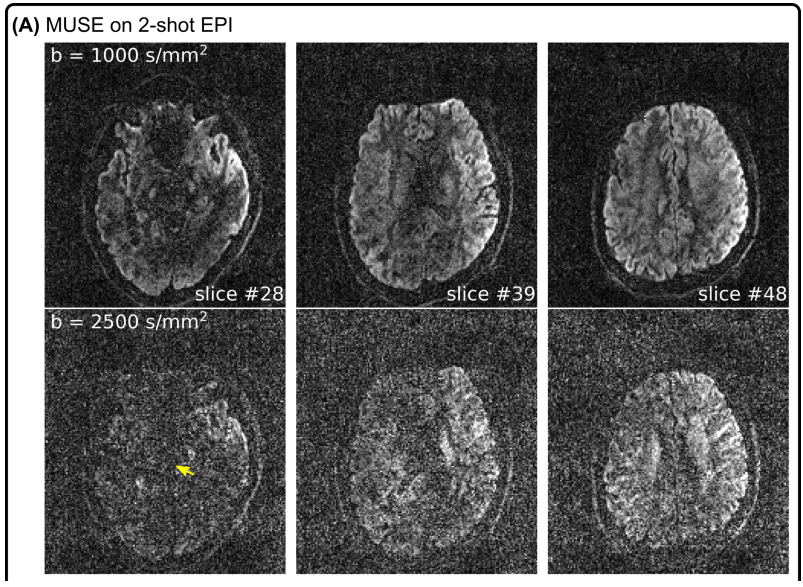
1-Shot EPI: LLR Regularization Strength



1-Shot EPI: Overlapping LLR



2-Shot EPI: Parallel Imaging Reconstruction



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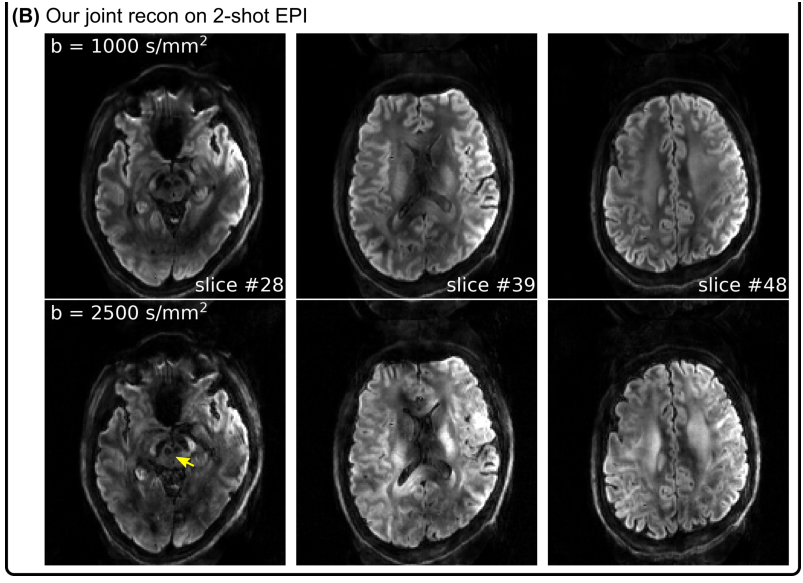

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