Reduced-FOV Single-Shot Diffusion-Weighted EPI: Extended Slice Coverage with Tailored RF Pulse Design

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Introduction: The use of a 2D echo-planar RF (2D-EPRF) excitation (1) has recently been proposed for high-resolution diffusion-weighted imaging (DWI) of targeted regions (1-6). This method excites only the region of interest, while providing inherent fat suppression and contiguous multi-slice imaging. However, the number of slices that can be acquired in a single TR is limited due to the periodicity of the excitation profile. In this work, we propose significant improvements in RF pulse design to overcome this limitation, and specifically demonstrate that the coverage can be doubled without any SNR or scan time penalty. We validate the proposed method with *in vivo* high-resolution axial DWI of the spinal cord.

Methods: The reduced-FOV method in Ref. 1 uses a hybrid between a blipped and a flyback 2D-EPRF excitation (Fig. 1a). The RF power is deposited while traversing both directions on the same excitation *k*-space line. A 180^{O} RF pulse is used after this 90^{O} 2D-EPRF pulse to refocus only the main lobe of the periodic 2D excitation. Although this design is robust to timing errors between RF and gradient waveforms, only a limited number of slices can be imaged in a single acquisition:

$$\max(N_{slices}) = \Delta d_{replica}/\Delta d_{SS} = N_{blip}/\ TBW_{SS},$$

where $\Delta d_{replica}$ is the separation between two adjacent sidelobes (see Fig. 1), Δd_{SS} is the slice thickness, N_{blip} is the number of blips in slice-select (SS) gradient and TBW_{SS} is the time-bandwidth product in that direction.

We can double the slice coverage using a blipped 2D-EPRF design, which can achieve twice N_{blip} for a fixed RF pulse duration by traversing each line in *k*-space only once (Fig. 1b). However, the misalignment of even/odd lines due to timing errors will then lead to “ghost” excitations between sidelobes, which can decrease SNR if the slices at the ghost locations do not fully recover until they are imaged.

In this work, we tailor the blipped 2D-EPRF pulse to minimize the adverse effects of the ghost excitation: For a desired reduced-FOV profile, we first calculate the shortest 2D-EPRF pulse using a variable-rate selective excitation (VERSE) algorithm (7). We then slowly increase the pulse duration by lengthening the plateau of the trapezoidal gradients. At each pulse duration, we simulate the level of ghost excitation and the resulting signal loss for a 4 µs timing error (a reasonable value in practice). As shown in Fig. 2, this analysis results in a clear trade-off between the pulse duration and signal loss. To avoid profile distortions, the shortest RF pulse duration that limits the maximum signal loss to below 5% is chosen.

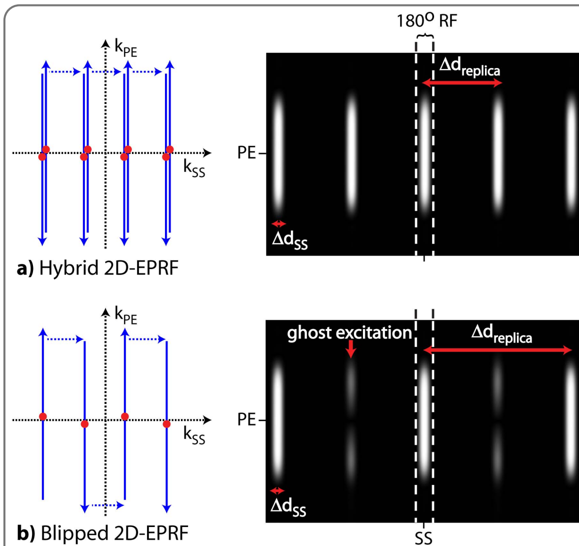

Figure 1. *Schematic trajectories and simulated excitation profiles for a 4 µs RF/gradient timing error of* ***(a)*** *hybrid and* ***(b)*** *blipped 2D-EPRF designs. For a fixed pulse duration, blipped design offers twice the number of slices but suffers from ghost excitations that can decrease SNR.*

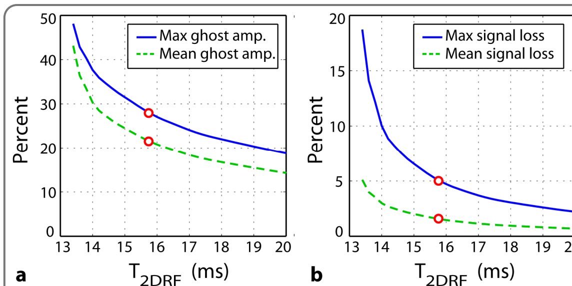

Figure 2. ***(a)*** *Maximum and mean ghost amplitudes (relative to the main lobe) and* ***(b)*** *the resulting maximum and mean signal loss within FWHM of the slab profile, as a function of RF pulse duration. The red circles denote the operating point used during in vivo imaging (Fig. 3b). Simulated for 4 µs timing error, FOV_{PE} = 4 cm, TBW_{PE} = 6, TBW_{SS} = 3, TR = 3.6 s, T_1 = 850 ms (white matter at 3T).*

Results: *In vivo* axial DWI of the cervical spinal cord was performed in healthy subjects on a 3T GE Signa HDx scanner with an 8-channel CTL coil. The maximum numbers of contiguous slices were acquired using **(a)** an 8-slice hybrid 2D-EPRF pulse, and **(b)** a 16-slice blipped 2D-EPRF pulse, both with 15.7 ms RF pulse duration. Other parameters were 0.8×0.8 mm^2 in-plane resolution, 5 mm slice thickness, 8×4 cm^2 FOV, b = 500 s/mm^2, BW = ±125 kHz, TE = 57 ms, TR = 3.6 s, 62.5% partial *k*-space ss-EPI, 3:50 total scan time for each scan.

Figure 3 shows the results for the proposed extended-coverage blipped 2D-EPRF pulse in comparison with the hybrid 2D-EPRF pulse. Even though the acquired number of slices was doubled in **(b)** for the same scan time as in **(a)**, there is no visible difference between the SNR levels, thanks to the decreased level of ghost excitation.

Conclusion: We have shown that the slice coverage in reduced-FOV ss-EPI can be successfully increased with the use of a blipped 2D-EPRF pulse. The ghost excitations due to timing errors are minimized with careful tailoring of the RF pulse, doubling the number of slices for a given scan time. The results were validated with *in vivo* high-resolution axial DWI of the spinal cord.

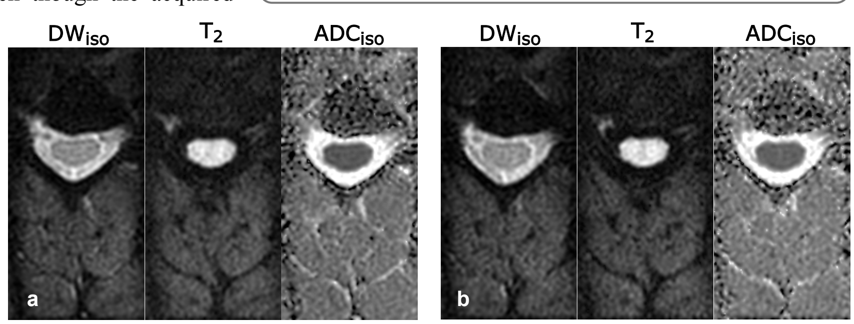

Figure 3. *Axial DWI of the cervical spinal cord acquired with* ***(a)*** *an 8-slice hybrid 2D-EPRF pulse, and* ***(b)*** *a 16-slice blipped 2D-EPRF pulse (same slice location shown). Even though the acquired number of slices was doubled in (b), there is no visible difference between the SNR levels, thanks to the decreased level of ghost excitation.*

References: 1. Saritas et al., MRM 60:468-473, 2008. **2.** Wheeler-Kingshott et al., Neuroimage 16:93-102, 2002. **3.** Jeong et al., MRM 54:1575-1579, 2005. **4.** Wilm et al., MRM 57:625-630, 2007. **5.** Finsterbusch et al., JRMI 29:987-993, 2009. **6.** Dowell et al., JMRI 29:454-460, 2009. **7.** Hargreaves et al., MRM 52:590-597, 2004.