High-Resolution DWI outside the CNS using Reduced-FOV Single-Shot EPI

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Introduction: Diffusion weighted imaging (DWI) has recently been recognized as a potential clinical tool for the diagnosis and treatment monitoring of cancer outside the central nervous system [1-3]. Even though single-shot EPI (ss-EPI) is the preferred method for these applications, its resolution is limited. Recently, a reduced field-of-view (FOV) method has been presented for high resolution DWI of the spinal cord, using a 2D echo-planar RF (2D-EPRF) excitation pulse [4]. In this work, we propose improvements on the 2D-EPRF pulse design to meet different imaging requirements in various parts of the body. Specifically, we perform prostate, breast, and larynx DWI with the improved method to demonstrate its high-resolution capability, with increased coverage in the slice direction.

Methods: The reduced-FOV method in [4] uses a 2D-EPRF excitation to reduce the FOV in the PE direction, while suppressing the signal from fat simultaneously. This method is compatible with contiguous multi-slice imaging without the need for slice skip, which enables single-acquisition imaging of small body parts such as the prostate. However, there is a limit on the number of slices that can be imaged in a single acquisition, determined by the slice thickness (Δd_{SS}) and the separation between two adjacent sidelobes of the 2D excitation profile ($\Delta d_{replica}$) (Fig.1.a):

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

Here, N_{blip} is the number of blips and TBW_{SS} is the time-bandwidth product in the slice-select (SS) direction. Note that larger N_{blip} values (i.e., longer RF pulses) are needed for more slices. In this work, to minimize the RF pulse duration, the phase-encoding (PE) gradients are designed to operate at the slew rate S_{max} (see Fig. 1.b). The optimal duration of each gradient lobe (T_{fast}) for a given FOV is:

$$T_{fast} = 2 \cdot \sqrt{\frac{2\pi \cdot TBW_{PE}}{\gamma \cdot FOV_{PE} \cdot S_{\max}}}\ .$$

The 2D-EPRF pulse durations were kept around 20 ms, to maximize the number of slices while avoiding long echo times (TE). A minimum-phase SLR design was employed to decrease the isodelay of the RF pulse, with TBW_{SS} =3.5. Finally, a TBW_{PE} of 12 was used to generate a sharp reduced-FOV profile.

In vivo scans of healthy subjects were acquired on a 1.5T GE Excite scanner (40 mT/m gradients with 150 mT/m/ms slew rates). Imaging parameters are listed in the captions of Figures 2-4. A partial k-space coverage of 62.5% was used for all scans, with TR = 3.6 s and ±62.5 kHz bandwidth. Refocusing reconstruction [5] was performed, with the central 12.5% of k-space treated as the "navigator" for each single-shot data, followed by a partial k-space homodyne reconstruction [6].

Results: Figures 2-4 display *in vivo* DWI images of prostate, breast, and larynx acquired with the reduced-FOV ss-EPI method. In each figure, T_2-weighted, isotropic DWI (DWI_{iso}) images and corresponding ADC maps (ADC_{iso}) are shown.

Conclusion: High-resolution DWI outside the central nervous system is demonstrated using the reduced-FOV method. The 2D-EPRF pulse needs to be carefully optimized to achieve the different number of slices and FOVs for each application, while considering the required readout durations. If more slices are needed, multiple acquisitions can be utilized at the expense of longer scan times. Prostate, breast and larynx are challenging to image, considering the surrounding air and the sources of motion around them (e.g., breathing and swallowing). Therefore, the robustness of the reduced-FOV ss-EPI method against motion-induced phase perturbations combined with its high-resolution capability makes it an ideal candidate for high-quality DWI of these body parts.

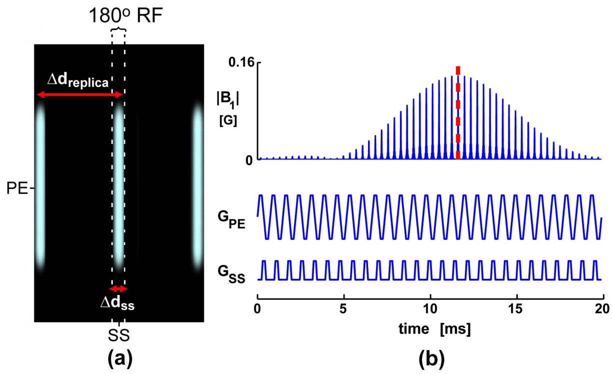

***Figure 1. (a)** Typical excitation profile for a 2D echo-planar RF pulse, showing the periodic sidelobes in the slice-select (SS) direction. **(b)** The 7-slice minimum-phase 2D-EPRF pulse used for prostate DWI. The red dashed line marks the isocenter.*

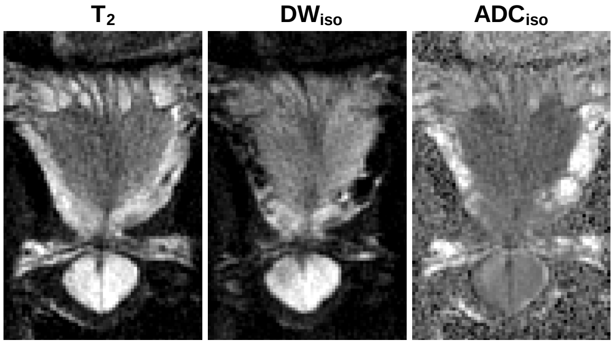

***Figure 2.** DWI of prostate: 7 coronal slices (only 1 shown here), 1.09x1.09 mm² in-plane resolution, 5 mm slice thickness, 0.5 mm slice spacing, 14x7 cm² FOV, readout in S/I direction, TE = 62 ms, b = 500 s/mm², 6 min total scan time, using an 8-channel cardiac coil.*

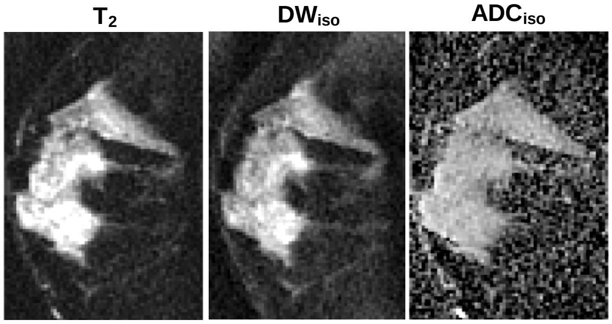

***Figure 3.** DWI of breast: 8 sagittal slices (only 1 shown here), 1.01x1.01 mm² in-plane resolution, 4 mm slice thickness, 0.4 mm slice spacing, 13x6.5 cm² FOV, readout in S/I direction, TE = 64 ms, b = 500 s/mm², 6 min total scan time, with an 8-channel breast coil.*

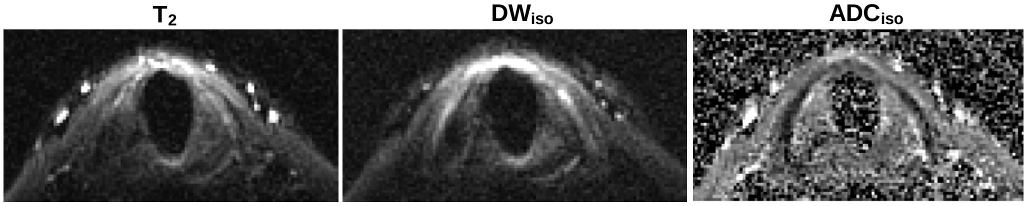

***Figure 4.** DWI of larynx: 6 axial slices (only 1 shown), 0.78x0.78 mm² in-plane resolution, 3 mm slice thickness, 0.4 mm slice spacing, 10x5 cm² FOV, readout in R/L direction, TE = 69 ms, b = 750 s/mm², 3:40s total scan time, using a custom built 3-channel anterior neck coil.*

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