In vivo High Resolution Renal Diffusion MRI: Diffusion-prepared Balanced Steady State Free Precession (Diffu-prep bSSFP)

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Introduction: Abdominal diffusion MRI has the potential to characterize benign or malignant tumors in various organs including the kidneys, liver, pancreas, and prostate [1]. Magnetic susceptibility, low SNR, and low spatial resolution have been the primary challenges for the conventional diffusion-weighted single shot echo planar imaging (DW SS EPI). To combat these limitations, multi-shot approaches have been explored to reduce the echo train length to allow for higher spatial resolution and less susceptibility artifacts [2,3,4]. We propose a novel application of diffusion-prepared balanced steady-state free precession (Diffu-prep bSSFP) [5] to yield high resolution, high SNR, and low distortion DW images of the kidneys.

Materials and Methods: *In vivo* volunteer experiments (n = 9) were performed at 3T (MAGNETOM Verio, Siemens) with Diffu-prep bSSFP (TR/TE=233.2/1.3 ms, FOV=384x384 mm^2, 256x256 matrix, 1.5x1.5x3 mm^3, TE_{prep} = 60 ms, b=0, 400 s^1mm^{-2}, timing diagram shown in Fig. 1), conventional DW SS EPI (TR/TE=1500/60 ms, FOV=384x384 mm^2, 128x128 matrix, 3x3x7mm^3, iPAT factor = 2, b=0, 400 s^1mm^{-2}), and product T1w FLASH anatomical sequence. The DW imaging was done within 1-2 breath holds to ensure full coverage. Diffusion encoding was prescribed along readout direction for all experiments with a coronal image orientation. ADC maps were calculated offline assuming a monoexponential fit in Matlab. Manual segmentation of the entire kidney was used to calculate the mean and standard deviation of the ADC values for each volunteer.

Results: The mean and standard deviation of the mean ADC values derived for the 9 volunteers was 2.36 ± 0.251 x 10^3 mm^2s^{-1} (Diffu-prep bSSFP) and 2.42 ± 0.256 x 10^3 mm^2s^{-1} (DW SS EPI) without any significant difference (p = 0.447). Fig. 2 shows a T1w image, typical b=0 s^1mm^{-2}, b = 400 s^1mm^{-2}, and accompanying ADC map for Diffu-prep bSSFP (Fig.2 a,d,e,f). For DW SS EPI, Fig.2 depicts in the same slice at b = 400 s^1mm^{-2} and ADC map (Fig. 2 b,c). The red arrows highlight a small benign hemorrhagic renal lesion (confirmed by the T1w and T2w b=0 s^1mm^{-2} images). Because of the higher resolution, Diffu-prep bSSFP clearly reveals the lesion with an expected reduced ADC value (1.18 x 10^3 mm^2s^{-1}). While DW SS EPI illustrates classic partial volume effect, where the lesion can be barely identified with a lesser reduction in ADC value (1.44 x 10^3 mm^2s^{-1}).

Conclusion: We have shown the feasibility of using diffusion-prepared acquisitions to derive high resolution, high SNR, and low distortion DW images of the human kidneys by employing Diffu-prep bSSFP. ADC values acquired from the 9 volunteers are consistent with prior *in vivo* human renal diffusion studies and DW SS EPI derived values [6]. For abdominal applications, multi-shot bSSFP readout has the potential to offer better image quality, higher resolutions, and higher SNR over conventional EPI-based sequences while maintaining the quantitative power of diffusion MRI.

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Fig. 1 (bottom) Timing Diagram with twice refocused spin echo diffusion encoding

Fig. 2 (right) T1w, (a) DW SS EPI (b) b=400 s^1mm^{-2} (c) ADC map, Diffu-prep bSSFP (d) b=0 s^1mm^{-2} (e) b=400 s^1mm^{-2} (f) ADC map