Tilted 2D RF Excitation with Extended Slice Coverage for High-Resolution Reduced-FOV DWI

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Introduction: The benefits of reduced FOV imaging have been shown for diffusion-weighted imaging (DWI) of many anatomies, such as the brain and spine [1-3]. Reducing the phase field of view (FOV) helps shorten the echo-train, increase in-plane resolution and reduce off-resonance artifacts in the single-shot EPI (ssEPI) sequence, dramatically improving image quality. One method for reduced-field-of-view (rFOV) imaging is to use a 2D spatially-selective RF excitation that zooms into a region of interest, obviating the need of encoding a large field-of-view in the phase-encoding direction, while avoiding aliasing artifacts [4]. A 2D echo-planar trajectory is generally used for the 2D RF pulse; because slab and slice design parameters can be chosen independently. However, one implementation challenge with such a rFOV approach is that additional excitation lobes (called sidelobes) appear along the blipped/slow gradient axis. These sidelobes either need to be positioned outside the object/region of coil sensitivity [5], or may limit the slice coverage [3]. For a 2D RF pulse with the blipped direction along the slab direction, Finsterbusch et al. proposed a novel solution to this problem: tilting the 2D RF excitation plane to position the sidelobes at an angle, such that they do not interfere with the imaging section [6]. However, there are several advantages to designing the slice encoding along the blipped direction. In such a design the 2DRF excitation pulse and the 180° pulse pair selectively choose the on-resonance water profile, providing an inherent fat suppression. In this work, we describe a tilted 2D RF pulse similar to [6] but with the blipped direction along the slice direction, which not only completely removes the limit on slice coverage, but also provides a robust fat suppression.

Methods: The 2D echo planar RF pulse was designed on a rotated excitation k-space, where the rotation angle α=asin(slab_thickness/ slice_stack_thickness). Figure 1a shows the simulated 2D water and fat excitation profile without tilting. The maximum allowable slice coverage with the original RF pulse was 16 slices. Figure 1b shows the excitation profile for the proposed 2D RF pulse with sidelobes tilted away from the imaging FOV. MR experiments were conducted on an MR750w scanner (GE Healthcare, Waukesha) using a 24 channel head and neck coil array in an oil-water phantom and in a normal subject. High-resolution DWI of the cervical spinal cord of a healthy subject was acquired in the axial plane with spatial resolution of 0.83x0.83x5 mm^3, FOV=8x4 cm^2, 32 slices, b = 500 s mm^{-2}, TR=4800 ms, 12 averages in a scan time of 4 minutes 40 secs. For comparison a diffusion-weighted scan was also acquired in the subject with the original (untilted) RF pulse with identical scan parameters.

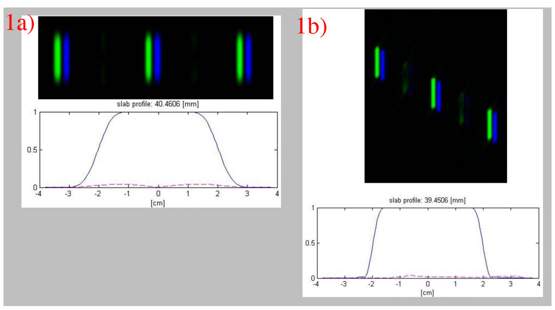

Figure 1: Simulated 2D excitation profile and the corresponding 1D slab profiles for the original RF pulse and the tilted RF pulse are shown in Figures 1a and 1b respectively. The sidelobes are tilted outside the imaging section, successfully removing the limitation on slices coverage. The slab profile sharpness and fat-water separation are still maintained for the tilted RF pulse.

--- Water --- Fat

Results: A screen shot of the scan prescription and b=0 image from the phantom scan are shown in Figure 2. Signal from the oil phantom has been completely suppressed by the tilted 2D RF and refocusing pulse pair. Figure 3 shows Apparent Diffusion Coefficient (ADC) maps for 4 slice locations (out of 32) in the normal subject obtained with the tilted RF excitation. Images from matched slice locations between the tilted and untilted RF had similar in-plane image equality, but the tilted RF was able to cover a much wider region in the slice direction.

Conclusion: This work demonstrated a tilted 2D RF excitation pulse, which removed the restriction on slice coverage from sidelobe considerations, while maintaining robust fat suppression in ssEPI DWI. This method will enhance the applicability of rFOV DWI in applications where large slice coverage is desired, such as axial imaging of the spine.

Reference: 1.WheelerKingshott C et al, Neuroimage 2002;16:93-102. 2. Wilm B et al, MRM 2007;57:625-30 3.Saritas E et al, MRM 2008; 60:468-73 4. Alley M et al, MRM 1997;37:260-67 5. Finterbusch J et al, JMRI 2009; 29: 987-93 6. Finterbusch J et al, ISMRM 2011 #174

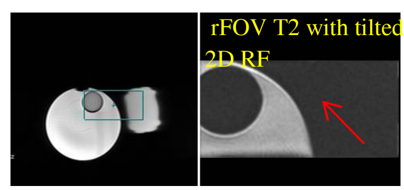

Figure 2: The tilted 2D RF pulse provides sharp profiles in the reduced-FOV direction (up/down), while completely suppressing the signal from the oil phantom (red arrow).

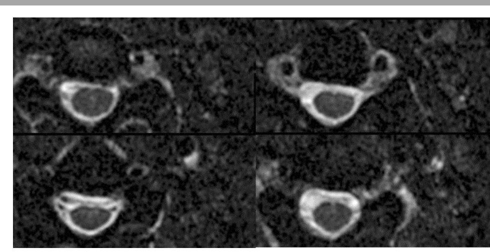

Figure 3: High-resolution (0.83 x 0.83 mm^2 in-plane) ADC maps of the cervical spine of a normal subject, acquired with the tilted 2D RF excitation. 4 out of 32 slices are shown.