Reduced field-of-view diffusion with 2D echo-planar RF excitation and Multiband refocusing for extended slice coverage and robust fat suppression

Suchandrima Banerjee[1], Emine Ulku Saritas[2,3], Rachel Connett[1], and Ajit Shankaranarayanan[1]

[1]Global Applied Science Laboratory, GE Healthcare, Menlo Park, California, United States, [2]Department of Electrical and Electronics Engineering, Bilkent University, Bilknet, Ankara, Turkey, [3]National Magnetic Resonance Research Center, Bilknet University, Bilknet, Ankara, Turkey

Target Audience: MR Physicists, Pulse programmers, Researchers and clinicians interested in Diffusion MRI

Introduction: Diffusion weighted imaging (DWI) is being increasingly adopted in routine clinical MR scans to assess the development or degeneration of tissue microstructure. Reduced field of view (rFOV) approaches have emerged as a way to achieve single shot echo-planar imaging (ssEPI) DWI with acceptable image distortion in susceptibility-prone anatomies and as an enabler for high resolution DWI [1-5]. 2D spatially selective echo-planar (EP) RF excitation pulses achieve rFOV by exciting a limited extent in the phase field-of-view direction, which obviates the need for spatially encoding the entire object extent out of aliasing concerns. In one implementation of this approach the blipped axis of the EP excitation trajectory was chosen along the slice direction. This provided the benefit of sharp phase field-of-view (FOV) profile and as a bonus, robust suppression of fat and sidelobe signal by the refocusing pulse following the 2D EPRF excitation in ssEPI. This technique has shown promising results in DWI of the spine, breast, prostate and other anatomies [3, 5-7] but one challenge has been the limited slice coverage per acquisition. Concerns about partial saturation in slice locations that might overlap with the periodic sidelobe locations limit slice coverage to the maximum number of slices that can be accommodated within the sidelobe separation distance. In applications such as axial DWI of the spine, this can result in insufficient S/I coverage. Recently, tilting of the excitation kspace was proposed to rotate the sidelobes away from the imaging section [8-9]. In this work, rather than considering the sidelobes an impediment, we aim to exploit their periodicity by a "multiband refocusing" scheme which simultaneously refocuses multiple sidelobes using a multiband refocusing pulse. Unlike an earlier work that used Hadamard slice encoding involving multiple acquisitions [10], we propose to separate the signal from the simultaneously refocused sidelobe locations by parallel imaging technique, utilizing coil sensitivity differences between these locations [11-12]. We hypothesize that our proposed method can increase slice coverage while still achieving reduced FOV in the PE direction and still preserving the fat suppression property of the 2D EPRF and the refocusing pulse pair.

Method: The multiband refocusing pulse was designed by cosine modulating a sinc pulse such that the spatial separation between the simultaneously refocused locations exactly matched the periodic sidelobe separation in the 2D EPRF excitation pulse. **Figure 1a** shows the simulated refocused water profile for a 3 band 180° pulse overlaid on the simulated 1D water and fat excitation profiles of the 2DEPRF. **Figure 1b** shows the multiband refocusing scheme on the simulated 2D excitation profile. The simulation plots suggest that slice coverage can be increased by the multiband refocusing scheme while maintaining fat suppression. The conventional 180° refocusing pulse in FOCUS, an ssEPI DWI sequence using a 16 slice 2D EPRF excitation, was replaced by the multiband refocusing pulse. Variable rate selective excitation (VERSE) algorithm was used to shorten the duration of the multiband 180° pulse [13]. MR scans were acquired on a GE Discovery MR750 scanner (GE Healthcare, Waukesha) using a six element spine coil array in an oil-water phantom and in the spine of a normal subject after informed consent. Scan parameters were: TR/TE=4000/57 ms, FOV=14x7 cm^2, resolution =1.09x 1.09x4 mm^3, averages=12 (T2)/ 16 (DW) ,16 prescribed slices, b = 500 s mm-2, scan time of 3 minutes and 40 secs. Images were reconstructed offline using low resolution calibration data that was acquired at all of simultaneously acquired slice locations, and ARC method of parallel imaging [14]. For a 16 slice prescription, 48 slice locations were reconstructed. For comparison, rFOV DWI scan was also acquired with the FOCUS sequence with the conventional refocusing pulse, using 3 acquisitions and 3x the above mentioned scan time for 48 slice coverage.

Results: A screen shot of the scan prescription and b=0 image from the phantom scan is shown in **Figure 2**. Signal from the oil phantom has been completely suppressed in the reconstructed slice in the rFOV+MB scan (2c), similar to the 3 acquisition rFOV scan (2b). This experimentally validate that fat suppression is preserved by the multiband refocusing scheme. **Figure 3** shows images from the *in vivo* rFOV+MB scan. Simultaneously acquired slice locations could be separated using parallel imaging for both the phantom and invivo scan. However there was considerable SNR degradation in the reconstructed slices, since the coil array used in our experiment had only 3 element separation in the slice direction.

Discussion: This work combined two rising trends in the field of DWI-rFOV and multiband-to address the slice coverage constraint associated with 2D EPRF excitation. Unlike existing multiband EPI methods, our work used the multiband pulse for refocusing only. Initial results indicate that the sharpness of the phase FOV profile and fat suppression are maintained by the rFOV +MB scheme. Factor of increase in slice coverage is equal to the number of bands in the refocusing pulse. Like in any parallel imaging method, reconstruction performance will improve with increased acceleration capabilities of the receiver array in the slice direction. Axial DWI of the spine and body could potentially be a good fit for the proposed method, since larger slice coverage is needed in these applications, and the receiver arrays used usually have S/I acceleration capability.

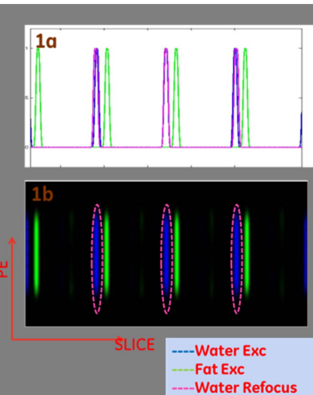

Figure 1: *1a shows an overlay of the simulated refocused water profile for a 3band 180° pulse on the simulated 1D water and fat excitation profiles of the 2D EPRF. 1b shows the multiband refocusing scheme in a simulated 2D excitation profile plot. The 3 band 180° pulse refocuses the main excitation lobe and 2 adjacent excitation sidelobes of the 2D EPRF and excludes fat signal.*

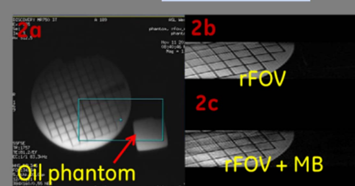

Figure 2: *2a shows the oil-water phantom set up Signal from the oil phantom is completely suppressed both in the 3 acquisition rFOV scan (2b) and in the resolved slice images from the rFOV+MB scan (2c).*

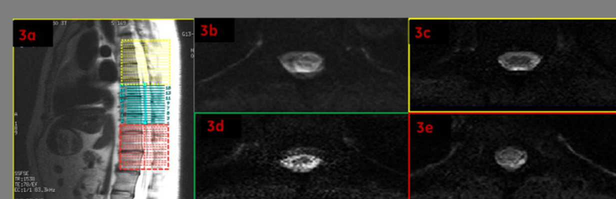

Figure 3*: Results from the invivo scan. 3a shows the graphical prescription in the spine: yellow, green and red indicate stacks from which corresponding slice location signals were simultaneously acquired. 3b is a representative acquired T2w image, showing superimposed signal from 3 slice locations. 3c, d and e show the corresponding resolved slices.*

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.**Finsterbusch J et al, JMRI 2009; 29: 987-93 **5.** Zaharchuk G et al, AJNR 2011;32:813-20 **6.**Singer L et al, Acad Radiol. 2012; 19:526-34 **7.** Korn N et al, ISMRM 2013 **8.** Finsterbusch J et al, ISMRM 2011 #174 **9.** Banerjee S et al, ISMRM 2013 #56 **10.** Saritas EU et al, ISMRM 2010 # 189 **11.** Larkman DJ et al, JMRI 2001;13:313-17 **12.** Blaimer M et al, JMRI 2006;24:444-450 **13.** Hargreaves B et al, 2004; 52:592-97 **14.** Beatty P.J, ISMRM 2007 #1749