B1 insensitive zoomed FOV imaging

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Purpose Diffusion weighted imaging (DWI) has been widely used for oncological applications. However it suffers geometry distortion, image blurring, and signal voids which are caused by the local B0 inhomogeneity [1]. It is a great challenge for small lesion detection for DWI which needs high resolution, such as prostate, spine, brain stem and nasal cavity. To improve the resolution of DWI, parallel imaging, such as SENSE [2], is conventionally used at the cost of SNR penalty and residual aliasing artifacts. Zoomed field of View (FOV) imaging based on two dimensional selective excitation pulse (2D RF pulse) has been proposed [3] to overcome the DWI problems without the g-factor penalty by reducing the FOV at the phase-encode (PE) direction. But the 2D RF pulse will have the side lobe excitation which was caused by the discrete excitation along the PE or slice direction. To avoid the side-lobe effects, Finsterbusch proposed a novel solution which tilts the excitation k-space [4]. This method takes the advantage of robustness against motion by single shot EPI, and has no slice coverage limitation. However there is still a limitation that it requires a higher RF bandwidth after tilting the excitation k-space, which in turn requires higher B1 than original sub-pulse. Therefore this scheme is sensitive to B1 nonlinearity which deteriorates the image uniformity. The goal of this work is to provide a new tilted algorithm for zoomed FOV DWI with improved image uniformity, and validate it on 1.5T system.

Methods 2D RF pulses based on echo planar trajectory provide independent control of slice thickness in two orthogonal directions by combining two RF pulses that can be designed separately. Using a rectilinear path in the excitation k-space, the "slow" (blipped) and the "fast" axes gradients and RF pulses are designed to achieve the desired excitation profiles in each spatial direction [5]. Previously existing method rotates the k-space at both slice and PE direction using rotation matrix [4], we briefly call the existing method as rFOV (reduced FOV). Because the FOV at PE direction is much bigger than the slice thickness, it needs to increase the sub-pulse bandwidth to ensure the excitation k-space coverage after tilting. The proposed method uses a different titled k-space trajectory, which is also blipped at slice direction, but just tilts the PE direction gradients, $G_{slice} = G_{slow} + G_{fast} \cdot \tan(\theta)$, $G_{phase} = G_{fast}$. It does not increase the k-space step at PE direction, so it has no influence on the sub-pulse bandwidth. It moderates the requirements for hardware components compared with rFOV. We called it iZoom (**I**mproved **Zoom** FOV imaging).

To evaluate the performance of iZoom, high resolution DWI images were acquired on a Philips 1.5T Multiva system (Philips Healthcare, Suzhou China) with a 16-ch head and spine coil. A single-shot spin echo EPI sequence using iZoom without parallel imaging was used for data acquisition, b =400 or 600 s/mm^2, FOV = 160 * 45 mm^2, in-plane spatial resolution = 1.5 mm^2, slice thickness 4mm, partial Fourier ratio = 0.75, FA = 90°, TR = 2.8s, and TE = 72ms, slice number = 22, 16 averages in a scan time of 2 minutes 59 seconds. Phantom study is used to evaluate the improvement of uniformity for the new method. Healthy volunteers were investigated, prostate and spine were studied with 1.5 * 1.5 mm^2 in plane resolution, and compared with conventional DWI with sense factor 2 which has 2.3 * 2.3 mm^2 in plane resolution and FOV equals 160 * 160mm^2.

Results Fig. 1 shows the comparison between rFOV [4] and iZoom. The image uniformity was dramatically improved with iZoom, see the red arrow at images. Fig. 2 shows the application of iZoom on prostate, and was compared with the conventional DWI. Fig. 3 shows the application of iZoom on spine and the comparison with TSE and conventional DWI. With the FOV reduction factor about 4 times along PE direction, iZoom shows less distortion than the conventional DWI without the penalty of SNR. iZoom also resulted in high uniformity for large coverage at spine with higher than conventional resolution.

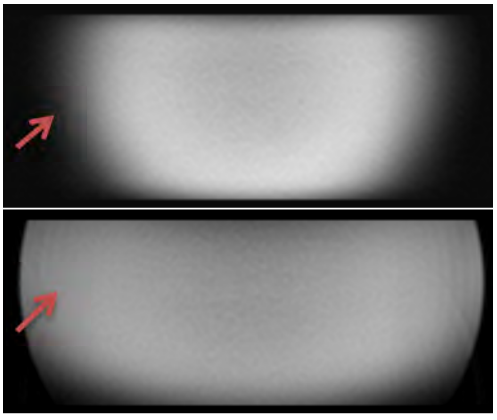

Fig. 1. Phantom images obtained with 1.5×1.5mm^2 inplane resolution, FOV = 230 * 45mm^2 2DRF excitations. (A) rFOV [1] and (B) iZoom.

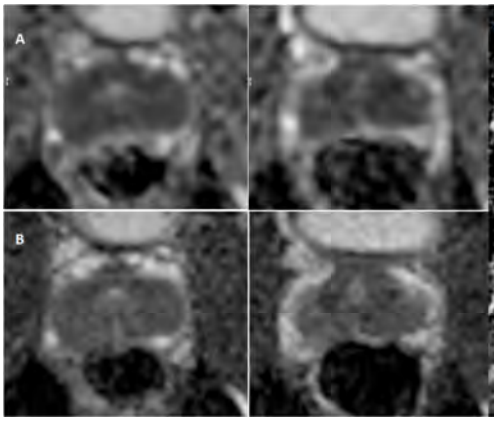

Fig. 2. ADC map of prostate b = 600s/mm^2, (A) Conventional DWI, 2.3 * 2.3mm^2 inplane resolution, FOV:160*160mm (B) iZoom, 1.5 * 1.5 mm^2 inplane resolution. The column is for different slices.

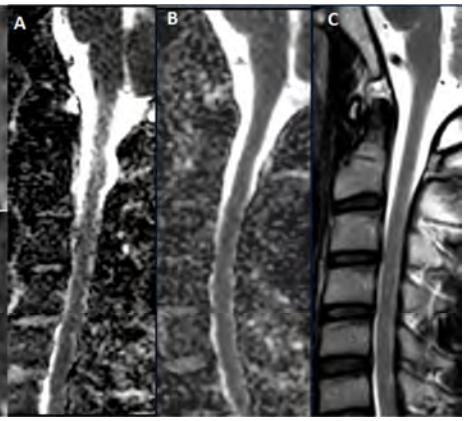

Fig. 3. ADC map of Spine b = 400s/mm^2, with inplane resolution (A) Conventional DWI, 2.3 * 2.3mm^2 (B) iZoom, 1.5 * 1.5 mm^2 (C) TSE, 1.0 * 1.0 mm^2

Discussion A new tilted 2D RF excitation pulse is introduced which only tilts the k-space along the PE direction. Because the proposed method decreases the echo train length and maintains the RF sub-pulse bandwidth, it reduces off-resonance induced artifacts, and not sensitive to the B1 non-linearity, and hence makes higher resolution DWI clinically possible. To further improve the performance of the proposed method, the minimum phase pulse can be used to shorten the 2D pulse duration since the long duration of 2D RF pulse will introduce T2 decay and decrease the SNR . Higher gradient strength and slew rate will also help. With more average to improve the SNR, higher resolution with 1.0*1.0mm^2 was also achieved.

Conclusion The proposed method improves the image uniformity compared with the rFOV, and enhances the applicability of zoomed FOV DWI in applications expecting high resolution, such as spine, prostate etc.

References : [1] Le Bihan D., et. al. JMRI 2006;24:478-488. [2] Pruessmann K.P., et. al. MRM 1999;42:952-962. [3] Saritas E., et. al. MRM 2008; 60:468–473. [4] Finsterbusch J., JMRI 2012; 35:984-992. [5] Bernstein M., et al. Handbook of MRI pulse sequence; 2004:128.