3D Adiabatic FSE with GRASE Acquisition at 4T

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Introduction

The ability to produce accurate 180° refocusing with B_1-insensitive adiabatic pulses can be advantageous in spin-echo sequences like FSE, especially at high fields. However, a quadratic phase results when using an adiabatic full passage (AFP) such as the hyperbolic secant (HS1) pulse for slice or slab selection. Although the quadratic phase can be removed by using a pair of AFP pulses[1], this approach lacks efficiency due to increased SAR and long echo spacing. Alternatively, a BIR-4 pulse, which can achieve the B_1 insensitive refocusing without quadratic phase, has been employed to compensate for B_1 inhomogeneity in FSE[2]; however, that approach is limited by BIR-4 not being slice- or slab-selective and that BIR-4 requires relatively high RF power (i.e. SAR). In addition, 3D FSE requires long scan time due to its relatively long recovery delay for each TR, making it difficult to use 3D FSE for human studies. Here, we introduce a novel adiabatic 3D FSE sequence that overcomes these problems by using the following 4 techniques: (1) Variable-rate selective excitation (VERSE)[3], (2) gradient- and spin-echo (GRASE) acquisition[4], (3) k-space undersampling[5], and (4) image space phase correction[6].

Method

The sequence diagram of the adiabatic 3D FSE sequence is shown in Fig.1a. VERSE HS1 pulses were used for both excitation and refocusing. Original parameters for HS1 excitation/refocusing are: pulse width T_p=5ms, truncation factor β=4.8, frequency sweep bw=6/3kHz and 4/2kHz for phantom and human brain scans, respectively. The VERSE pulses were generated under the condition that T_p was unchanged (5 ms) and maximum gradient was limited to 110% of the original maximum gradient. The VERSE procedure reduced RF peak power and SAR to 65% and 82% of the original HS1 pulse. GRASE acquisition that has been installed successfully in PROPPELLER[6,7] was implemented with turbo factor tf=3 or 5. For further scan acceleration, k-space was sampled cylindrically and undersampling was employed; the sampling density on the phase encoding plane decreased from the center to periphery according to Gaussian distribution (Fig.1d). A gelatin phantom and in vivo human brain imaging were performed with a 4T 90 cm bore scanner (Agilent technologies Inc.). First, quick reference scan (~1min) was acquired for phase correction, and then 2 row resolution reference images (even and odd echo images) were reconstructed. The phase mismatch between the echoes was corrected in image domain by using the low resolution references. Image reconstruction was done using an in-house program running on Matlab.

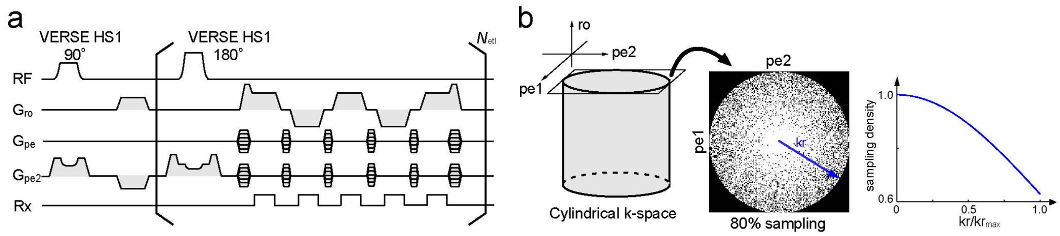

Figure 1. Sequence diagram of the 3D adiabatic FSE sequence (a) and k-space undersampling strategy (b).

Results

Gelatin phantom images with and without image space phase correction are shown in Fig.2. While edges of vials inside the phantom showed severe blurring on the image without the correction, the image with the correction showed clear edges, demonstrating that correction of phase mismatch between even and odd echo is critical. In both images, signal intensity decreases toward the periphery of the phantom due to relatively large B_1 field variation at 4T. Hence, image space phase correction is even more important for high field applications, since the method removes the B_1 field dependent phase as well as the quadratic phase resulting from the use of AFP pulses.

In vivo human brain images are shown in Fig.3. Image space phase correction significantly improved the image quality; the sulcus in cerebral cortex and sharp boundary between brain and skull were clearly shown on the phase corrected image.

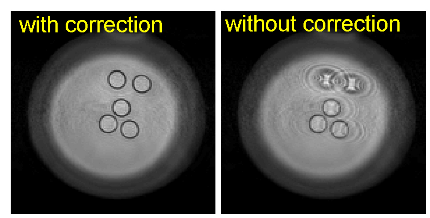

Figure 2. Phantom images reconstructed with (left) and without (right) image space phase correction. (TE_{eff}=25 ms, TR=500ms, N_{etl}=8, tf=5, 1min 30sec)

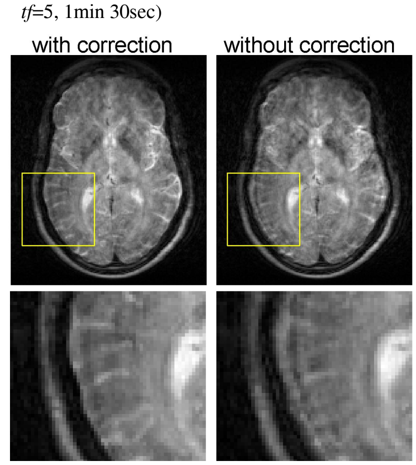

Figure 3. Brain images reconstructed with (left) and without (right) image space phase correction. (TE_{eff}=69 ms, TR=1,000 ms, N_{etl}=6, tf=3, 7min 54sec).

Discussion

The main focus of this study was to address the high SAR and long scan time in 3D adiabatic FSE. The VERSE procedure reduced RF peak power and SAR while keeping the excitation profile. By using the GRASE technique, multiple k-space lines were acquired for each spin echo, reducing the number of the refocusing pulses and accelerating the scan. The image space phase correction enabled to use all (odd and even) echoes for a single image reconstruction by removing phase difference between odd and even echoes that includes not only quadratic phase from the adiabatic pulses but also B_0 and B_1 dependent phase in space. As a result, the proposed sequence allowed 3D in vivo human brain FSE imaging with acceptable SAR and scan time at 4T. Further acceleration can be done by using multi-slice acquisition and compressed sensing reconstruction combined with the k-space undersampling.

Acknowledgements

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