Scan Time Reduction for Non-CPMG 3D FSE Imaging Based on Phase Cycling

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Introduction: Fast spin echo (FSE) imaging plays a central role in clinical MRI. When combined with flip angle modulation (1), very long echo train can be used without excessive blurring, which makes 3D FSE imaging feasible in a clinical setting. Compared to 2D FSE, a major advantage of 3D FSE is that data can be acquired with isotropic resolution and reformatted into arbitrary plane. FSE requires CPMG condition. However, this condition can be violated in a number of applications due to system imperfection and result in image artifacts. Reported non-CPMG approaches (2-4) can be used to address this problem, but these methods have limitations, such as increased echo spacing, use of only half signal pathway, or limited choice of flip angle. We recently proposed a non-CPMG FSE acquisition based on a phase cycling method (5,6) without imposing these limitations. However, this approach doubles the scan time. Here we discussed methods to reduce the scan time of this approach.

Methods: When the CPMG condition is violated in FSE acquisition, destructive interference between the echoes with even and odd parity occurs, which results in image artifacts. By phase cycling of the RF pulses (5), it is feasible to separate these two groups of echoes and then realign them to form artifact-free images (6). Theoretically it can be shown that the error after phase correction caused by omitting high frequency data in the second acquisition (CP) is $I_{Odd}^{(H)}(1-\exp(j\theta))$, where θ is the phase error, and $I_{Odd}^{(H)}$ is the corresponding high frequency component of the image of echo with odd parity. Therefore, when the phase error is moderate, we can only collect low resolution CP data to reduce scan time without great penalty of image quality. Figure 1 shows the sampling pattern and in vivo example images acquired using this approach.

Saturation RF pulses to suppress signal from outer volume can also be used to reduce scan time. We used high bandwidth dual band saturation pulses with quadratic phase (7) to achieve sharp saturation profile in our applications. Multiple saturation pulses are applied consecutively to achieve insensitivity to B1 inhomogeneity and T1 variation (8). Sufficient crusher at the end of each saturation pulse is used to avoid fine line artifacts. To mitigate eddy current effect, a waiting time is applied after each crusher. The values of flip angle and such waiting times are optimized to achieve the best insensitivity to B1 inhomogeneity and T1 variation.

High resolution in vivo shoulder data sets were collected from a Discovery MR750 3T scanner (GE Healthcare, Waukesha, WI) using a 3-channel shoulder coil. The parameters included: TR/TE 1200/17ms, FOV 18x10.8cm, ETL 60, 0.5NEX, BW ±62.5kHz, fat sat, resolution 0.7x0.7x0.8mm, 128 slices with scan time 6min.

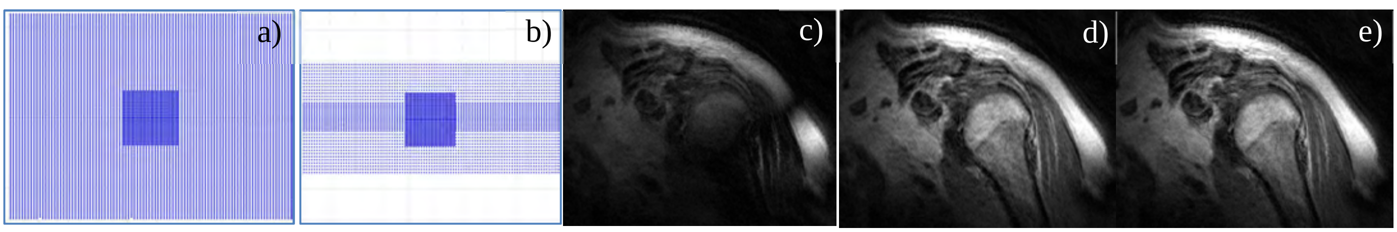

Figure 1: a) sampling pattern for CPMG acquisition; b) sampling pattern for CP acquisition. The calibration region is fully sampled; the low frequency k-space of CP has low acceleration factor; the middle k-space of CP has high acceleration factor; and the outer region of CP is not collected. c) An in vivo shoulder scan (after reformat) using conventional CPMG; d) our non-CPMG acquisition using the sampling pattern in a) and b) with 150% total scan time of that in c); and e) our non-CPMPG acquisition with 200% of total scan time of that in c).

Results and Discussion: Figure 2 compares the results from conventional and our approach. The shading artifacts are obvious in both the original coronal acquisition plane and the axial reformat in conventional 3DFSE. In contrast, these artifacts were greatly suppressed in our non-CPMG acquisition approach. Using 3D isotropic acquisition, we demonstrated that our approach is feasible to collect 3D FSE data sets far off isocenter in one single acquisition and then reformat the acquired images at arbitrary plane. Compared to current routine practice, which collects 2D FSE in multiple planes in separated scan, our method can provide reduced total scan time and simplified workflow.

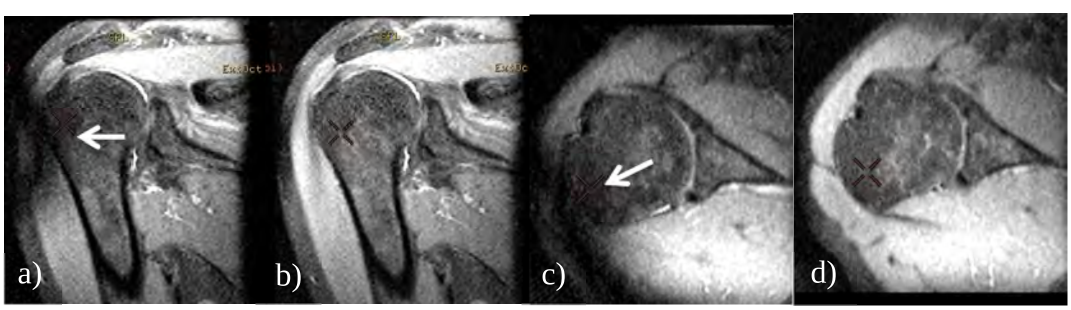

Figure 2: Shoulder scan. a) Conventional 3D FSE in original coronal acquisition plane; b) our non-CPMG 3D FSE approach in original coronal acquisition plane; c) conventional 3D FSE reformat in axial plane; d) our non-CPMG 3D FSE reformat in axial plane

Conclusion: We demonstrated a non-CPMG 3D FSE imaging approach based on phase cycling and discussed the means to reduce its scan time. This approach enables high resolution 3D FSE imaging at far off isocenter which is challenging to conventional 3D FSE. This approach may also be beneficial for other FSE based applications where CPMG condition is difficult to meet.

Reference: 1. Mugler et al, ISMRM 2000, p687 2. Norris et al, MRM 1992, p142; 3. Alsop, MRM 1997, p527; 4. Le Roux, JMR 2002, p278; 5. Zur et al JMR 1987 p212; 6. Zur et al, ISMRM 2014 p1648; 7. Schulte et al, JMR 2004 p111; 8. Wilm et al, MRM 2007, p625