Improve Volume Selective 3D Fast Spin Echo Acquisition

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Introduction: Fast spin echo (FSE) (1) imaging plays a central role in clinical imaging. Recently there is growing interest in using pseudo-steady-state (PSS) FSE with flip angle modulation (2) for high-resolution 3D anatomical imaging due to its high SNR efficiency. Fast spin echo sequences require the CPMG condition and the violation of it can result in image artifacts such as banding or SNR loss. A major cause to the violation of CPMG condition occurs with volume selective 3D FSE due to the eddy current effect from gradients, particularly when imaging at far off isoceter. This problem has been previously addressed in 2D FSE acquisitions (3), but solutions for 3D FSE can be time consuming or difficult to implement (4, 5). In this work, we demonstrate that a recently developed phase correction approach can be used to improve the robustness of volume selective 3D FSE acquisition and its relevant applications.

Theory and Method: In FSE acquisitions, the eddy current effect on the initial RF pulses is the primary cause to image artifacts. For 3D FSE acquisitions, one of the authors (DH) has previously demonstrated that by removing the slab selective and its refocusing gradients, and rearranging the timing of crusher gradients, we can reduce the risk of having image artifacts from the eddy current effect. This approach is particularly beneficial when the center of k-space is acquired at the beginning of echo train. This condition is necessary for applications based on 3D FSE, such as a recently developed 3D relaxometry method (6), in order to reduce quantification errors. The whole volume excitation approach, however, is impractical when wrap-around artifacts are significant.

In FSE sequences, the spins at each echo can be categorized into two groups based on the parity of the times their phase has been inverted (7). The CPMG condition causes constructive interference between these two groups of spins, whereas the violation of it causes destructive interference. If the CPMG condition is violated, phase cycling methods (7) can be used to realign the phase of these spins before summing them together to create artifact free images. A phase correction method is developed based on this to improve robustness of volume selective 3D FSE acquisitions.

The data sets were collected from 3T Discovery MR750 scanners (GE Healthcare, Waukesha, WI). For volunteer scan, hip was scanned using a 16-channel surface coil (GE Healthcare, Waukesha, WI). The imaging parameters include: Sagittal, TR/TE 1200/16ms, FOV 22×22cm, 40 slices with 3mm thickness, ETL 60, BW ±62.5kHz, image matrix 256×256. We also collected phantom data to demonstrate the effect of this approach on relaxometry based on 3D FSE acquisition. We used the sequence described in (6) for phantom data acquisition. The data sets were collected using same coil at off iso-cetner of the scanner.

Results and Discussion: Figure 1 shows the magnitude image from the relaxometry acquisition. Note the whole volume selection approach significantly reduced the banding artifacts which appeared in conventional volume selective 3D FSE acquisition. With phase correction, we obtained same artifact-free images but preserved volume selectivity. Figure 2 and 3 show the hip images from 3D FSE acquisition in sagittal plane and its reformat in axial plane, respectively. Note significant aliasing artifacts when there is no volume selectivity. In conventional volume selective 3D FSE acquisition, wrap-around artifacts were removed but obvious shading artifacts were observed. 3D FSE with this new phase correction approach removed both wrap-around and shading artifacts.
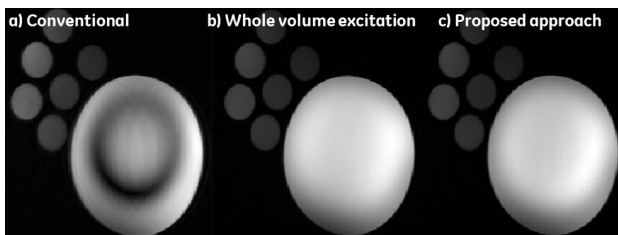

Figure 1: The magnitude image from relaxometry acquisition. a) conventional volume selective 3D FSE acquisition; b) 3D FSE using whole volume excitation approach; c) Volume selective 3D FSE imaging with new phase correction approach
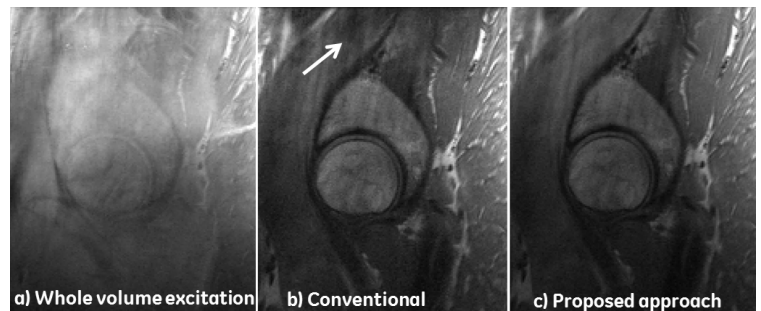

Figure 2: 3D anatomical hip imaging using 3D FSE acquired in sagittal plane. a) whole volume excitation approach; b) conventional volume selective acquisition. The white arrow shows the shading artifacts; and c) volume selective 3D FSE with new phase correction
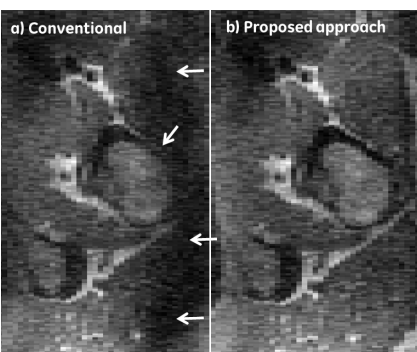

Figure 3: 3D anatomical hip imaging reformatted to axial plane. Left is conventional volume selective 3D FSE acquisition and right is volume selective 3D FSE with new correction approach. The white arrows indicate the shading artifacts seen in conventional imaging.

Conclusion: Whole volume excitation can significantly reduce artifacts from the violation of CPMG condition in 3D FSE. However, volume selection is necessary in a number of applications. Here we demonstrate that a recently developed phase correction approach can be used to achieve improved robustness for volume selective 3D FSE acquisition and its relevant applications.

Reference: 1. Hennig et al MRM 1986 p823 2. Busse et al MRM 2008 p640 3. Hinks et al US patent 6,160,397 4. Granlund et al ISMRM 2012 p3382 5. Granlund et al ISMRM 2011 p2822 6. Chen et al ISMRM 2011 p231 7. Zur et al JMR 1987 p212