Prescan Phase Correction for Off-isocenter 3D FSE Imaging

Kristin L Granlund[1,2], Weitian Chen[3], Dawei Gui[4], Donglai Huo[4], Patrick LeRoux[5], and Yuval Zur[6]

[1]*Radiology, Stanford University, Stanford, California, United States,* [2]*Electrical Engineering, Stanford University, Stanford, CA, United States,* [3]*Applied Science Laboratory, GE Healthcare, Menlo Park, CA, United States,* [4]*MR PSD and Applications, GE Healthcare, Waukesha, WI, United States,* [5]*Applied Science Laboratory, GE Healthcare, Europe,* [6]*GE Healthcare, Israel*

Introduction

3D fast spin echo (FSE) sequences are useful for acquiring isotropic, high-resolution images for applications including neuro-, musculoskeletal, and breast imaging [1]. Off-isocenter, image quality is degraded by gradient non-idealities (such as gradient-induced eddy currents and concomitant terms), which limits the use of 3D FSE sequences for shoulder, wrist, and hip applications. When the CPMG conditions are not met for sequences with non-180 degree refocusing pulses, phase errors cause the spin echo and stimulated echoes to destructively interfere, resulting in shading or bands across the image [2]. Currently, there are limited solutions for correcting the phase errors for 3D FSE sequences, and those that exist can take over 1 minute of prescan time. We present a method for measuring the phase errors and calculating the sequence parameters to compensate for those errors in a short prescan time.

Methods

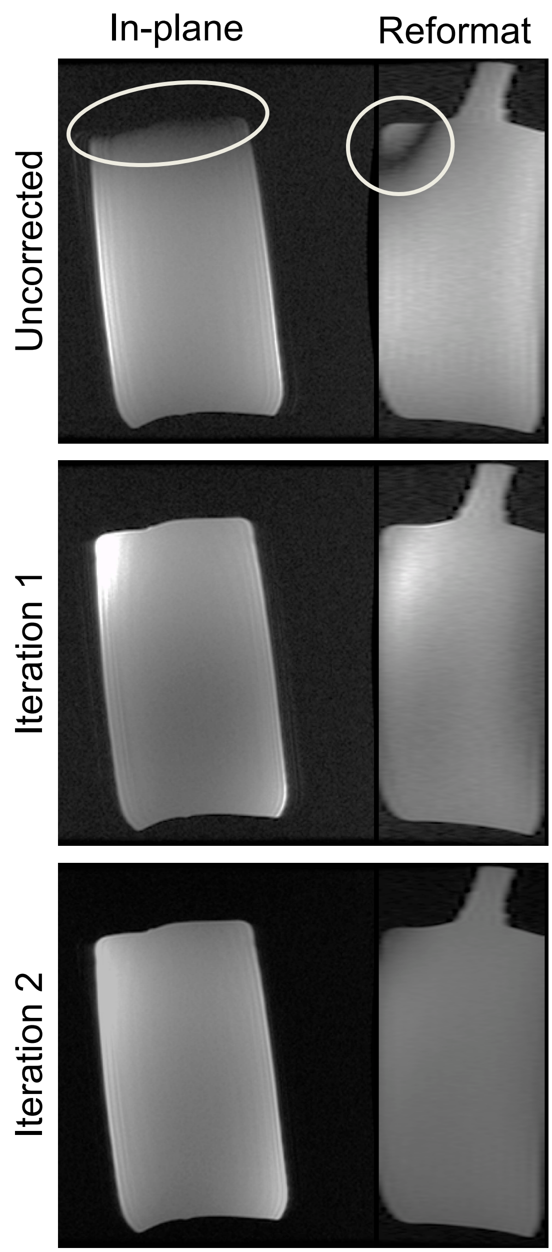
Since the phase errors are dominated by the zeroth and first order terms, we model the phase error with a constant error and linear errors in the readout (x) and slice encoding (z) directions. Extending the work by Zur [3], we first measure and correct the constant and linear terms in x by acquiring a standard 3D FSE echo train without phase encoding gradients and then acquiring the same echo train with phase cycling for the refocusing pulses (the phase of the refocusing pulses alternates between +90 and -90 degrees relative to the excitation pulse). Phase cycling causes the stimulated echoes to have the opposite phase relative to the spin echoes for the two acquisitions. By calculating linear combinations of the acquired echoes, we are able to separate the spin echo and stimulated echo components. From the stimulated echo component, we can calculate the phase error that needs to be corrected. Then, measure and correct the linear term in z by acquiring two echo trains with different z phase encoding gradients to model the linear phase error in the z direction based on the phase difference between the acquired echoes of the two echo trains.

For both the constant/x correction and the z correction, the phase errors are calculated in the image domain. The acquired echoes are Fourier transformed and the phase error is calculated as the difference between the phases of the resulting projections. From the constant and linear phase errors, we can calculate the sequence parameters (phase of the refocusing pulses, Gx dephaser area, Gz dephaser area) that are required to compensate for the phase errors [4].

This correction was tested at 3T with the phantom centered at 100mm off isocenter. The 3D FSE sequence parameters are TR = 1500ms, ETL = 64. FOV = 26cm (256×256), 32 3-mm-thick axial slices. The prescan parameters that differ from the scan sequence are TR = 1000 ms, ETL = 4, xres = 128, 3:30 scan time.

Results

Scans of a uniform bottle phantom show that the severe signal loss can occur and vary in the slice encode and readout directions. After a single iteration (constant/x correction followed by z correction), the signal is recovered, though there are still signal variations across the image. A second iteration can be used to further improve the image quality, resulting in a more uniform signal intensity. Generally, more than two iterations do not provide further improvement in image quality.



At 100mm off isocenter, uncorrected images show signal loss (circles). One iteration removes banding (signal loss), but an additional iteration may further improve image quality.

Discussion

3D FSE is limited for imaging off-isocenter volumes due to poor image quality. By measuring the phase errors that occur, we are able to adjust the acquisition parameters to compensate for the system non-idealities. With this correction, 3D FSE sequences can be used to acquire isotropic, high-resolution images off isocenter.

Conclusion

We have presented a method for correcting phase errors in a reasonable prescan time (~10s) to improve the image quality of 3D FSE for off-isocenter imaging volumes.

References

[1] AJR 2007, 188:1278, [2] Rev Sci Inst 1958, 29:688, [3] J Mag Reson 71:212, [4] US Patent 6,160,397, 2000.

Acknowledgements

GE Healthcare