Prosepective Phase Correction for 3D FSE

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Introduction

Fast spin echo sequences are useful for musculoskeletal imaging [1], however their use is limited by poor image quality for off-isocenter FOVs, such as wrist, shoulder, and hip imaging. Image artifacts are caused by gradient non-idealities, which are worse off-isocenter. Artifacts include ghosting and banding and are often severe enough to obscure the anatomy.

FSE sequences use a train of refocusing pulses to rapidly acquire the data. Reduced flip angles are used for the refocusing pulses to reduce the SAR of the sequence and provide a more uniform signal over the echo train. With reduced flip angles, the acquired signal is a combination of spin and stimulated echoes. In order for these signals to constructively add, the sequence must meet the CPMG conditions; otherwise, phase errors degrade image quality [2]. Unlike the phase corrections for 2D FSE, the phase errors for 3D FSE have not been extensively investigated. We present a method for measuring the phase errors during prescan and calculating corrections to be applied during the main 3D FSE scan sequence.

Methods

In order to model the phase errors that exist within the imaging volume, we acquire 2D phase information in the x and z directions. Two consecutive echoes are acquired during prescan for a number of different slice encoding gradients without phase encoding gradients. The acquired data are Fourier transformed in x and z to generate projection images for the first and second echoes of the echo train. The phase error is calculated as the difference between the phases of the two images and is modeled with a plane. The parameters of the plane (intercept, x-slope, z-slope) are converted to RF phase and gradient area corrections (Figure 1) [3]. The prescan correction is iterative: the corrections are applied to the sequence and the prescan data is reacquired and processed until the phase errors are less than 10%, which is the limit of visible artifacts in reconstructed images based on simulations.

Since the phase is smoothly varying, the six central slice encodes were acquired to generate the phase difference images while limiting the length of the prescan acquisition. The data is zero-padded in the slice encode direction before it is Fourier transformed to match the matrix size of the prescribed volume.

This correction was tested at 1.5T and 3T; the images shown were collected at 1.5T. The 3D FSE sequence parameters are TR = 1500ms, ETL = 64. FOV = 26cm (256×256), 32 1-mm-thick axial slices. The prescan parameters that differ from the scan sequence are TR = 100 ms, ETL = 4, xres = 128.

Results

A scan of a uniform bottle phantom shows severe signal loss in bands perpendicular to the readout direction (Figure 2a). Using the correction parameters calculated during prescan, the resulting image shows uniform signals across the phantom (Figure 2b). The correction corresponds to 40% of the default RF phase, 2.5% of the Gx dephaser area, and 0.3% of the Gz dephaser area.

Reformatted images show that the banding can vary in both the x and z directions (Figure 3a), highlighting the need for both a Gx and a Gz correction. Following correction, the image intensity is uniform throughout the volume (Figure 3b).

Discussion

Without correction, many off-isocenter 3D FSE images have banding artifacts that can obscure the anatomy and pathology of interest. Post-processing corrections are limited by the acquired data; if the phase errors are significant enough, the signal cannot be restored. By acquiring additional data during prescan, we can model and correct for the phase errors that cause the artifacts. While this does increase the prescan time, it dramatically improves image quality.

Conclusion

We have demonstrated a method for measuring and correcting the gradient errors that occur during 3D FSE. This method allows us to make corrections beyond what is possible with post-processing and enables *in vivo* off-isocenter imaging.

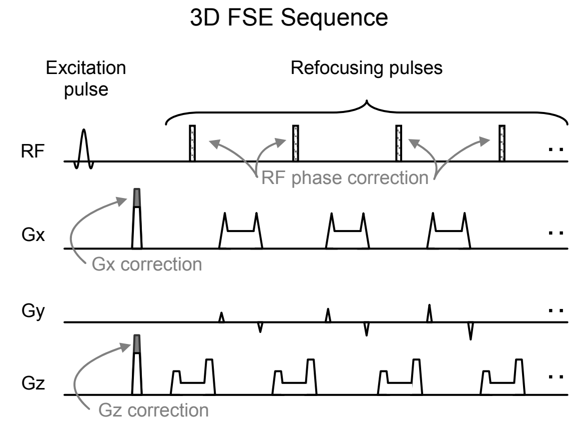

Figure 1 FSE sequence diagram showing sequence corrections. Constant phase errors are corrected by modifying the phase of the refocusing pulses relative to the excitation pulse. The linear phase errors are corrected by modifying the area of the rephaser gradients.

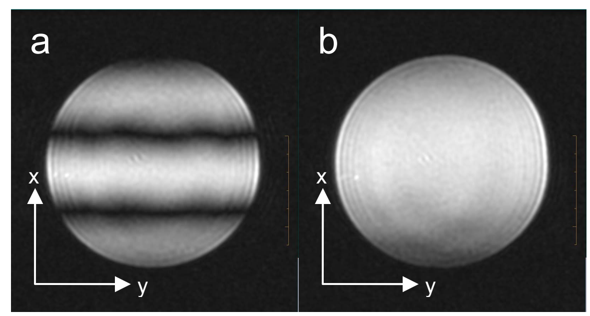

Figure 2 Uniform phantom scan. Before correction (a), there is severe banding with severe signal loss. Following correction (b), the image quality is drastically improved and the bands are no longer visible.

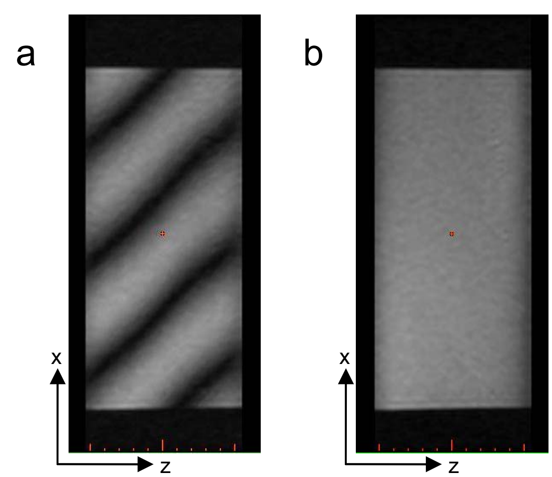

Figure 3 Reformatted images. The uncorrected image shows banding in the x and z directions (a), which have been removed by the prescan correction (b).

References [1] Musc Imag 2007, 188: 1278-93, [2] Rev Sci Inst 1958, 29:688 , [3] US Patent 6,160,397, 2000.

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