Reducing a Localized Signal Fluctuation Artifact in fMRI using Spectral-Spatial Fat Saturation

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INTRODUCTION

The conventional fat saturation scheme for thin-slice fMRI is to use a 90° flip angle, spatially non-selective, 1D RF pulse at fat resonance frequency to rotate fat spins (or water spins under a B0 frequency offset that equals the fat-water frequency difference) in the whole 3D space to transverse plane. This scheme relies on a sufficiently strong following crusher gradient to remove the fat signals, which is an easy task when fat spins are at or close to the isocenter of the magnet. However, for locations further away from isocenter in the superior-inferior direction (e.g., neck or chest areas for brain fMRI), gradient linearity becomes increasingly worse and in some locations (e.g., >20 cm away from isocenter), gradients at some or all axes can become negligibly small, failing to crush out the fat spins in these areas. These fat spins produce artifactual signals that are aliased to contaminate the in-plane water signal. In the image domain, the artifactual signal affects one or multiple localized voxels because the imaging gradients that encode these out-of-plane signals have weak amplitude as well. The artifact can sometimes be seen as "clouds" in the background; more often, it overlaps with water signal and manifests itself as an additional temporal fluctuation in one or multiple voxels due to motion and/or system instability in the out-of-plane areas. For the latter case, the locations of voxels with the additional fluctuation are coherent through slices; therefore, one or multiple dark bands in the slice direction can appear in the sagittally or coronally reformatted signal-to-temporal-fluctuation-noise (SFNR) map. The additional temporal fluctuation can generate false result in the brain activation map and affect the accuracy of any subsequent data analysis. In this paper, we propose a spectral-spatial fat saturation method to remove the above-mentioned artifact.

PROPOSED METHOD

We replace the conventional spatially non-selective, 1D fat saturation pulse with a 2D spectral-spatial saturation pulse. In the spectral domain, the 2D pulse selects only spins whose resonance frequencies are close to the fat frequency; in the spatial domain, the 2D pulse selects a slice that is centered on the imaging slice of interest (i.e., the slice excited by the subsequent water excitation pulse) but with a wider slice thickness to ensure fat spins inside the imaging slice are fully saturated (Fig. 1). Note that the slice saturated by the spectral-spatial pulse always moves along with the location of the imaging slice when acquiring off-centered slices. Owing to the spatial selectivity, fat spins far off isocenter (e.g., spins in the neck or chest) would not be excited and therefore not aliased back to the imaging plane to create the signal fluctuation artifact. Meanwhile, this new fat saturation scheme preserves thin slice capability because the slice thickness is determined by the ensuing 1D water excitation pulse.

RESULTS

EPI-based fMRI images on a volunteer were acquired using the conventional 1D fat saturation and the proposed spectral-spatial saturation. The conventional pulse was a minimum phase SLR pulse [1]. The spectral-spatial pulse was based on an echo-planar excitation k-space trajectory with 12 subpulses and designed using the method described in [2]. The two pulses have similar pulse duration (8.2 and 8.6 ms for 1D and spectral-spatial, respectively). Other scan parameters were: Axial scan plane, matrix size = 64×64, slice thickness for water excitation = 2.5 mm, slice thickness for fat saturation (when the spectral-spatial pulse is used) = 2 cm, number of slices = 25, number of temporal phases = 140, TR = 1400 ms, TE = 18 ms. Figure 2a shows an arbitrarily chosen slice (slice number 14) where two voxels of interest are picked for further analysis: One voxel (marked by a red square) at (x,y) = (34,40) where x represents the readout axis and y represents the phase encoding axis, and the other voxel (marked by a blue square) at (34,45). Figure 2b compares the temporal profile of the signal at the two voxels of interest for images acquired using the 1D spatially non-selective fat saturation. After a second order polynomial detrending in the temporal phase axis, the normalized temporal fluctuation, defined as (current signal - temporal mean)/(temporal mean), has a significantly higher value in the red voxel (average absolute value of fluctuation = 1.7%) than the blue voxel (0.6%), because the red voxel is contaminated with additional fat signal fluctuation from outside the brain (which is more obvious by comparing Figs. 2d and e in the following discussion). Figure 2c compares the same two voxels for images using the proposed spectral-spatial fat saturation. Both voxels have similar temporal fluctuation values (0.5% vs. 0.6% for average fluctuation), indicating good suppression of the additional fluctuation from fat signal outside the brain. Temporal fluctuations are evaluated at every voxel in every slice and represented by a 3D SFNR map (where each voxel of the map is defined as the temporal average of the signal at that voxel divided by the temporal standard deviation of the signal at the same voxel). Darker color in the map means larger fluctuation while lighter color means lower fluctuation. One layer (x = 34) of the sagittally reformatted map (phase encoding axis y is in horizontal direction and slice axis z is in vertical direction) based on the 1D fat saturation images is shown in Fig. 2d. The dark vertical band corresponds to the same voxels across all slices that have significantly higher temporal fluctuation. Note that the red voxel in Fig. 2a is inside the dark band and the blue voxel is outside of it (locations of both voxels are also marked in Fig. 2d). The dark band disappears in the SFNR map using the proposed spectral-spatial fat saturation (Fig. 2e), which not only shows that the proposed fat saturation method is capable of removing the localized additional temporal fluctuation, but also confirms that the additional fluctuation is from signal outside the brain because spatial suppression of such signal reduces the overall fluctuation to the normal level. Note that the remaining sporadic dark dots in the sagittally reformatted map are due to low signal in the corresponding anatomies.

CONCLUSION

Conventional 1D, spatially non-selective fat saturation can lead to uncrushed fat signal, which manifests itself as "clouds" in image background (not shown for limited space) or localized signal fluctuation. The proposed spectral-spatial fat saturation is quite effective in removing such artifacts while preserving thin slice capability, pulse duration, and fat suppression performance.

REFERENCES

[1] Pauly et al., *IEEE-TMI*, vol. 10, pp. 53-65, 1991.
[2] Zur et al., *MRM*, vol. 43, pp. 410-420, 2000.

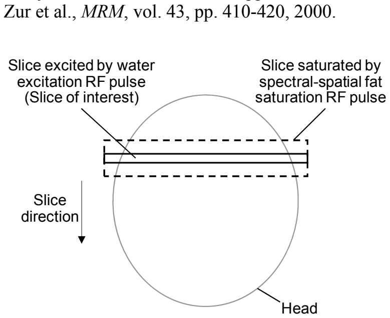

Fig. 1. Relative locations of the slice excited by a water excitation pulse (solid rectangle) and the slice by the preceding spectral-spatial fat saturation pulse (dashed rectangle).

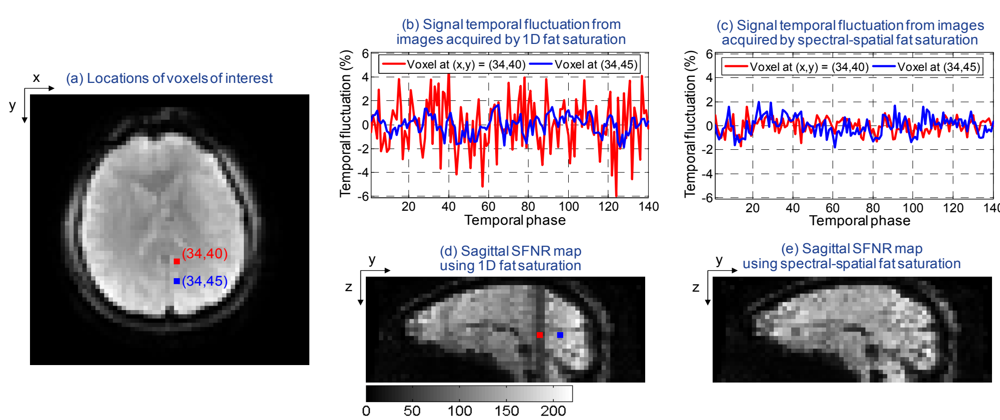

Fig. 2. Temporal fluctuation analysis comparing fMRI images acquired by the conventional 1D fat saturation and the proposed spectral-spatial fat saturation. See detailed description of the figure in the "RESULTS" section.