Unpaired Adiabatic Refocusing Pulses for Volume Selection in Spectroscopic Imaging

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Introduction: As in-vivo NMR spectroscopy moves towards higher field strengths, chemical shift displacement errors during volume localization increase. While these can be minimized by shorter RF pulses and stronger gradients, RF power deposition often limits the improvement. Here we present a method of reducing both the chemical shift displacement error and SAR for spectroscopic imaging by using single, unpaired adiabatic pulses for volume selection. AFP pulses have many advantages such as insensitivity to B_1 and excellent slice profiles, at the expense of requiring higher peak RF power and inducing a non-linear phase shift across the slice during refocusing [1]. Traditionally a second identical AFP pulse has been used to reverse the phase introduced by the first pulse at the expense of increased power and echo-time [1]. Here it is shown that single AFP pulses selecting slices at 90˚ or 45˚angles will give partial or almost complete phase refocusing. Employing a sufficient number of phase-encoding steps ensures that the remaining phase does not lead to intravoxel signal loss. A similar approach was proposed in 3D imaging [2]. To minimize the chemical shift displacement error even further, the conventional AFP pulses have been replaced for single slice selection by gradient modulated FOCI pulses, which increase the effective bandwidth without increasing peak RF power [3].

Methods: Experiments were performed on a 4.0 T Bruker Magnet interfaced to a Bruker Avance Spectrometer with Magnex gradients and shims. RF reception and transmission was carried out by a birdcage volume coil. Volume selection pulses were incorporated into a spin echo spectroscopic imaging sequence following water suppression and slice-selective RF excitation, and preceding two dimensional phase encoding gradients. The modified volume localization consisted of four adiabatic FOCI pulses of duration 6 ms. Each pulse was preceded and followed by crusher gradients. The slice angles of the four pulses were incremented sequentially at 0˚, 45˚, 90˚, 135˚. Computer simulations were used to predict the net phase across an ROI selected by this method. The simulations were also used to predict the minimum imaging resolution needed to keep signal loss from intravoxel phase variation to < 5% for all voxels. In-vivo 128x128 MRI and 20x20 SI images were collected with and without volume localization with TE = 80 ms, TR = 2 sec, voxel size 1.26 x 1.26 x 1cm.

Results:

Figure 1A.

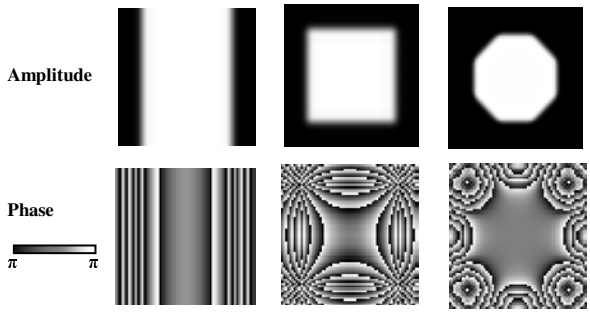

Figure 1B.

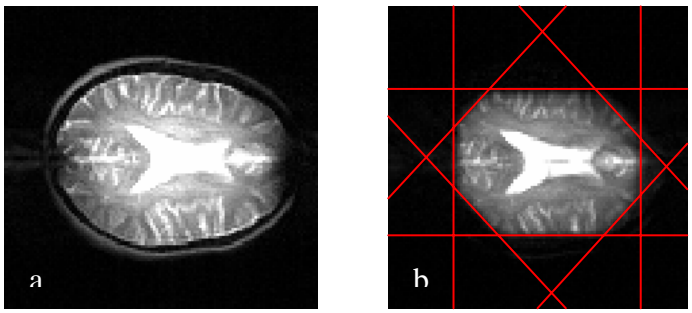

FIGURE 1A: Matlab simulation of signal magnitude and phase over a slice with a single volume localization band at 0˚, two bands at 0˚ and 90˚, and four bands at 0˚, 45˚, 90˚, and 135˚angles selected by 6 ms FOCI adiabatic full passage pulses.

FIGURE 1B: 128x128 MRI with FOV = 25.6x25.6 cm (a.) Without volume localization (two sets of refocused 6 ms FOCI pulses at 0˚, 0˚, 90˚, 90˚, 20 cm slice bandwidth). (b.) With volume localization (four FOCI pulses at 0˚, 45˚, 90˚, 135˚ with slice position and bandwidths shown). With these settings the water-lipid chemical shift displacement was 0.48 cm, much smaller than the nominal SI voxel size.

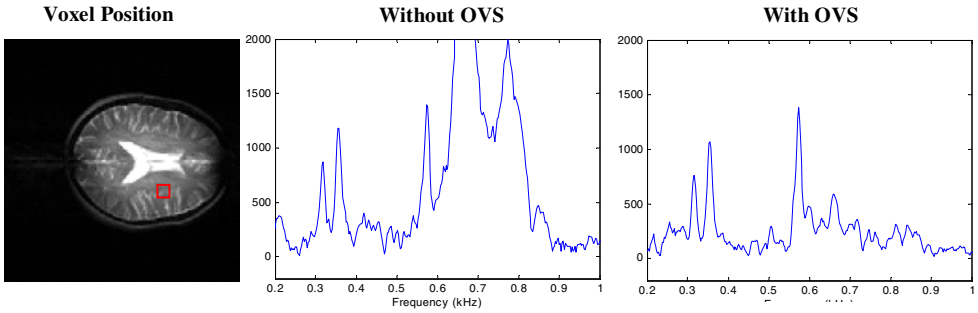

FIGURE 2: Sample voxel with position shown above from a 20x20 SI, voxel dimensions: 1.26x1.26x1 cm, without volume localzation (two sets of refocused 6 ms FOCI pulses at 0˚, 0˚, 90˚, 90˚, 20 cm slice bandwidth) and with OVS (four unrefocused FOCI pulses as shown in Figure 2.).

Discussion: From both the computer simulation and the in-vivo data, four sequentially applied 45˚ adiabatic pulses can provide good volume selection. Although the spatial phase shift is not completely refocused, the additional spatial localization by phase-encoding ensures negligible intravoxel signal loss. The advantage of this new technique is that the sequence is B_1-insensitive, significantly decreases the chemical shift displacement artifact, and provides identical localization at half the power and echo-time compared to a paired AFP sequence, or can be used to achieve a more advanced localization shape at the same power and TE settings. Using FOCI gradient modulated pulses further reduces spatial displacements and improves (sharpens) the spatial localization without increasing the pulse peak power.

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