Interleaved narrow-band adiabatic spatial-spectral pulse sequence for 1H MRSI at 7T

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Introduction: ^{1}H Magnetic resonance spectroscopic imaging (^{1}H MRSI) is a useful technique for measuring metabolite levels in the brain. Some of the main metabolites of interest are Choline (Cho), Creatine (Cr) and N-Acetyl-Aspartate (NAA). ^{1}H MRSI at higher fields, such as 7T, offers the advantages of increased SNR and spectral separation. However, severe B_1 inhomogeneity and chemical shift localization (CSL) errors limit the spatial coverage that can be achieved. Approximately 40% B_1 variation was measured across the adult human head in our 7T GE whole body magnet. CSL error scales with field resulting in signal loss at the PRESS box edges. Adiabatic spectral-spatial (SPSP) pulses [1] may be used instead of standard sinc 180º pulses to provide some immunity to B_1 variations as well as CSL errors. However, simulations show that adiabatic SPSP pulses hit peak RF amplitude limits (approx 17 μT) at a spectral bandwidth of approx 500 Hz, leaving no room to overdrive the pulses. In addition, the increased spectral separation at 7T combined with the limited spectral passband makes the pulses less robust to shifts due to B_0 inhomogeneity. Therefore, we have developed an interleaved [2] narrow-band adiabatic SPSP PRESS sequence that acquires two separate spectral passbands (one for Cho/Cre and a second for NAA) within one TR. Since each pulse now has a narrower bandwidth, greater immunity to B_0 shifts and a higher overdrive factor can be achieved, without an increase in scan time. Each band is acquired using a linear phase SPSP 90º pulse followed by two narrow-band adiabatic SPSP 180º pulses for volume localization. The adiabatic SPSP 180º pulses are adiabatic over a 60% variation in B_1 before hitting peak RF amplitude limits for our 7T magnet. Additionally, there is negligible CSL error since the transmit frequency is centered between Cho and Cre for the first band and on NAA for the second band.

Method: Initially a 24 ms adiabatic hyperbolic secant pulse was designed with a spectral bandwidth of 300Hz (large enough to account for metabolite shifts due to B_0 inhomogeneities). The pulse was then subsampled to the correct number of sublobes chosen for an optimal tradeoff between sidelobe distance and minimum slice thickness. The sidelobes had to be placed at a sufficient distance away from the main passband such that NAA didn't get excited in the first acquisition. The final adiabatic SPSP pulse was comprised of standard sinc subpulses scaled by the sampled values of the adiabatic hyperbolic secant envelope. A linear phase SPSP 90º pulse was also designed to have the same spectral passband. In the final sequence, volume excitation for each interleaved band was achieved by the SPSP 90º degree pulse followed by two adiabatic SPSP 180º pulses. This was repeated within the same TR and the two echoes acquired were from passbands centered on Cho/Cre and NAA respectively. The duration of each interleave was 520 ms and a TR of 3000 ms was used. Figure 1 shows A) the final adiabatic SPSP 180º pulse, B) the spectral profile for the adiabatic SPSP 180º pulse, C) the spatial profile for the adiabatic SPSP 180º pulse and D) the gradient and RF waveforms for the excitation portion of the final interleaved narrow-band adiabatic SPSP PRESS sequence.

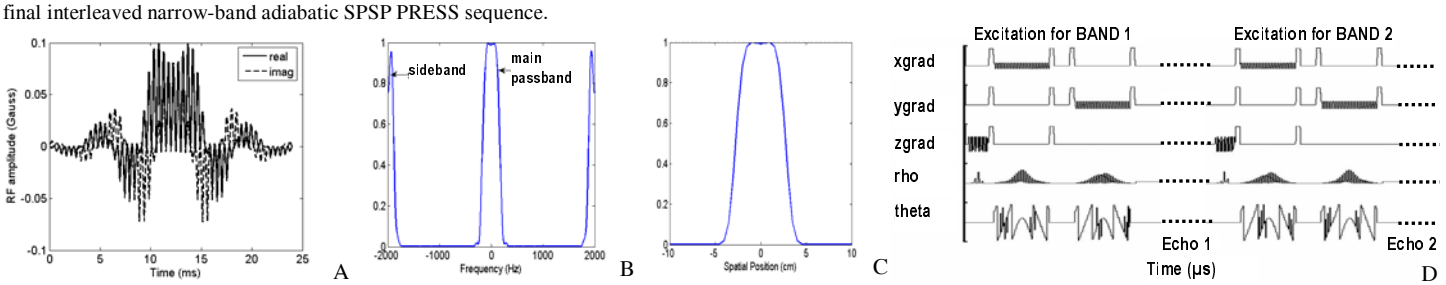

Figure 1: Simulations for 7T adiabatic SPSP 180º pulse: (A) RF waveform, (B) spectral profile, (C) spatial profile and (D) gradient and RF waveforms for interleaved narrowband excitation.

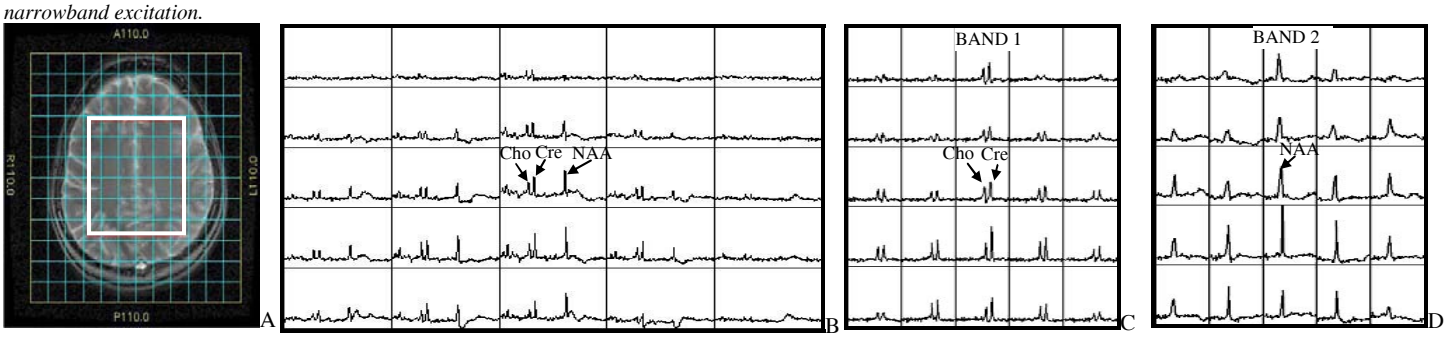

Figure 2: In vivo data from normal volunteer: (A) ROI and PRESS box, (B) spectral grid using standard GE PRESS, (C) spectral grid for Cho & Cre band using adiabatic SPSP 180º pulses, and (D) spectral grid for NAA band using adiabatic SPSP 180º pulses (all spectra are plotted to the same scale).

Results: Refer to Figure 2 for in vivo spectra from the brain of a normal volunteer scanned at 7T (GE Whole Body Magnet) using a standard head coil. Figure 2 A shows the ROI with 3.375 cc voxels within the selected PRESS box. The spatial coverage achieved using a standard GE PRESS sequence (TE/TR = 90/3000 ms) can be seen in the metabolite map shown in Figure 2 B. When the same region is excited with the interleaved narrow-band adiabatic SPSP PRESS sequence (TE/TR= 90/3000 ms), the metabolite map for Cho,Cre and NAA in Figure 2 C & D are obtained (all spectra are plotted to the same scale). It is evident that spatial coverage over regions of varying B_1 has been significantly increased.

Discussion: It can be seen from in vivo data that the interleaved narrow-band adiabatic SPSP sequence provides much better spatial coverage and increased signal even at the isocenter of the coil. In the spectra obtained using the standard PRESS sequence (Figure 2 B), voxels away from the isocenter of the coil have reduced signal overall due to severe B_1 drop off. The interleaved narrow-band sequence provides much more signal in these areas (Figures 2 C & D). The SPSP 90º pulse is still not adiabatic, so some signal loss off isocenter is to be expected. We are currently looking into creating an adiabatic alternative for this pulse. For the standard PRESS sequence (Figure 2 B), voxels in the rightmost region of the PRESS box contain almost no NAA signal due to chemical shift localization error. This is considerably improved in the interleaved narrow-band acquisition (Figures 2 D). The sequence is geared towards imaging three of the main metabolites of interest in the brain (Cho, Cre, NAA). A similar sequence with more interleaves and wider passbands may be explored to capture some of the other metabolites of interest. In the future, we plan to include a fat selective inversion pulse for fat suppression although some fat suppression is provided by the spectral selectivity of SPSP pulses. We are also considering interleaving a third spectral band centered at water to provide a signal for absolute quantification.

References: [1] Conolly S., et al. *Magn Reson Med* 1992 Apr;24(2):302-13. [2] Hirata S, et al. *Magn Reson Med.* 1996 Apr;35(4):611-6.

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