Single-Shot 3D Localized Indirect ^{13}C Detection

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Introduction

Indirect ^{13}C detection has been used in a number of MRS studies to measure metabolic fluxes. The primary advantage of this technique over direct ^{13}C detection is the higher sensitivity of the ^{1}H nucleus. *In-vivo* indirect ^{13}C spectra of three dimensionally localized volumes have been obtained by combining the “Proton Observe Carbon Edit” [1], POCE, technique with the standard localization sequences PRESS, STEAM, and ISIS [2-4]. However, the POCE sequence is a difference method, and thus is susceptible to subtraction errors and motion artifacts. ^{13}C coherences can be detected indirectly in a single scan by using heteronuclear gradient sequences [5]. The gradient-enhanced heteronuclear multiple quantum coherence sequence (ge-HMQC) has been used *in vivo* to obtain indirect ^{13}C spectra of a localized slice in cat brain by making the excitation pulse slice selective [6]. We demonstrate here that in a single scan indirect ^{13}C spectra of 3D volumes can be obtained while suppressing resonances from ^{12}C bonded protons by combining the ge-HMQC technique with the PRESS sequence. Such a technique also exhibits inherent water suppression.

Rationale and Methods

Theory: The pulse sequence is shown in figure 1. At the end of the PRESS localization, there exists in phase transverse proton magnetization in the voxel of interest. The $1/2J_{CH}$ delay (where J_{CH} is the scalar coupling between the ^{1}H and ^{13}C nuclei) followed by the 90° ^{13}C pulse, generates multiple quantum coherence states for protons coupled to ^{13}C nuclei. The ratio of the gradient strengths G_1:G_2 (gradient lengths are equal) determines which coherence pathway is selected for detection, and this coherence state is transformed back to in phase observable proton magnetization by the second ^{13}C 90° pulse and the final $1/2J_{CH}$ delay. Any signal from protons not coupled to ^{13}C nuclei is dephased by the coherence selection gradients ($G_1 \neq G_2$). Note that compared to non-gradient methods, this methodology suffers from a loss in signal by a factor of two [5].

Experimental methods: All experiments were carried out using an 80cm bore, 3T magnet (Magnex Scientific PLC, Abingdon, UK) in conjunction with a SMIS console, a home-built 7cm diameter ^{1}H birdcage r.f. coil, and a 3cm diameter ^{13}C surface coil. The efficacy of the sequence was verified on a 2.7cm diameter spherical phantom containing 10M natural abundance ^{13}C acetic acid, as well as on a similar phantom containing 1M natural abundance ^{13}C glutamate. The pulse sequence was applied as shown in figure 1, with no additional pulses for water suppression. To improve suppression of unwanted resonances the phase of the first 90° ^{13}C pulse as well as that of the receiver was alternated between ±x. All experiments used the following parameters: repetition time = 3s, TE_1=9ms, TE_2 = 8ms, voxel size = 1.0x1.0x1.0 cm^{3}. For the acetic acid phantom $1/2J_{CH}$ = 3.85ms, and for the glutamate phantom it was set to 3.7ms. A ratio of G_1:G_2 of 3:5 [5] was used for coherence selection and these gradients were applied in all three directions with a duration of 1 ms each. The ^{1}H nuclei were ^{13}C decoupled during acquisition using the WALTZ-16 sequence.

Results

Figures 2 and 3 display the results obtained with the phantoms described above. Figure 2a shows the PRESS spectrum of the acetic acid phantom with no ^{13}C editing, while figure 2b shows the result of applying the sequence shown in figure 1, without the decoupling pulses. The efficiency of the sequence in suppressing signal from water as well as from protons bonded to ^{12}C nuclei while maintaining only signal from protons coupled to ^{13}C nuclei is clearly demonstrated. The two satellite proton peaks are ^{13}C decoupled in figure 2c. The efficiency of the sequence is also demonstrated in figure 3, where 3a shows a water suppressed PRESS spectrum of the glutamate phantom, and 3b shows the corresponding ^{13}C edited spectrum. Note for spin systems such as glutamate where the protons exhibit strong homonuclear coupling it is important to minimize the echo times of the PRESS sequence in order to minimize J-evolution during those times.

Conclusion

We have demonstrated that by combining the standard PRESS localization sequence with the ge-HMQC technique, ^{13}C coherences can be detected indirectly from 3D volumes in a single scan while suppressing any resonances from protons not coupled to ^{13}C nuclei.

Figures

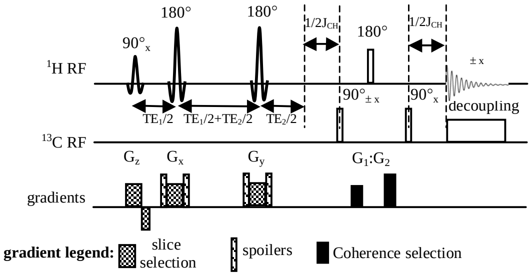

Figure 1: The combined pulse sequence

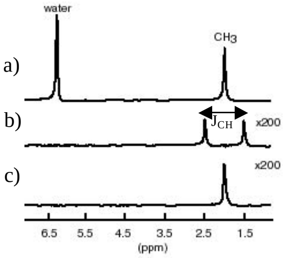

Figure 2: The top spectrum is a PRESS spectrum of the acetic acid phantom. (b) is the spectrum obtained with the sequence shown in figure 1 but without decoupling, showing the two satellite peaks. (c) is the same as (b) but with ^{13}C decoupling. All spectra were acquired in 32 averages.

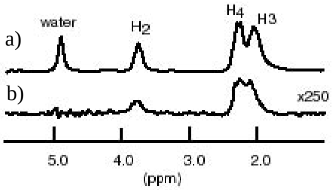

Figure 3: (a) is a water-suppressed PRESS spectrum of the glutamate phantom, 32 averages. (b) is the spectrum obtained with the sequence shown in figure 1, 256 averages.

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