Polarization Transfer for sensitivity-enhanced spectroscopy using a single RF transmit-channel on (clinical) MR systems

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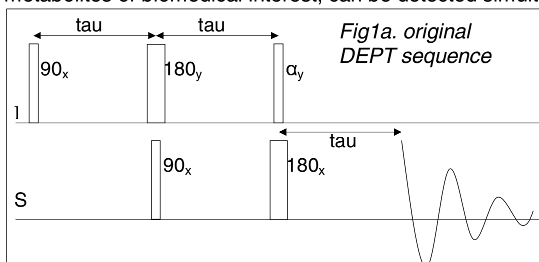
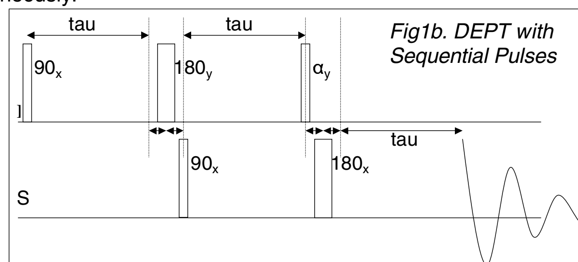
Introduction

Polarization transfer techniques are used to enhance sensitivity and improve localization in multi-nuclear MR spectroscopy, or to transfer magnetization from hyper polarized nuclei nuclei. Clinical MR scanners are in general not equipped with a second transmit RF channel, making conventional polarization transfer techniques like Distortionless Enhanced Polarization Transfer (DEPT) [1] impossible. The problem can be solved by adding a separate RF channel to the MR system that enables simultaneous transmission for two different nuclear spin species (e.g. ^{13}C and ^{1}H) [1]. An additional RF channel is expensive and requires extensive effort to integrate into a clinical MR system, alternatives are required. So far there has only been a single report that enables polarization transfer using a single RF channel implementing an INEPT sequence [2]. Here we present a DEPT sequence using sequential pulses (DEPT-SP) that can be used on a single transmit channel. The great advantage of DEPT over INEPT is that different species with different chemical shifts and J-couplings, which is the case for metabolites of biomedical interest, can be detected simultaneously.

Theory

The DEPT pulse sequence consists of a 90-tau-180-tau-alpha pulse at the I nuclei (e.g. 1H), combined with a 90-tau-180-tau-acquisition at the S nuclei (e.g. ^{13}C) simultaneously (tau = 1/2J) (Figure 1a). The function of the 180˚ pulses is to make the sequence independent of chemical shift differences; therefore applicable to the required broad bandwidths in for instance ^{13}C MRS. Another function of (single nuclei) 180˚ pulses is that it refocuses J modulation as well, which implies that the time delay between the pulses on the same nuclei can be increased once a 180˚ pulse on a single nuclei is put in between. Therefore simply by shifting the timing between the pulses on one nucleus with respect to the other and equally increasing the delay between the pulses on the same nucleus (Figure 1b), one obtains the same functionality as the conventional DEPT sequence.





Materials and Methods

Quantum mechanical simulations were used (Qsim [3]) to verify the performance of DEPT-SP compared to DEPT for sensitivity enhancements, bandwidth behavior, differences in J-couplings and number of bonded nuclei. Measurements were performed on a single transmit channel 3T MR system (Trio, Siemens, Erlangen) to validate the results from the simulation. A homogeneous circularly polarized ^{1}H coil was used combined with a circularly polarized ^{13}C surface coil, optimized for ^{13}C MRS at the human brain [4]. As the ^{13}C coil generates an inhomogeneous B_1 field, a semi-adiabatic version of the DEPT-SP sequence was used (i.e. replacing the 90_x and 180_x pulses of the S nuclei by a BIR4 pulse [5]). Phantom measurements were performed to determine the sensitivity enhancements and bandwidth performance using γB_1 amplitudes of 1500Hz, BIR4 elements of 1ms and switching-times of 100μs. Localized (ISIS) in vivo measurements were performed on a healthy (26 years old) volunteer using either a direct ^{13}C method or the DEPT-SP method (both with broadband (Waltz16) ^{1}H decoupling). Natural abundant ^{13}C MR signals from Myo inositol (Ins) were used as in vivo markers for sensitivity enhancement. Finally another volunteer was measured using the ISIS localized DEPT-SP method during a hyperinsulinemic glucose clamp, using 50% ^{13}C-1 enriched glucose 20%.

Results

No differences were found in the results from simulations between the DEPT and DEPT-SP method. A fourfold sensitivity enhancement (compared to a direct ^{13}C method) can be obtained in phantoms and in vivo by DEPT-SP. At bandwidths of over 100 ppm, the enhancement is 2.5 or better at 3T (i.e. sufficient for ^{13}C MRS measurement of glucose metabolism) using a single transmit channel (Figure 2).

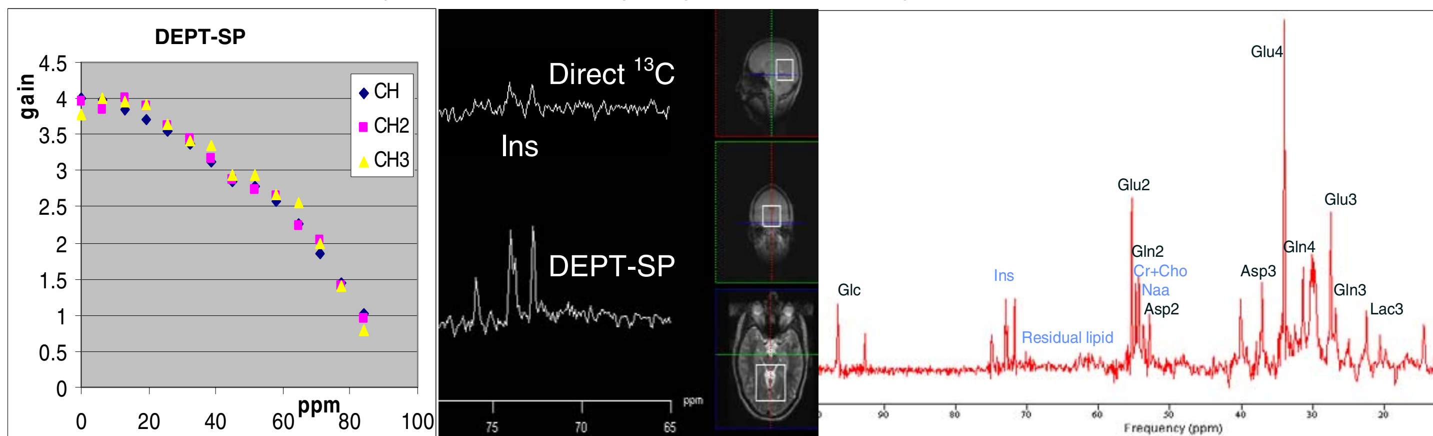


Fig. 2a. frequency profile of DEPT-SP measured in phantoms; b. sensitivity enhancement of naturally abundant ^{13}C Ins signals in vivo; c. ISIS localised in vivo ^{13}C MRS of the human brain at 3T during 50% ^{13}C-1 labelled glucose infusion.

Discussion

Theoretical simulations, phantom measurements and in-vivo results from human brain at 3T demonstrate that apart from a negligible T2 loss, the DEPT-SP method performs equally well as the conventional DEPT method. The results indicate that an independent 2nd RF transmit channel for simultaneous pulsing at different nuclei frequencies is not needed for polarization transfer, facilitating the use of these methods on common clinical systems.

Acknowledgement

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