Efficient ^{1}H to ^{31}P polarization transfer in the human brain on a clinical 3T MR system with a single RF transmit channel

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Introduction

^{31}P MRS has shown clinical potential in following tumor treatments as the signals of ^{31}P spins from phosphocholine (PC), glycerol phosphocholine (GPC), phophoryl elthanolamine (PE) and glycerol phosphoethanolamine (GPE) within tumors at 1.5T correlate with clinical outcome [1]. However, the sensitivity of ^{31}P MRS is relatively low, resulting in long measurement times, relatively large voxels and low SNR. In addition, the availability of ^{31}P MRS is limited in clinical MR systems limiting the assessments of these methods to a small number of institutes.

The sensitivity of ^{31}P MRS can be improved by using the higher clinically available B_0 field strength of 3T. In addition, the use of ^{1}H to ^{31}P polarization transfer can improve the sensitivity even further using for instance a refocused INEPT method. However, for PE, PC, GPE and GPC such a method actually cancels the signals at the traditional ^{1}H inter-pulse timing (TE_{1H}) of $^{1}/_{2J}$ due to J couplings between ^{31}P and ^{1}H that have similar magnitudes for homonuclear J couplings in those metabolites. Even optimization of the TE_{1H} leads to a sensitivity enhancement of less than 50% of the potential enhancement of γ_{1H}/γ_{31P} (i.e. 2.4 fold). A method to cancel the homonuclear J coupling effects in polarization transfer experiments is to apply frequency selective refocusing pulses during spin evolution, which becomes feasible at 3T due to the increased chemical shift dispersion as compared to 1.5T.

In this study, we demonstrated the possibility of applying full ^{1}H to ^{31}P polarization transfer using chemical shift selective refocusing pulses at 3T and quantified the gain in SNR including T1 and T2 effects for PE, PC, GPE and GPC, localized in the human brain. In addition, we have used shifted RF pulses to enable the method on a broadband MR system with a single RF system [2].

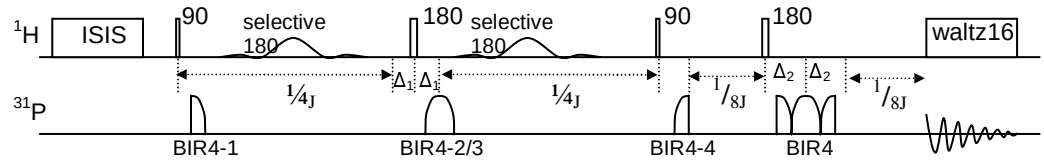

Figure 1: Pulse sequence of refocused INEPT with chemical shift selective refocusing pulses applied on a single transmit channel (pulses are applied sequentially with Δ_1=1.3ms and Δ_2=2.3ms).

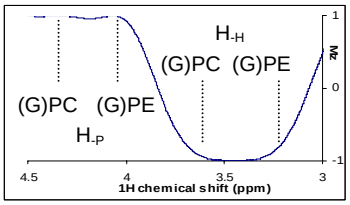

Figure 2: Frequency profile of the selective refocusing pulses

Methods

When no homonuclear J coupling effects are present, a refocused INEPT method can be used for ^{1}H to ^{31}P polarization transfer with a ^{1}H echo time of 80ms (i.e. 1/2J) followed by a ^{31}P echo time of 40ms (i.e. 1/4J, optimized for PE and PC). Within 80 ms, a non-selective ^{1}H refocusing pulse in combination with 2 selective refocusing pulses on the ^{1}H nuclei that have similar J couplings (Fig. 2) is used. In addition, an ISIS localization scheme is added. Adiabatic (BIR4) ^{31}P pulses are employed and a small echo shift is included to allow polarization transfer on a single RF channel [4] (Fig. 1).

The sensitivity of this new method is compared to the conventional refocused INEPT at an optimized ^{1}H echo time of 30ms, localized in the parietal/occipital lobe of 5 healthy volunteers. The T2 of the ^{31}P spins was determined by adding an additional adiabatic refocusing pulse before acquisition and repeating the measurement at different ^{31}P delays (0, 30, 60, 120ms). The T1 of the ^{1}H spins was determined by adding an additional inversion pulse before the ISIS part of the sequence and repeating the measurement at different inversion times (0, 0.5, 1.5, 3s) with a TR of 10s, whereas the T1 of the ^{31}P spins was determined by using a direct (adiabatic) pulse-acquire method including ISIS localization with an additional inversion pulse at inversion times of 0, 1, 3, and 9s with a TR of 20s.

All measurements were performed on a 3T MR system (Siemens, Erlangen) using an optimized coil concept for multi-nuclear MRS of the human brain[3] (volume TxRx ^{1}H coil and a quadrature TxRx surface coil for ^{31}P).

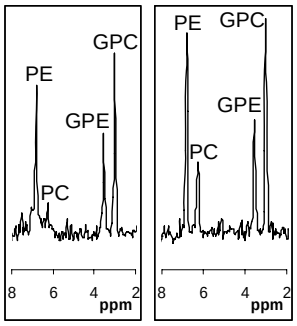

Figure 3: ^{31}P MR spectra obtained with INEPT (a. conventional; b. + selective 180º)

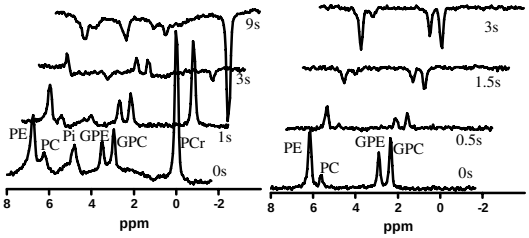

Figure 4: ^{31}P MR spectra localized in the human brain at different inversion times to determine the T1 of either the ^{31}P spins (a) or the ^{1}H spins (b) of the metabolites.

Results and discussion

All ^{1}H to ^{31}P polarization transfer measurements performed with a single transmit channel show resonances of only the coupled spins, all in phase, indicating proper use of shifted RF pulses (Fig. 3 and 4). The sensitivity gain of the refocused INEPT with selective refocusing (TE_{1H}=80ms) is 10 to 60% compared with a conventional INEPT with an optimized TE_{1H} of 30ms (Fig. 3, table I). Compared to direct ^{31}P MRS, the SNR per unit of time of the INEPT methods also benefits from the 4 to 6 fold lower T1 of ^{1}H spins compared to the ^{31}P spins of PE, PC, GPE and GPC (Fig. 4 and table I). Taking into account the gain for using ^{1}H to ^{31}P polarization transfer and including the losses due to T2 relaxation, the overall gain in SNR per unit of time is about twofold as compared to direct ^{31}P pulse acquire methods (table I).

	PE	PC	GPE	GPC
Intrinsic gain conventional INEPT/direct ^{31}P	0.9	0.5	0.8	0.9
Gain selectively refocused INEPT/conventional INEPT	1.3 (±0.04)	1.6 (±0.4)	1.1 (±0.06)	1.1 (±0.08)
T_1 ^{1}H	1.5 (±0.04) s	1.2 (±0.13) s	1.2 (±0.14) s	1.2 (±0.03) s
T_1 ^{31}P	6.7 (±0.5) s	5.3 (±1.4) s	7.8 (±0.9) s	7.0 (±0.5) s
T_2 ^{31}P	263 (±21) ms	263 (±53) ms	147 (±12) ms	171 (±13) ms
SNR Gain selectively Refocused INEPT/direct ^{31}P	**2.6**	**1.6**	**2.2**	**2.4**

Table I: Summary of the results of intrinsic gain comparisons between selectively refocused INEPT, conventional INEPT and direct ^{31}P as well as the T1 and T2 measurements leading to the calculated SNR gain per unit of time.

Conclusion

These results indicate that chemical shift selective pulses can be used to enable ^{1}H to ^{31}P polarization transfer effectively for PC, PE, GPE and GPC. In combination with the shorter T1 values of these metabolites measured at 3T, SNR of ^{31}P MRS is substantially increased when using ^{1}H to ^{31}P polarization transfer. Additionally we have shown that these methods are feasible on a broadband clinical MR system with only a single RF transmit channel, making the increased SNR available on broadband clinical MR systems.

References

[1] Negendank. NMR Biomed 1992;5:303; [2] Klomp et al. NMR Biomed in press; [3] Klomp et al. Magn Reson Med 2006;55:271