In vivo 31P-MRS at 7T by single voxel E-ISIS with GOIA selection pulses

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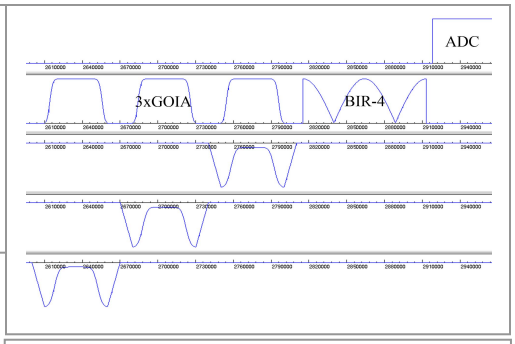
Introduction:

Image Selected In vivo Spectroscopy (ISIS) is a commonly used localization method for 31P-MRS, because it allows efficient detection of 31P metabolites with short T2 relaxation times.[1] At 7T, both T1 and T2 relaxation times of 31P metabolites are significantly shorter than for lower magnetic field strengths.[2] High-field MR systems (i.e. 7T) offer substantial advantages in terms of sensitivity and spectral resolution, as reported for non-localized 31P-MRS. However, for many clinical studies localized MRS is necessary. Only one preliminary study reported using CSI localized 31P-MRS at 7 T.[3] The aim of our study was to develop an ISIS sequence that allows localized 31P-MRS in clinically feasible measurement time (~3-4 min) and good spatial resolution (~2-2.5 cm isotropic).

Fig. 1: illustrates the schematic time table of the designed ISIS sequence with BIR-4 excitation and GOIA-HS(8,4) inversion pulse before ADC readout.



Methods and Materials:

There are four factors that degrade ISIS localization accuracy: First, the use of low-bandwidth selective inversion pulses leads to chemical shift displacement errors (CSDE). Second, susceptibility of the inversion pulses to B1 inhomogeneities may reduce sensitivity and increase contamination. Third, B1 inhomogeneities cause contamination ("T1 smearing") for short repetition times (TR). Forth, short T2 relaxation (i.e. 10ms) during inversion pulses may degrade the localization performance for long inversion pulses and high B1. In this study, the first two issues were overcome by use of gradient offset independent adiabatic (GOIA) inversion pulses with high bandwidth.[4,5] "T1 smearing" was eliminated by special ordering schemes (E-ISIS) and adiabatic excitation.[6] T2 sensitivity of the slice profiles was reduced by application of short inversion pulses with low power requirements as provided by GOIA.

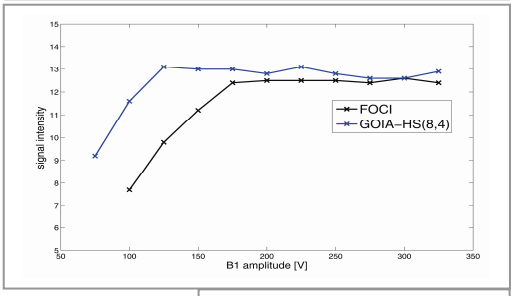


Fig. 2: shows signal intensity of ISIS with a GOIA-HS(8,4) and FOCI pulse for variable B1 (30 kHz, 5 ms, 25 mT/m max. gradient) for 31P at 7T. 5cm distance to surface coil.

Pulse profiles were determined experimentally for a Larmor frequency of 123MHz (1H at 3T Trio, Siemens, Erlangen, Germany). The localization accuracy and contamination of the final ISIS sequence (Fig.1) was investigated using a localization phantom for 120MHz (31P on a 7T system, Siemens, Erlangen, Germany) and a double-tuned surface coil (1H/31P) with a diameter of 10 cm.. The localization was compared to standard ISIS using FOCI pulses for isocenter/offcenter, on-resonance/off-resonance, and variable B1.

The localization phantom consisted of a cubic (3.3x3.3x3.3cm) container inside of a bowl (20cm diameter), both filled with inorganic phosphate (Pi) solution, but with different pH to achieve 3ppm chemical shift. To test the contamination a 3x3x3 cm voxel was placed inside the cubic volume and relative signal contamination from outside was quantified.

The possible spectral quality and reproducibility were explored *in vivo* (brain, muscle). Data of one male healthy volunteer (age 28 y) were acquired at 7T using the surface coil. The right calf of the volunteer was positioned on the coil with the medial head of the right gastrocnemius muscle over the center of the coil. For acquisition of brain spectra the head of the volunteer was placed with the occipital lobe over the center of the coil.

To test the reproducibility of the designed ISIS sequence, 31P-MRS was performed repeatedly in the right calf muscle of the volunteer (~5cm coil distance) with the following sequence parameters: TR = 6 s; TE* = 0.3 ms; spectral width 5000 Hz; 2048 points; 10 ms BIR-4 (cos/sin) excitation pulse; 3 ms HS(8,4)-GOIA pulses; 2.5 cm isotropic resolution; E-ISIS (32 averages + 3 times 6 dummy scans); total measurement time 3:48 min. The volunteer was measured five times within one hour on the same day. Every measurement repetition included full repositioning of the volunteer, shimming, pulse adjustment, and data acquisition.

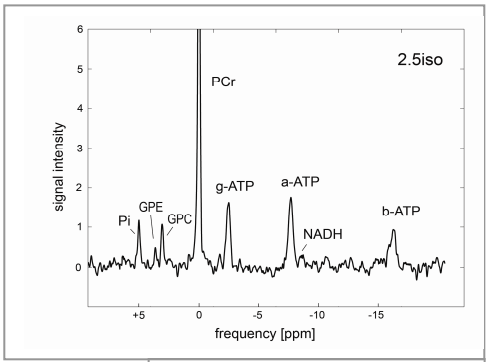


Fig. 3: representative *in vivo* 31P spectrum of a 2.5x2.5x2.5 cm voxel acquired by ISIS in the calf muscle in 3:48 min acquisition time (exp filter).

Results:

The GOIA-HS(8,4) pulses used for ISIS localisation offered excellent slice profiles with high bandwidth (20-40kHz) similar to FOCI but at lower B1 (Fig.2) or shorter pulses (~3 ms) even in 5 cm distance to the surface coil. Large selective gradients (25mT/m) reduced the CSDE to ±1.4mm for the most important metabolites (PME to γ-ATP) independent of voxel size. Contamination tests with TR~1.2T1 revealed ~10-15% contamination for combination of ISIS+rectangular excitation, ~7-9% contamination for ISIS+BIR-4, and ~2-3% contamination for ISIS+BIR-4+E-ISIS schema.

High spectral quality was achieved *in vivo* for small voxel sizes (2.5cm iso) in only 3:48 min measurement time. (Fig. 3) Reproducibility measurements underline the reliability of the spectral quantification of *in vivo* muscle spectra. The determined metabolite ratios were (mean±SD) 0.13±0.02 for Pi/PCr, 0.06±0.01 for PDE/PCr, 0.23±0.02 for γ-ATP/PCr, 0.25±0.02 for α-ATP/PCr, and 0.12±0.01 for β-ATP/PCr.

Discussion and Conclusion:

The designed ISIS sequence offers accurate spatial localization for 31P-MRS with negligible signal contamination even at 7T and in inhomogeneous B1 fields. It can be used in any clinical research, where accurate localization is mandatory (i.e. cancer research) and is even potentially applicable for clinical routine due to its short acquisition time and good reproducibility.

References:

[1] Ordidge RJ, et al. MRM 1986; 66(2):283-294
[2] Bogner et al. MRM 2009; 62:574-582
[3] Lei H, et al. MRM 2003; 49:199-205
[4] Tannus A, et al NMR Biomed 1997 ;10(8) :423-434
[5] Andronesi, et al. ISMRM 2009; #332
[6] Ljungberg M, et al. MRM 2000; 44(4):546-555