Slice Selective Adiabatic Pulse for Human ^{31}P Cardiac Spectroscopy

William T Clarke[1], Christopher T Rodgers[1], Stefan Neubauer[1], and Matthew D Robson[1]
[1]*OCMR, University of Oxford, Oxford, United Kingdom*

Background

^{31}P magnetic resonance spectroscopy (^{31}P-MRS) is an established method for measuring high energy phosphorus metabolites.[1] Successful use of ^{31}P-MRS in Oxford has proven its research value in an extensive range of diseases, but in the clinic ^{31}P-MRS's great promise is largely untapped because the low intrinsic signal ($\gamma_{31P} < \gamma_{1H}$, mM metabolite concentrations and relatively long T_1s) require long acquisitions (>30 minutes) to produce spectra even with a low spatial resolution.

Purpose

Using slice selective adiabatic pulses for surface coils (ASSESS[2]) we can aim to decrease the scan time for ^{31}P-MRS by reducing the number of phase encoded dimensions from 3D to 2D. A spectroscopy CSI sequence takes nT_R intervals where n is the product of the resolution in three dimensions, the number of averages desired and an optional weighting function. The standard oxford 3D CSI cardiac sequence is an acquisition weighted 16x16x8 scan, with 10 averages at the centre of k-space to give acceptable SNR. Thus with a T_R = 1s, a single scan takes 28 minutes.

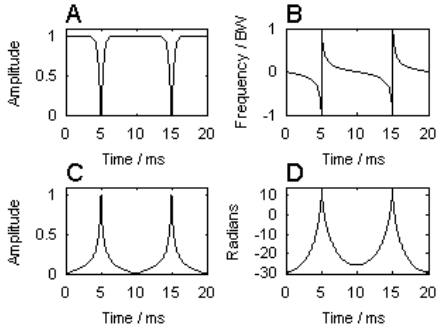

Fig. 1: Tanh/tan modulation functions. A. B_1 Amplitude, B. B_1Frequency, C. Gradient, D. B_1Phase.

Methods

General: Using 'BIR4 type' adiabatic RF pulses, arbitrary flip angle excitation can be created even with much B_1 inhomogeneity. With the addition of modulated gradients 'BIR4 type' pulses can be made slice selective, the gradient modulation function is the magnitude of the frequency function of the RF pulse. The large variation in B_1 created by surface coils causes significant dephasing outside the slice. [3] The upshot is that a slice of magnetisation can be excited, i.e. spatially localising in one dimension, and the slice position is even independent of chemical shift. Thus, only two phase encoding dimensions are required, in the slice plane, and a significant reduction in scan time may be achievable.

Simulations: Solving the Bloch equations numerically in MATLAB (The MathWorks, Inc.) shows that several modulation functions (e.g. tanh/sech, tanh/tan) produce the desired slice selective behaviour. The adiabatic onset limit (minimum B_1 required for <5% error in resultant flip angle) was determined for a range of parameters. The B_1 pattern from the coils was simulated to evaluate which available coils could be used to feasibly run ASSESS at the depth of the interventricular septum of myocardium.

Experimental: Scans were performed using a Trio 3T scanner (Siemens, Germany). In vivo scans were performed using 20ms, tanh/tan, bandwidth = 4000Hz, ASSESS pulse;[4] chosen to minimise the adiabatic onset. For cardiac scans an 8Ch receive array coil with a 20cm transmit loop was used. The CSI matrix was 16x8, 10avg, FOV = 420 x420mm, FA = 45°, T_R = 1.9s. For the calf muscle scans a 10cm loop transmit/receive (T/R) coil was used. The CSI matrix was 8x8, 10avg, FOV = 160 x160mm, FA = 45°, T_R = 8.3s. The total scan time was 8 and 12 minutes respectively. Residual phase roll from the ASSESS excitation was removed from spectra using calculated B_1 maps.

Results

Adiabatic onset B_1 was 400Hz, which was achievable using both the 10cm T/R loop and the 20cm transmit, receive array coil. Implementation was validated in ^{1}H FLASH imaging and ^{31}P CSI phantom experiments (Fig. 2). These experiments showed that the pulse behaves as predicted in simulation and the slice selectivity operates properly in arbitrary orientations and also off-isocentre. Simulations and phantom experiments were carried out to characterise the amount of contamination from extraneous tissue (Fig. 3). In vivo spectra were acquired from 2 volunteers, in both the heart and calf muscle (Fig. 4). Some residual phase roll remains after correction. The method is feasible and yields spectra with an SNR of 37.5 (calf) and 14.22 (heart), and showing all major peaks.

Discussion

ASSESS makes possible a fully localised rapid 2D CSI protocol for ^{31}P-MRS, yielding spectra of acceptable SNR, however the incomplete phase correction makes quantification with standard tools difficult. Time-domain fitting, accounting for residual phase, will be explored. Figure 3 demonstrates that there is a significant decrease in performance at distances, from the coil, of greater than 10cm, i.e. as B_1 approaches the adiabatic onset. The B_1 is limited by hardware and SAR considerations. For cardiac studies ASSESS is a feasible method compared to multi pulse sequences such as semi-LASER, and motion sensitive difference methods such as E-ISIS.

References **1**.Neubauer, S. *NEJM 2007; 11: 1140-1151* **2**.Shen, J., Rothman, D. L. *JMR 1997; 1: 72-79*
3. DeGraaf, R.A. et al *MRM 1996;5:652-657* **4.** Staewen, R. S. et al *Invest Radiol 1990; 5:559-567*

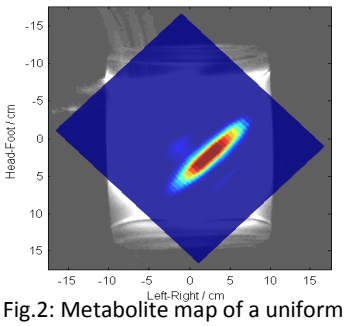

Fig.2: Metabolite map of a uniform ^{31}P containing phantom, showing the implementation of the ASSESS pulse.

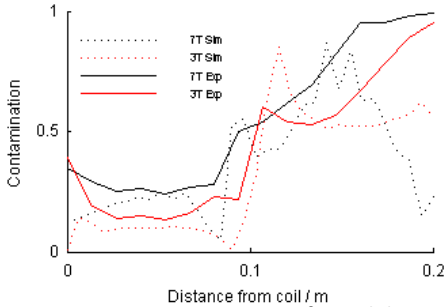

Fig.3: Contamination, ratio of signal detected outside slice to all signal as a function of distance from the coil. Simulated and results from a slice phantom are shown.

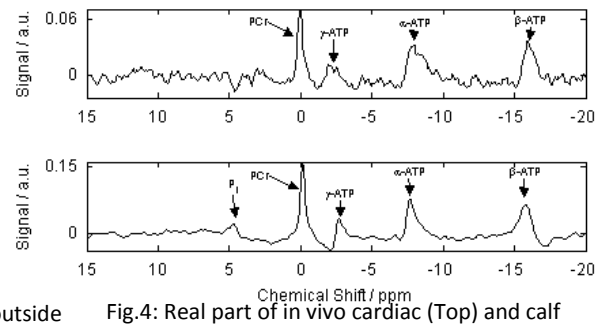

Fig.4: Real part of in vivo cardiac (Top) and calf muscle spectrum (bottom) acquired at 3T, using a 20ms ASSESS pulse.