In vivo large flip angle ^{31}P MRS in the human brain at 3T

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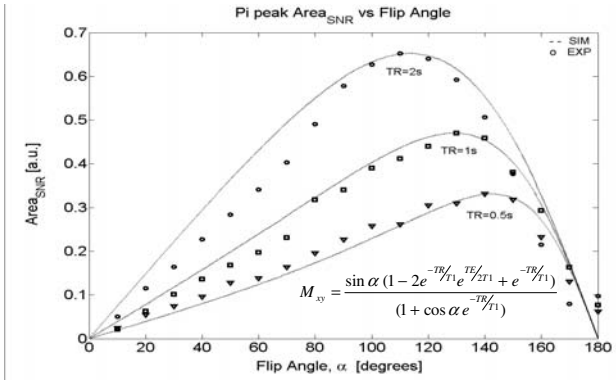
Introduction: In the past ten years, the ^{31}P nucleus has been used on 1.5T systems to study many neuropsychiatric diseases including bipolar disorder. However, the ^{31}P MRS quantitative techniques used are confounded by low signal-to-noise ratio (SNR). These problems result from the inherently low sensitivity of ^{31}P nuclei, low physiological metabolite concentrations, short metabolite T_2 times, and long T_1 times which necessitate long data acquisition times. To address these issues, our approach was to develop a short TR, short TE, large flip angle (LFA) technique at 3T that maximizes the SNR of specific ^{31}P brain metabolites. Large flip angle spin-echo imaging has been known to selectively increase the signal, by as much as 150%[1], of materials that have T_1 times greater than the TR times of the scan. A decrease in TR, by as much as 50%, has also been shown to be possible without loss of SNR[1,2]. LFA MRS uses an α°-180°-echo scheme, such that 180° > α > 90°. Since α is larger than the conventional 90° pulse, after a single 180° refocusing pulse, the alignment of a substantial fraction of the longitudinal component of magnetization with the B_0 field at the end of the TR interval results in increased signal. In this study, the LFA effect is shown in phantom experiments and the three ^{31}P metabolites of interest – phosphocreatine (PCr), phosphorylethanolamine (PE) and phosphocholine (PC) – were measured in vivo with the LFA technique in seven healthy subjects.

Materials & Methods: All experiments were conducted on a GE 3T SIGNA scanner (GE Healthcare, Waukesha, WI) using a dual-tuned ^{1}H-^{31}P head coil (Clinical MR Solutions, Brookfield, WI). The T_1 relaxation time of the inorganic phosphate (P_i) in the GE MRS-sphere was measured, and theoretical predictions of peak intensities and the optimal flip angles at short TR with excitation angles 0-180° were calculated from the equation shown in Figure 1. The P_i peak intensity was then measured experimentally over the same 0-180° range at short TR – P_i peak linewidths were 3-5 Hz. In vivo studies were conducted on seven healthy subjects who gave written informed consent: 3 men and four women, aged 25-55 and weighing 41 - 97 kg (IRB#98-05). The linewidths of the PCr resonance observed were 7 - 10 Hz without Gaussian line broadening. Both phantom and volunteer spectra were acquired from a 240×240×20 mm^3 axial slice, located centrally and above the ventricles respectively. All first- and second- order shim currents were adjusted on water with an automated shim protocol and for each in vivo measurement at TE=11.7 ms, 128 scans were acquired with 4096 data points and a spectral width of 5000 Hz. ^{31}P volunteer spectral data were acquired with the LFA technique for later comparison to their correlates acquired with conventional spin-echo methods. The half spin echoes were summed, reconstructed (Gaussian filtered, Fourier transformed and zero-order phase corrected) and migrated to TDFDFIT[3].

Results & Discussion:

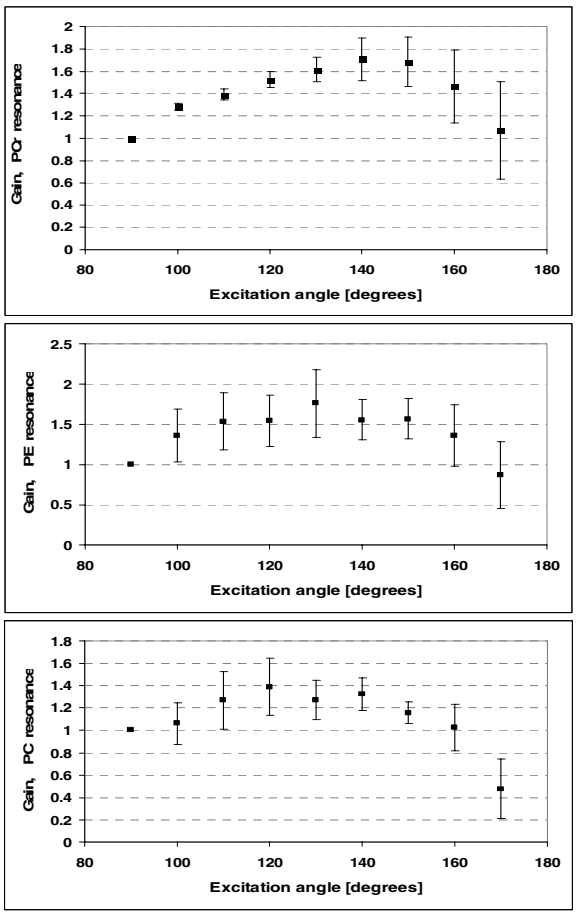
Figure 1 shows good correlation between predicted data and experimental measurements of the LFA effect in the phantom. The excitation angles that maximized the P_i peak area experimentally, 110°, 130° and 140°, were close to those predicted by theory, 113°, 130° and 143° respectively for measurements with TR of 0.5s, 1s and 2s.

Figure 1.



The cell membrane synthesis precursors PE and PC, and the energy-storing moiety PCr, are of particular interest since bipolar subjects typically have decreased levels of PMEs in their temporal[4] and frontal lobes[5] and a deficit of PCr in their frontal lobes[6], as compared to normal subjects. LFA can be used to maximize the SNR of these specific peaks, as depicted in figure 2 where mean signal gain is plotted as a function of excitation angle. Note that PE and PC are maximized with two different flip angles, 130° yielding a signal gain of 1.76±0.42 (mean± std) and 120° yielding a signal gain of 1.39±0.26 respectively. A maximal signal gain of 1.71±0.20 for PCr is achieved with a flip angle of 140°. The optimal flip angle depends on the TR of the sequence and the T_1 of the metabolite, as given by $\alpha=\cos^{-1}(-e^{-TR/T1})$.

Figure 2.



Conclusion:

These in vivo data show that the LFA technique can be employed to maximize the signal of long T_1 ^{31}P metabolites at a given TE and TR.

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