Autotriggering for DNP-polarized in-vivo ^{13}C experiments

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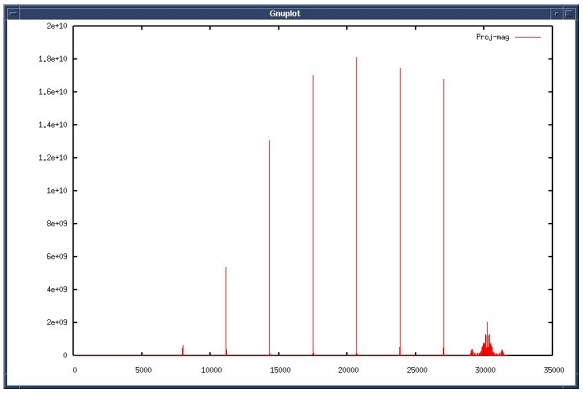
Introduction:
Hyperpolarized ^{13}C labeled pyruvate via DNP has been used to study metabolic processes in-vivo [1, 2]. Recently ^{13}C pyruvate has been used to study cardiac metabolism [3, 4].

In such applications, it is advantageous to know the transit time taken for the hyperpolarized contrast to travel from injection site to the imaging area of interest. This information can then be used to start an imaging sequence such as Chemical-Shift-Imaging (CSI) at a specific time most suited for the desired contrast. It is difficult to predict this transit time because in humans this transit time is dependent on physiological factors such as heart rate, cardiac output, age and pathological factors such as the severity of vascular disease. Usually a dynamic non-localized free induction decay (FID) experiment is needed to glean this information. This is repeated if the physiological conditions change. Here we present a method to gather and plot the FID spectra dynamically in real-time and trigger the imaging sequence at the appropriate delay. This technique is conceptually similar to those used in fluoro-triggered MR angiography [6, 7].

Methods:
All experiments were done on a 3T GE-Signa Excite Scanner (GE Healthcare, Waukesha, WI) using a custom-built ^{13}C/^{1}H rat coil (Magvale, Palo Alto, CA). To simulate an in-vivo experiment, an empty 5ml syringe was placed inside the coil prior to the experiment. A bolus of 3ml/80mM hyperpolarized ^{13}C pyruvate was then injected into the empty syringe over 10s. The ^{13}C imaging pulse sequence was a double spin-echo sequence with small tip excitation, adiabatic refocusing and an echo-planar fly back readout trajectory [5]. This sequence was modified to include a monitoring part of the sequence which generates an FID spectrum every two seconds. The monitoring sequence has the same parameters as the imaging sequence except that the phase encodes were switched off, TR was longer (2 sec) and used a low constant flip angle (2 deg). Further changes were done to quickly switch between the monitoring and the imaging part of the pulse sequence using a real-time sequence prepared (rsp) variable which can be changed easily from the scanner UI. All the data were gathered and stored as they were acquired.

During the monitoring phase, the spectra were calculated from the data acquired and displayed in real-time using Gnuplot. For easy visualization, the latest 10 spectra were plotted in sequence and updated in a sliding-window manner as and when the data is acquired. By default, the operator makes the decision of when to trigger the imaging sequence using the information from the real-time plots. There is also a mode to completely automate this decision.

Results and discussion:
The plotting window showing real-time dynamic spectra is shown in Figure-1. We have used SAGE (GE Healthcare) and MATLAB (The Mathworks Inc, Natick, MA) to analyze both dynamic spectra and imaging (CSI) data. The monitoring sequence was initiated prior to the bolus of hyperpolarized ^{13}C pyruvate, and peak amplitude of the spectra increased as the injection took place. Once the operator triggers the imaging sequence, the 3D CSI imaging sequence was then started after a user-specified delay of 5s. The data from the CSI sequence has been shown overlaid over the proton image in Figure-2.
Fluoro-triggering, in Gadolinium-enhanced MR-angiography, has been demonstrated to be clinically useful [6]. Similarly, the manual triggering mode demonstrated in this study for hyperpolarized ^{13}C tracer gives precise control over the timing of the ^{13}C imaging sequence depending on factors such as bolus amount, injection rate, sequence parameters and the metabolic products we want to study.



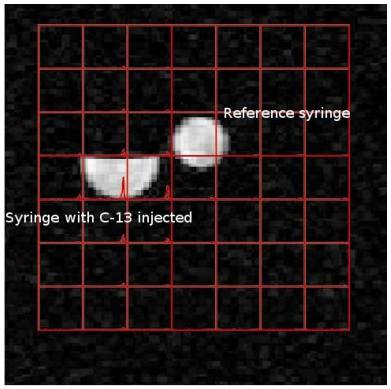


Figure 1 (Left): This shows a screen capture of the realtime plotting window. The plots show the latest 10 spectra placed contiguously from left-to-right, the leftmost 9 were from the monitoring sequence at which point the imaging sequence was triggered yielding the rightmost spectrum.

Figure 2 (Right): This shows the spectra from the CSI sequence overlaid over the proton image showing two syringes one injected with hyperpolarized ^{13}C (left) and the other a reference syringe.

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