Unambiguous detection of cardiac Pi using long TM 31P STEAM

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Synopsis

Inorganic Phosphate is a resonance that holds important information on the metabolic state of tissues. From its resonance frequency, intracellular pH can be derived. The ratio of P_i to PCr or ATP are also important markers. Unlike in other tissues, myocardial P_i is frequently hidden underneath blood DPG signals. Using STEAM's T_M delay to be one cardiac cycle, blood-pool originating signals are gone and the Pi resonance is clearly visible. In 3 subjects, P_i signal was detected and quantified. The signal was around 4.89±0.02ppm, corresponding to a pH of 7.08±0.02. This is a breakthrough for the investigation of cardiac metabolism.

Introduction

Investigating cardiac metabolism and its pathological alterations are essential in understanding various diseases. Cardiac ^{31}P MRS is one of very view techniques capable of measuring metabolic markers in-situ and non-invasively. So far, the inorganic phosphate signal (P_i), commonly found in ^{31}P MRS data has escaped unequivocal detection, so far. The aim of the project is to be able to reliably quantify P_i and hence pH in human subjects at 7 T using ^{31}P MRS. This would increase the value and usefulness of cardiac MRS dramatically. In protocols with short acquisition delay or T_E contributions from blood-pool 2-3 diphospho-glycerate (DPG) signals around 5.5 ppm give rise to overlapping resonances due to imperfect localisation and limited spectral resolution [1]. The STEAM sequence offers two interesting properties: First, 90 deg RF pulses are comparatively easy to achieve, second, the magnetisation during the T_M time is stored along the longitudinal axis where T_1 decay occurs. P_i has a long T_1 of about 5.1 s [2]. Long T_M short T_E STEAM should give rise to signal from myocardium while suppressing fast moving blood.

Methods

A 7 T (Magnetom, Siemens, Germany) STEAM sequence (Figure 1) was adapted to ECG triggering twice, before the first and the third pulse, resulting in an effective TM of one heartbeat. Thereby, a significant fraction of the blood pool has left the voxel before the acquisition. Furthermore, the spoiler gradients during the TE intervals act as motion-sensitising gradients, probably contributing significantly to blood suppression [3]. Unfortunately, the weak B1+ field (16 channel array, RAPID, Germany) requires pulses (4.5 ms truncated sinc shapes) and hence significant chemical shift displacement. This was circumvented using interleaved acquisitions with shifted excitation 0 (PCr) and 570 Hz (Pi) every TR (Figure 1). Effective repetition times for each metabolite were six heart-beats. Healthy subjects were scanned in supine position. Localiser images in the main cardiac orientations were acquired before spectroscopy acquisition. Voxels were placed to cover the septum, dimensions varied between subjects (148±86 ml) (Figure 2). WSVD [4] coil combination was used based on the PCr signal in both scans. Matlab AMARES [5] was used to fit peaks, first the PCr-only spectrum and then Pi, which line widths was constrained to that of PCr. The phase of PCr was used as initial value. This helped the fit converge to reasonable values judged by visual inspection.

Results and Conclusions

Cardiac ^{31}P single voxel spectroscopy has not been attempted at 7 T before, we think. Unlike in UTE-CSI data (Figure 3), 2,3 DPG signal is gone and P_i nicely observable [Figure 4]. Using this approach, PCr and in particular P_i signals were measured quantified in 3 subjects (SNR P_i > 4, SNR PCr > 50), so far. pH values 7.078 ± 0.017 P_i signal is 0.09 ± 0.02 times weaker than PCr, which are very similar values reported in patients with hypertrophic cardiomyopathy [6].

Unlike previous reports, this technique resulted in spectra with P_i clearly visible and without a predominant DPG signal in the 5 ppm spectral area in all subjects after a few minutes' scan time even in healthy subjects with low P_i concentrations and thin myocardia. The chemical shift displacement is really quite strong so even ATP in the PCr scan is significantly affected. The small PCr peak in Figure 4 is a residual originating from some completely different location. This is a significant boost to the utility of cardiac ^{31}P MRS and a new tool for cardiology research.

Acknowledgements

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References

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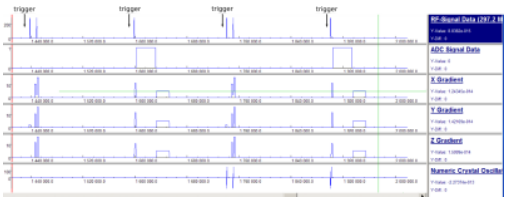
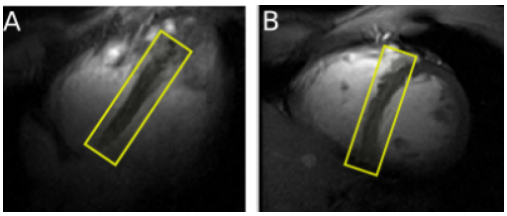
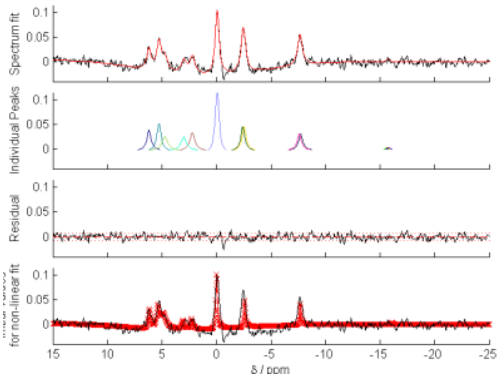
Figures



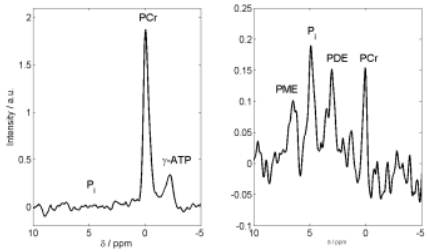
Double-triggered STEAM sequence with interleaved frequency shifts in RF pulses. The timing is set for visualisation purposes only. The sequence waits for the next trigger pulse during T_M before the last excitation.



Short and long axis view showing voxel placement. The volume was chosen to cover most of the septum, taking into account that signal from the ventricles will not contribute.



Typical cardiac ^{31}P spectrum from a 3D CSI pulse-acquire scan from a healthy volunteer at 7T. P_i is barely visible as a shoulder to the 2,3-DPG peak at around 5 ppm.



Spectra from two interleaved acquisitions centred at 0 and 4.8 ppm. The pulse bandwidth is so small that the chemical shift displacement between PCr and P_i is several times the voxel size.