High Resolution Cardiac ^{31}P 2D MRS Using an Actively Decoupled Coil Setup for Metabolic Phenotyping in Mice

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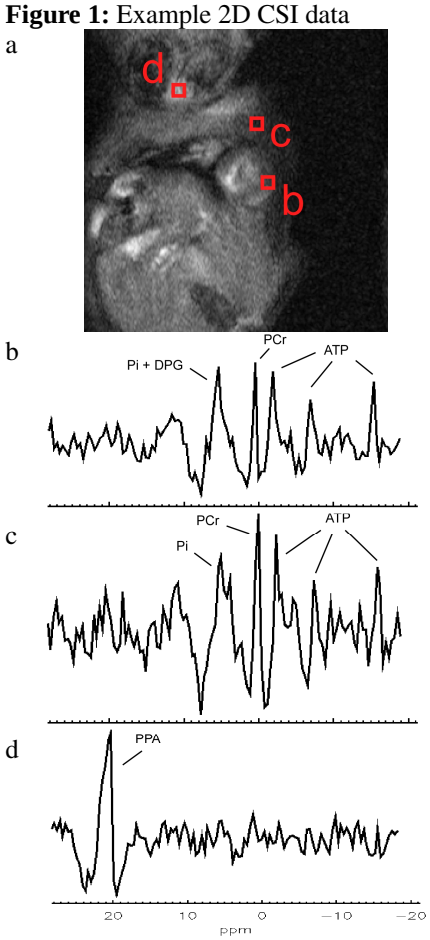
Introduction: Mice have become the predominant species in the study of the molecular basis of cardiac disease. Creatine and phosphocreatine (PCr) levels have been observed to be reduced in heart failure [1]. We, and others, have shown that ATP levels are also reduced in severe heart failure [2]. Magnetic resonance spectroscopy (MRS) allows the opportunity to monitor and quantify cardiac metabolism *in vivo*. Due to the small size of the mouse heart, the low metabolite concentrations involved and the low MR sensitivity, *in vivo* ^{31}P MRS is technically demanding. Only a few studies have employed chemical shift imaging (CSI) in the mouse heart using either a surface coil and 1D CSI, [3-5] or a volume coil and 2D CSI [6]. Here we present pilot data showing that spatial resolution at acceptable scan times can be substantially improved by using a volume Tx/surface Rx setup.

Methods: MR experiments were carried out on a 9.4 T/210 mm bore Magnex magnet with a Varian direct drive console (JNMRS, Varian Inc., USA). An actively decoupled variable tune/match 14 mm diameter ^{31}P surface coil was purpose built in house and used in conjunction with a double tuned ^{1}H/^{31}P volume resonator (Rapid Biomedical, Germany) for acquisition. Shimming and scouting were carried out using the ^{1}H channel of the volume coil. A removable 4 mm point sphere filled with 15 M H_3PO_4 was placed outside the animal cradle to allow accurate and rapid pulse calibration using an unlocalized one pulse experiment. A 200 mM pyrophosphonic acid (PPA) sample was included in the cradle to facilitate later signal quantification. 2D CSI data were acquired for five mice in short axis orientation using acquisition weighting (Hanning) with an in plane voxel size of 1.1 x 1.1 mm (nominal resolution 1.9 x 1.9 mm, 27 x 27 PE steps) before zero filling in a 30 x 30 mm field of view, slice thickness of 4-12 mm with 16407 scans in total. Acquisitions were cardiac gated and a TR of ~250 ms (two cardiac cycles) was used with a 30° flip angle. Total scan time for the experiment was approximately 1 h 10 min. Multi slice ^{1}H anatomical images covering the field of view of the CSI experiment were acquired to confirm the position and tissue content of the CSI voxels. Data were fitted using AMARES [7].

Figure 1: Example 2D CSI data



Results: Figure 1 shows (a) an example ^{1}H anatomical image from a multi slice stack with CSI voxel positions indicated for (b) myocardium, (c) skeletal muscle and (d) PPA sample; associated spectra are shown (fig 1b-d). Differences can be seen between skeletal and myocardial ^{31}P spectra with myocardial voxels yielding a PCr/βATP ratio (± SD, N=5) of 2.0 ± 0.37 and skeletal muscle 2.8 ± 0.57 after correction for partial saturation. ATP, PCr, inorganic phosphate (Pi) and diphosphoglycerate (DPG) resonances are well resolved. Clear spectra were also observed for the PPA concentration reference sample (fig 1d).

Discussion & Conclusions: Through the use of an actively decoupled surface coil, it is possible to acquire higher spectral and spatial resolution ^{31}P spectra in the beating mouse heart *in vivo* within a physiologically acceptable time frame. Placing the H_3PO_4 sphere outside the animal cradle permits its removal prior to CSI data acquisition without disturbing the position of the animal. The CSI data are acquired in short axis orientation covering the approximately cylindrical region of the left ventricle. In this orientation each voxel projects along the full length of the myocardium and not into neighbouring tissues thereby reducing signal contamination of myocardial voxels whilst maximizing signal from the heart. By using 3D Tx and Rx B1 maps it will be possible to quantitatively map high energy phosphate metabolism. These tools will allow a more in depth study of myocardial high energy phosphate metabolism and its correlation with pathology in the failing heart.

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