In vivo T1 Mapping of ^{31}P Metabolites at Short TR

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Introduction: We, and others, have observed that creatine, phosphocreatine (PCr) and ATP levels are reduced in severe heart failure [1,2]. A better understanding of the energetics of the failing heart requires a quantitative measure of PCr and ATP levels in the myocardium. We have previously shown that high spatial and spectral resolution ^{31}P chemical shift images can be acquired in the beating mouse heart in the context of a recovery experiment [3]. The direct measurement of the levels of phosphocreatine (PCr) and ATP in the myocardium allows tissue metabolism to be directly monitored and, potentially, quantified absolutely. However, the low metabolite concentration, and the need for high spatial resolution necessitate the acquisition of a large number of averages. In conjunction with the limited time available in the recovery experiment, a TR substantially shorter than the T1 relaxation times of the metabolites has to be employed. Therefore, quantitation of such measurements relies on knowing the T1 of the nuclei involved in each tissue in order to account for any partial saturation effects arising from the short TR. Here we present an investigation into the optimal parameters required to accurately map T1 at short TR/T1 (<0.25), which can then be employed *in vivo* within a recovery experiment. **Methods:** MR experiments were carried out on a 9.4 T/210 mm bore Magnex magnet with a Varian direct drive console (Varian Inc, USA). Phantom experiments were conducted using a double tuned ^{1}H/^{31}P volume resonator (Rapid Biomedical, Germany) for both transmit and receive. For *in vivo* experiments, an actively decoupled variable tune/match 14 mm diameter ^{31}P surface coil was used for receive in conjunction with the same volume resonator for transmit. 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 enabled pulse calibration using an unlocalized pulse-acquire experiment. For phantom experiments, 200 mM NaH_2PO_4 was placed in a 14 mm sphere and 2D CSI acquisition weighted data acquired with a voxel size of 2.3 x 2.3 x 8 mm (nominal resolution 3.75 x 3.75 x 8 mm, 13x13 PE steps, 2050 averages in total). Similar data were acquired *in vivo* in the mouse in short axis orientation using cardiac gating, voxel size 2.3 x 2.3 x 4 mm (nominal resolution 3.75 x 3.75 x 4 mm, 13x13 PE steps, 8191 averages in total) and TR ~250 ms (2 cardiac cycles). **Results:** Dual angle T1 measurement was compared against 3 and 4 angle measurement to test the performance of the dual angle method at the lower signal-to-noise ratio (SNR) and the low TR/T1 values employed in high resolution ^{31}P CSI (TR/T1 ~ 0.1) [4,5]. Example T1 maps are shown (Figure 1).

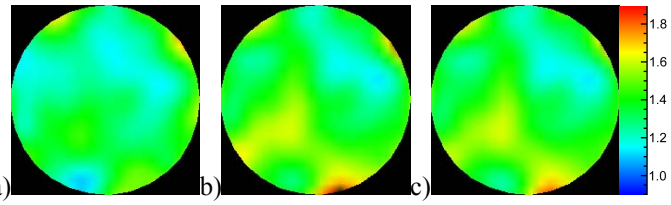

Fig 1. T1 maps of a homogeneous phantom acquired using (a) 4, (b) 3 and (c) 2 flip angles. T1 values were 1.30±0.10 s, 1.39±0.12 s and 1.37±0.12 s respectively. The T1 value as determined using an inversion recovery experiment was 1.42 s.

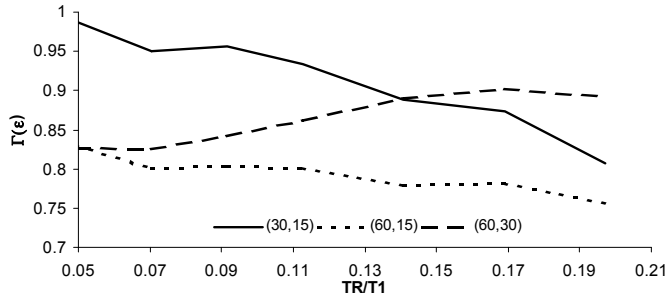

Fig 2. Example net SNR of two CSI experiments conducted using flip angles α and β relative to a pair of Ernst angle, ε, acquisitions (Γ(ε)), where Γ(ε) = [S(α) + S(β)]/[2 x S(ε)]. α and β are indicated. ε varied between 17.8 and 34.8˚.

In phantom studies, the dual angle method remained accurate even at TR/T1 = 0.09 yielding an approximately uniform T1 map. Γ(ε) (defined in Figure 2) was measured to determine a combination of flip angles, which would yield an optimal SNR at low TR/T1 (Figure 2). A combination of 15 and 30˚ flip angles yielded the highest Γ(ε) value at very low TR/T1. Therefore, 15 and 30˚ flip angles were applied *in vivo* in the mouse and the resulting ^{31}P spectra fitted using jMRUI [6]. For PCr in skeletal muscle, a T1 value of 3.14±0.16 s was observed and work is in progress to extend this method to the heart.

Discussion & Conclusions:

It is possible to accurately map T1 *in vivo* in order to determine tissue specific T1 values of high energy metabolites using the dual angle method. 60 and 15˚ flip angles have been proposed for acquisitions with 0.1 < TR/T1 < 1.0 [4], however for TR/T1 < 0.2 lower flip angle pairs are beneficial. It has also been observed that low flip angles render S(α)/S(β) more sensitive to changes in T1 at low TR/T1 [4], but also leaves the T1 measurement more sensitive to errors in flip angle calibration. With the use high resolution B1 maps, it should be possible to further refine the technique by accurately calibrating the flip angle on a voxel by voxel basis. Accurate T1 values enable the quantitative interrogation of energy metabolism in the failing mouse heart whilst being able to recover the mouse for further study.

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References:

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