Continuous Saturation Correction in the Presence of Changing Metabolite Concentrations

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INTRODUCTION : Quantitative phosphorus (^{31}P) spectra are usually acquired with a short repetition time and multiple averages. The acquired spectra are then corrected for the effects of saturation, either empirically, using saturation factors calculated through the acquisition of an unsaturated spectrum, or theoretically, using the flip angle, TR and T_1 values. Both of these methods are inaccurate if the 'effective' T_1 values of the metabolites change through the course of the experiment[1], as may occur during ischaemia-reperfusion in an isolated perfused heart due to changing metabolite concentrations. To correct for T_1 value errors, we have implemented a protocol that allows continuous monitoring of metabolite T_1 values using the 'dual-angle' method[2], as suggested by Bottomley *et al* to correct for saturation in the presence of changes in the 'effective' T_1 values, without any increase in the experimental time.

METHODS : All experiments were conducted on an 11.7 T (500 MHz) MR system comprising a vertical magnet (Magnex Scientific, Oxford, UK) and a Bruker Avance console (Bruker Medical, Ettlingen, Germany). A birdcage coil with an inner diameter of 20 mm (Rapid Biomedical, Wurzburg, Germany) was used to transmit/receive the NMR signals. All investigations conformed to Home Office Guidance on the Operation of the Animals (Scientific Procedures) Act, 1986 (HMSO) and to institutional guidelines. Male Wistar rats (n = 5, BW = 332 ±9g) were anasthetised and their hearts excised and perfused in Langendorff mode with Krebs Henseleit buffer (11 mM glucose, 4.5 mM pyruvate, 0.5 mM lactate). After shimming, tuning & matching and flip angle calibration, alternate spectra were acquired with flip angles of 15° and 60° (TR 0.25s, 240 averages) every minute for 60 minutes. Normal perfusion (20 min) was followed by 20 min low-flow (0.5 ml.gwwt^{-1}.min^{-1}) ischaemia and 20 min reperfusion. Spectra were fitted in the time-domain using the AMARES algorithm within jMRUI[3], fitting for PCr, P_i, ATP and PPA (phenylphosphoric acid, a reference standard, doped with gadolinium). Individual metabolite T_1 measurements were calculated from the alternating spectra, using the 'dual-angle' method. After correction for the effects of saturation, the peak amplitudes were used to calculate the individual metabolite concentrations with reference to the signal from the PPA in the centre of the coil.

RESULTS : Figure 1 (right) shows an example spectrum, detailing the peaks from PPA, P_i, PCr and ATP. Figure 2 (below) shows the variation in the raw signal intensities, calculated T_1 values and corrected signal intensities of the PCr peak over time for one typical heart. Periodic variations in the raw intensities can be seen due to the dual-angle method, which are completely removed in the corrected signals.

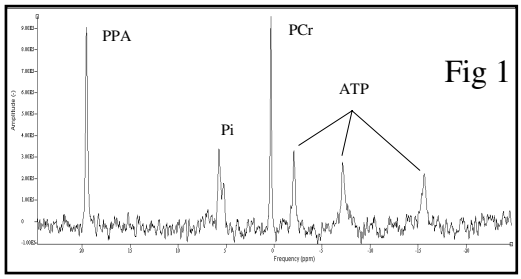

Fig 1

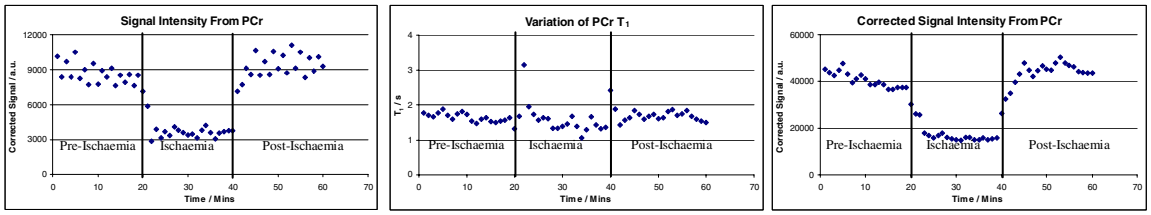

Fig 2

Figure 3 (right) shows the average T_1 values and concentrations obtained during normal perfusion, low-flow ischaemia and reperfusion. An increase of ~75% in the T_1 of P_i can be seen during ischaemia, associated with a 5-fold increase in concentration. All other metabolites showed little or no change in T_1 values, although there was a considerable drop in PCr concentration during ischaemia.

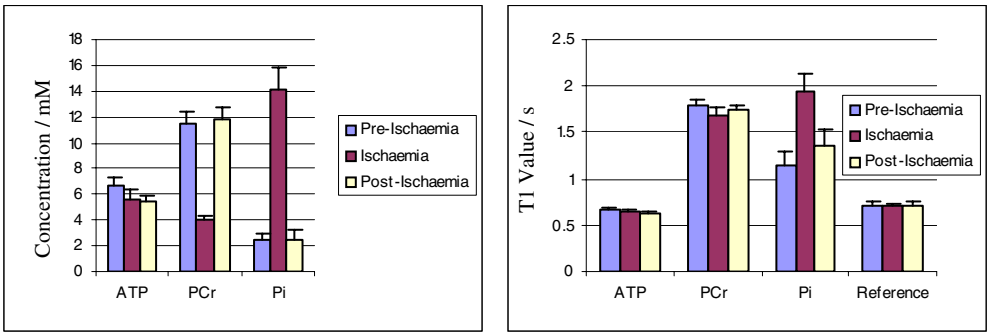

Fig 3

DISCUSSION AND CONCLUSION : We have demonstrated the feasibility of performing continual T_1 measurements to allow correction of saturation effects. The experiments were performed in the same time as a usual spectroscopic study, which would have required prior knowledge of T_1 values or the lengthy acquisition of a fully relaxed spectrum.

REFERENCES : [1]Ouwerkerk R, Bottomley, PA. Journal of Magnetic Resonance, 148:425-435 (2001)
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[3]Vanhamme L, *et al*. Journal of Magnetic Resonance 129:35-43 (1997)