Human cardiac ^{31}P magnetic resonance spectroscopy at 7 Tesla

Christopher T. Rodgers[1], William T. Clarke[1], Carl Snyder[2], J. Thomas Vaughan[2], Stefan Neubauer[1], and Matthew D. Robson[1]
[1]*Univ Oxford, Oxford, United Kingdom,* [2]*CMRR, Univ Minnesota, Minneapolis, MN, United States*

Purpose: Cardiac ^{31}P spectroscopy (^{31}P-MRS) has provided unique insight into the supply of energy in the heart. Yet, clinical applications of cardiac ^{31}P-MRS have been hampered by the technique's low signal-to-noise ratio (SNR). Theory predicts that the SNR will increase approximately linearly with field strength B_0. This could permit a reduction in scan times allowing the study of dynamic processes, or could give sufficient spatial resolution to study focal disease or could make visible metabolites that cannot be detected at lower fields, such as inorganic phosphate. With the growing popularity of 7T cardiac magnetic resonance, it is timely to give a proof-of-principle for 7T human cardiac ^{31}P-MRS and test its performance relative to 3T.

Methods: Experiments used a Trio 3T scanner (Siemens, Germany) equipped with a 10cm ^{31}P Tx/Rx loop coil (PulseTeq, UK) and a Magnetom 7T scanner (Siemens, Germany) with a purpose-built 10cm ^{31}P Tx/Rx loop coil having the same subject–coil distance as the 3T coil. Both coils had a ^{31}P fiducial and position markers.

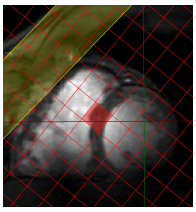

Fig. 1: 7T CINE FLASH image showing the mid-septal voxel chosen for analysis. The yellow band denotes BISTRO saturation.

Safety tests were performed at 7T on a meat phantom using fibre-optic temperature probes (Neoptix, UK) to determine power deposition.[1] A 3D UTE-CSI protocol[2] in established use at 3T was adapted to conform with the limits on peak B_1^+ and SAR at 7T. The principal changes were to use a 5 pulse BISTRO-style saturation scheme to suppress skeletal muscle signal effectively at 3T and 7T. At 7T, we reduced the excitation pulse[2] duration to still cover metabolites from 2,3-BPG to β-ATP, we localized with CINE FLASH images using a separate ^{1}H coil before swapping to the ^{31}P loop, and we used ^{31}P-FLASH projection images of ^{31}P-containing markers to locate the ^{31}P coil during post-processing for flip angle calculation and saturation correction. NOE enhancement was not used at 3T or 7T.

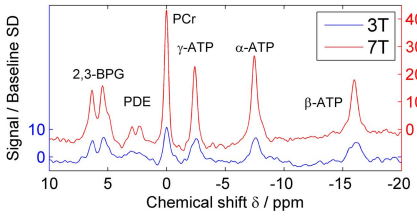

Fig. 2: Spectra from the same subject at 3T and 7T. Spectra are phase corrected, filtered with an exponential matched to the PCr signal and normalised to the baseline standard deviation.

Phantom experiments tested the accuracy of coil position and B_1 calculations, and optimised the saturation band pulse scheme. T_1 values for saturation correction at 7T were measured in a pilot experiment on 6 normal volunteers using a novel Look-Locker IR 3D CSI pulse sequence with adiabatic inversion. The acquired FIDs were fitted simultaneously to a Bloch simulation to extract T_1s (details in Robson's abstract).

Field strength B_0	3 T	7 T
PCr SNR	11 ± 3	31 ± 13
PCr SNR (90°, TR >> T1)	44 ± 15	105 ± 45
PCr Amplitude CV / %	3 ± 1	0.7 ± 0.3
Linewidth / Hz	16 ± 2	37 ± 11
Corrected PCr/ATP	1.5 ± 0.4	1.8 ± 0.2
Flip angle	20 ± 9	20 ± 5

Table 1: ^{31}P-MRS performance studied in 9 volunteers.

The field strength comparison was then made as a paired study with 9 normal volunteers. ^{31}P spectra were recorded from a 16x16x8 matrix with 15x15x25 mm^3 nominal voxel size using acquisition weighting with 10 averages at k=0, with a 1s TR. Subjects were scanned supine to allow coil exchange at 7T. The ^{31}P coil was adjusted for each subject using an RF Sweeper (Morris Instruments Inc., Canada) in the magnet room. At 7T, excitation was at full power and the FAs in the septum at 3T were matched to 7T by calculating the correct voltage before starting the CSI acquisition. A voxel from the centre of the septum (Fig. 1) was selected in each subject for analysis by fitting with AMARES for 11 peaks (ATP, PCr, PDE and 2,3-BPG), before correcting for partial saturation and for blood contamination to yield the PCr/ATP ratio. SNR was calculated after application of a matched filter.[3]

Results: Fig. 2 shows ^{31}P spectra acquired from the interventricular septum of the same subject at 3T and at 7T. It is apparent that there is a significant increase in signal quality at 7T, evidenced by the 2.8x increase in PCr SNR and the 4.3x decrease in Cramer-Ráo lower bounds on PCr concentration. The PCr/ATP ratio has smaller SD at 7T, but the mean does not differ significantly (P=0.48).

Discussion: The PCr SNR in Table 1 has ~30% SD at both fields, which reflects the challenge of positioning a surface coil and anatomical variations in the heart–surface distance. At 7T, we also observed a 2.3x increase in linewidth and an increase in the linewidth SD. Future studies using a more sophisticated coil geometry and subject-specific B_0 shimming should therefore improve still further on the already substantially higher quality ^{31}P spectra obtainable at 7T.

Conclusion: Cardiac ^{31}P-MRS at 7T shows great potential and will soon become the field strength of choice for clinical applications.

References: 1. El-Sharkawy AM *et al. Magn. Reson. Med.* **61** (2009). 2. Tyler *et al*. *NMR Biomed.* **21**, (2008). 3. Ernst, Bodenhausen & Wokaun. *Principles of nuclear magnetic resonance in one and two dimensions*. (Clarendon Press, 1987).

Acknowledgements: We thank P.A. Bottomley and D.J. Tyler for helpful discussions. Funded by the NIHR Oxford Biomedical Research Centre; the Medical Research Council (UK); Merton College; the Royal Society and Wellcome Trust [098436/Z/12/Z].