Reproducibility of cardiac 31P MRS at 7 T

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Synopsis

Cardiac PCr/ATP ratios measured by ^{31}P MRS change in cardiovascular disease giving them value as a biomarker. We scanned 13 healthy volunteers at 7T, assessing their PCr/ATP with 6 ½ min ^{31}P CSI scans. These data have better reproducibility than a 30min 3T protocol previously published by our centre. Repeated PCr/ATP measurements from subjects in this study were not significantly (P=0.83) different. Measurements were significantly different (P<0.001) from DCM patient data acquired in a previous 7T study using the same coil and pulse sequence. This data will allow us to plan future 7T ^{31}P-MRS clinical studies.

Purpose

In most major heart diseases the ratio of phosphocreatine (PCr) to adenosine triphosphate (ATP) concentrations ("PCr/ATP") changes, making PCr/ATP a useful indicator of energetic state of the heart.[1,2]

However, ^{31}P MRS has historically been limited by its intrinsically low SNR. Work by Rodgers *et al*[3] showed an increase in SNR by 2.3x at 7T compared to 3T. Additionally, the SNR of 7T ^{31}P spectra can be further increased with per-subject B_0 shimming.[4] The purpose of this work was to:

(i) assess the reproducibility of PCr/ATP measurements using 7T ^{31}P MRS in the human heart; and

(i) confirm that the observed improved spectral quality using the optimised "custom" B_0 shimming does not incur a penalty in the reproducibility of measurements.

This will provide data needed for power calculations to design clinical studies.

Methods

Data acquisition: 13 healthy volunteers (11M/2F, age 29±8yrs, BMI 22.1±3.0 kg/m^2) were recruited according to local regulations. Scans were performed on a Magnetom 7T MRI scanner (Siemens). Localiser images were acquired using a 10cm loop coil (Rapid Biomedical) and ^{31}P spectra were acquired with a 16-element ^{31}P array[5] (Rapid Biomedical). Subjects were scanned supine to facilitate coil swapping and for comfort.

Scan protocol: After localisation, two iterations of optimised B_0 shimming (starting from the vendor's default, "tune-up", shim) were performed as described previously.[4] 3 sets of ^{31}P spectra were then acquired in 6 ½ min each with a 3D UTE-CSI sequence, 8x16x8 matrix and WSVD coil combination.[10] The first and third data-sets used our optimised "custom" B_0 shim; the second used the vendor's default "tune up" shim. Subjects were then removed from the magnet. This constituted 'session 1'. For 6 subjects (4M/2F), the above was repeated ('session 2') after a short (~5min) break. The other 7 subjects only did 'session 1'. Data-sets were labelled A-F (see fig. 1 for description).

Data analysis Data were fitted using the Oxford Spectroscopy Analysis (OXSA) toolbox.[6] Prior knowledge specified 11 Lorentzian peaks, fixed amplitude ratios, and literature values for the scalar couplings for the multiplets. Blood contamination and partial saturation was then corrected using literature T_1 values.[3,7]

Assessment of reproducibility

Inter-session variability was assessed by comparison of PCr/ATP ratios from equivalent data-sets in both sessions for each subject. i.e. by comparing data-set B with E, and comparing data-set C with F.

Inter-subject variability was assessed by the mean and standard deviation of PCr/ATP ratios within the same data-sets across all subjects.

Intra-session variability was assessed by comparison of PCr/ATP ratios from equivalent data-sets within the same session. i.e. by comparison of data-set A with C and data-set D with F.

The coefficient of repeatability (CR) was calculated according to Bland and Altman.[8] We compared to our previous results from a 28 min protocol with the same hardware in 25 DCM patients.[9]

Results

The custom optimised shim sequence reduced the mean linewidth of the 2,3-DPG and γATP peaks (fig. 2). It also improved the repeatability of inter-session measurements (coefficient of repeatability was only 0.43 for custom shim vs. 0.70 for tune-up, fig 3).

There was no significance difference (P=0.83 for "tune-up" shim, P=0.54 for "custom shim") in PCr/ATP ratios in the same subjects between sessions. PCr/ATP ratios measured in this work were significantly different (P<0.001) to those measured in 25 DCM patients with the same hardware[9] (fig. 4).

Discussion

Good reproducibility of cardiac ^{31}P MRS has previously been reported at 3T.[7] This 7T study acquired data-sets in approximately 1/5th of the time of that 3T study. The CR between inter-session measurements was reduced in this work (CR 0.43 7T vs 1.1 3T), suggesting spectra can be acquired quicker without cost to reproducibility. Ability to acquire ^{31}P spectra quickly is important as it allows more detailed study of the response cardiac energetics to stressors, such as exercise or dobutamine infusion.

Intra-session variability shows the 'best-case' reproducibility – any differences in PCr/ATP are due to the 31P acquisition. The inter-session variability was not larger than the intra-session (CR 0.43 vs 0.80) – this means the differences between data-sets are not due to the 'set-up' of the san (e.g coil positioning, localisers).

PCr/ATP ratios were consistent with literature values[3] , and – as expected – there was no significant difference in mean PCr/ATP measurements between sessions.

Conclusion

We acquired cardiac ^{31}P MRS spectra at 7T with improved reproducibility to previously reported 3T measurements,[7] and in 1/5th of the time. Optimised B_0 shimming improved spectral quality without incurring a penalty on measurement reproducibility: it is therefore recommended for use in future cardiac studies.

Acknowledgements

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References

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Figures

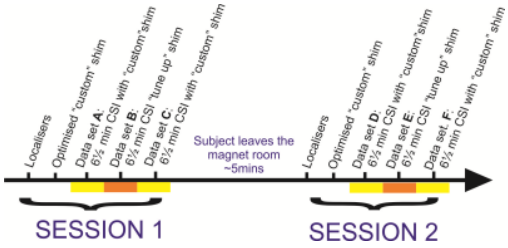

Figure 1 Study protocol. A 'session' was defined as a series of consective sequences, acquired without the patient leaving the magnet. 'Data set' refers to a single 6 ½ min CSI sequence acquired within a visit.

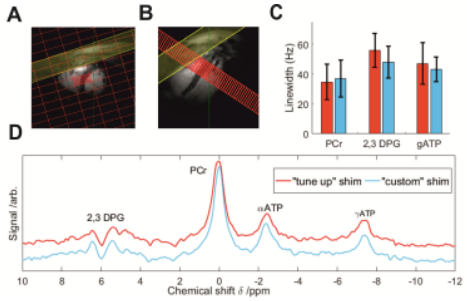

Figure 2 A,B: Orientation of the CSI matrix showing the rotation of the grid and the target voxel (pink shaded) in the central septum. The position of the saturation bands (yellow) were adjusted to cover the chest wall, minimising skeletal muscle contamination. **C** linewidths (mean ± inter-subject SD) for "custom" (blue) and tune-up (red) shim settings **D** cardiac spectra from one subject with "custom" (blue) and tune-up shims (red). N.B spectra have been vertically offset for clarity.

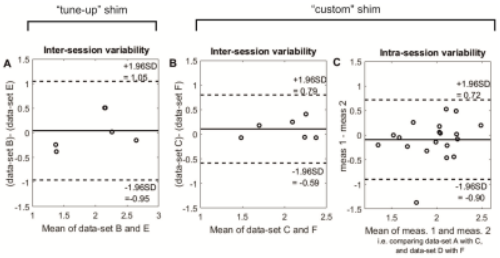

Figure 3 Bland-Altman plots of variability in PCr/ATP for **A** inter-session comparison using tune-up shim (bias 0.04, CR 0.70), **B** inter-session comparison using "custom" shim (bias 0.11, CR 0.43), and **C** intra-session variability using "custom" shim (bias -0.09, CR 0.80). Solid lines show the bias, dashed lines mark ±1.96SD. NB: CR is the coefficient of repeatability, defined by Bland and Altman as “the value below which the absolute difference between two repeated test results may be expected to lie with a probability of 95%”.

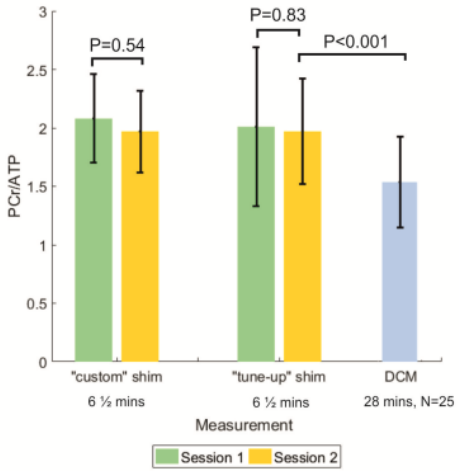

Figure 4 inter-subject PCr/ATP (mean± SD) for both sessions using the custom and tune-up shims. Blue bar shows mean±SD PCr/ATP for 25 DCM patients (DCM data are from ref. 9)