^{31}P Cardiac Magnetic Resonance Spectroscopy During Leg Exercise at 3 Tesla in Healthy Volunteers

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Introduction: The use of phosphorus (^{31}P) Magnetic Resonance Spectroscopy (MRS) provides a unique non-invasive tool to investigate myocardial high-energy phosphate metabolism. Impaired resting energetics have been demonstrated in a number of disease states including hypertension and cardiomyopathies[1]. However, in many situations the alterations in cardiac energetics can be small and will only be unmasked when the heart is stressed[2]. Previous exercise ^{31}P MRS spectral acquisitions at field strengths of ≤2 Tesla have been limited by low spatial and temporal resolution requiring the achievement and maintenance of a modest level of exercise for long scan durations (up to 30 minutes)[3]. Our aim was to establish cardiac ^{31}P MR spectroscopy during leg exercise at 3T, which, due to the higher signal to noise ratio compared with 1.5T[4], should allow improvements in temporal (8 minutes 29 seconds) resolution in healthy volunteers. Shorter scan times allow for more strenuous levels of exercise such that a significant workload can be placed on the heart.

Figure 1: Exercise protocol consisting of knee flexion against elastic cord with 0.5 kg weights attached to each ankle.

Materials and Methods: ^{31}P MR cardiac spectra were obtained using a 3 T MR system (Trio, Siemens Medical Solutions, Erlangen, Germany) in 20 healthy volunteers (10 male and 10 female, mean age 28±3 years) with no history of cardiac disease. ^{31}P MR spectra were acquired at baseline (rest), during exercise and on recovery from exercise. The exercise consisted of alternate knee flexion with 0.5 kg weights applied to each ankle and an elastic cord providing additional resistance, as shown in Figure 1. All spectra were acquired with a 3D acquisition weighted chemical shift imaging sequence (AW-CSI), TR/TE 1000/2.3 ms, Acquisition matrix size 8x8x12, interpolated to 8x16x16, FOV 240x240x200mm. The CSI matrix was aligned such that the direction of highest resolution was perpendicular to the septum, minimizing skeletal muscle contamination and the local flip angle in the septum was 37°. To prevent confounding saturation issues with changing heart rates during exercise, the repetition time was fixed at 1.0 s without ECG gating, resulting in a total acquisition time of 8 minutes 29 seconds. During the exercise haemodynamic measurements were taken every 90 seconds allowing for the calculation of the mean exercise Rate Pressure Product (RPP, a measure of cardiac workload, calculated using the product of the heart rate and systolic blood pressure).

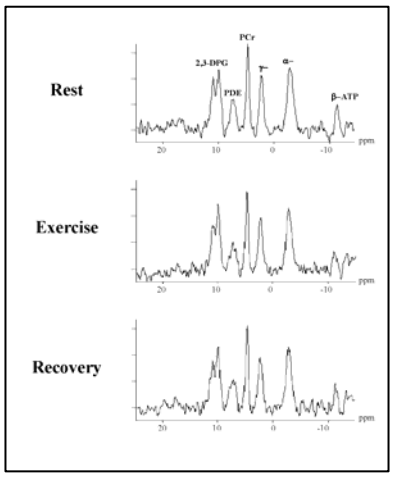

Figure 2: Example cardiac spectra from a typical volunteer during rest, exercise and recovery.

Results: Figure 2 shows typical spectra acquired from a healthy male volunteer at rest, during exercise and on recovery from exercise. The mean T_1 and blood contamination corrected PCr/ATP ratios for healthy subjects at rest was 2.02±0.43, exercise 2.14±0.67 (p=0.54 vs. rest, paired t-test) and at recovery 2.03±0.52 (p= 0.91 vs. rest and p=0.62 vs. exercise, paired t-test). All datasets were of sufficient quality to be analysed. During exercise the mean heart rate increased by 73% and the rate pressure product showed an increase of 115%, levels only previously achieved during MRS with pharmacological stress protocols.

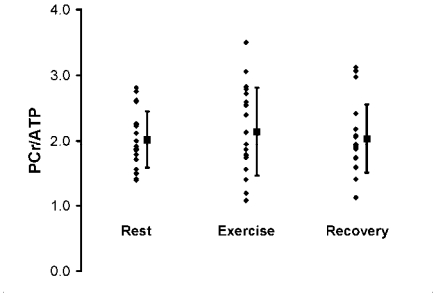

Figure 3: Individual and mean PCr/ATP ratios measured during rest, exercise and recovery from exercise.

Conclusion: A cardiac ^{31}P MR spectroscopy physiological exercise-recovery protocol is feasible at 3T, allowing substantial improvement in temporal resolution compared to lower field strengths. There was no significant difference in high-energy cardiac phosphate metabolite concentrations in healthy volunteers at rest, during physiological leg exercise or during recovery. This protocol is now being used in patients to provide new insights into pathophysiological changes in cardiac metabolism in response to exercise.

References: (1) Neubauer S et al. Circulation 86(6):1810-18 (1992), Weiss RG et al. N Engl J Med 323(23):1593-1600 (1990), (3) Conway MA et al. Br Heart J 65(1):25-30 (1991), (4) Tyler DJ et al. Intl. Soc. Mag. Res. Med. 14:3089 (2006).

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