

Dynamic 3D imaging of phosphocreatine recovery at 3T and 7T

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Introduction: Dynamic measurements of phosphocreatine (PCr) recovery after exercise have been used to probe the oxidative capacity of mitochondrial function [1]. Although valuable information can be obtained by unlocalized MRS methods, spatial mapping of PCr recovery can improve our understanding of the patterns of disease propagation [2]. The fast dynamics of PCr recovery (typically tens of seconds in normal subjects) require more rapid imaging techniques than localized spectroscopic methods (CSI), which are prohibitively slow and result in coarse spatial resolution. Alternatively, imaging a single metabolite (i.e PCr), can be achieved at much faster rate and higher spatial resolution. In this work, we attempt to image PCr directly (baseline during exercise and recovery) in the entire volume of the calf muscle both at 3T and 7T and compare the recovery rates to the more established unlocalized MRS methods. **Methods and Materials:**

All the experiments were performed on a 3T and 7T Siemens scanners (using two geometrically identical dual-tuned ($^{31}\text{P}/^1\text{H}$) quadrature volume coils (Rapid MRI, Ohio). Three normal volunteers (2 male and 1 female, ages 32-36) and a patient (51 year old with type II diabetes mellitus) were recruited. All subjects performed a calf exercise (plantar flexions using resistance bands) until fatigued. In one of the volunteers, a pneumatic pressure cuff positioned around the thigh was inflated to reduce the oxygen supply during the exercise and recovery. Unlocalized spectra were acquired during and after the exercise using a repetition time (TR) of 6 s (3T acquisition bandwidth 2 kHz, 7T acquisition bandwidth 4 kHz). Imaging experiments were performed using a fully centric 3D turbo spin echo (TSE) sequence, developed using the 'SequenceTree' software [3]. TSE parameters at 3T: echo train length (ETL) 24; effective echo time and echo-spacing 26 ms; acquisition bandwidth 1.6 kHz; matrix size 24 x 24 x 4; field of view (FOV) 220 x 220 x 200 mm (Resolution 9.2 x 9.2 x 50 mm); repetition time (TR) 6 s, resulting in 24 s acquisition time per image. A 16 ms spectral selective Gaussian pulse was used for excitation. At 7T the TSE parameters used were: ETL 24; effective echo time and echo-spacing 13 ms; acquisition bandwidth 3.3 kHz; matrix size 24 x 24 x 8; field of view (FOV) 3 s, resulting in 24 s acquisition time per image. An 8 ms spectral selective Gaussian pulse was used for excitation. The integral area under the PCr and the mean voxel signal of the imaged were modeled as mono-exponential growth. **Results and Discussion:** Typical ^{31}P spectra of a healthy subject are shown in Fig.1.a. PCr recovery rate constants from imaging experiments (Fig.1.e) were very close to those obtained by the unlocalized method (Fig.1.b). A slower recovery rate was observed in the same volunteer when the pneumatic pressure cuff was inflated to 60 mmHg (Fig.1.c). At 7T, the additional SNR gain (2.8 fold increase) allowed for higher spatial resolution. The dynamic recovery of PCr in the diabetic patient was much longer compared to the normal volunteers (Fig.2).

Fig. 1. a) Typical ^{31}P spectrum of a healthy subject pre-exercise (top). At the end of the exercise PCr has been depleted (middle) and recovers almost completely (bottom). b) The mono-exponential fit of the data resulted in a recovery constant of 22.4 s. c) The recovery rate in the ischemia-recovery exercise on the same volunteer was prolonged to 34.5 s. d) Imaging experiment (at 3T) on the same volunteer, immediately after the exercise ($t=0$) until recovery ($t=144$ s). e) The mono-exponential growth rate of the mean signal of the calf muscle was 21.2 s, very close to that obtained with the unlocalized method. The red circles represent the acquisition time of the three images shown in d.

192 x 192 x 200 mm (Resolution 8 x 8 x 25 mm); repetition time (TR) 3 s, resulting in 24 s acquisition time per image. An 8 ms spectral selective Gaussian pulse was used for excitation. The integral area under the PCr and the mean voxel signal of the imaged were modeled as mono-exponential growth. **Results and Discussion:** Typical ^{31}P spectra of a healthy subject are shown in Fig.1.a. PCr recovery rate constants from imaging experiments (Fig.1.e) were very close to those obtained by the unlocalized method (Fig.1.b). A slower recovery rate was observed in the same volunteer when the pneumatic pressure cuff was inflated to 60 mmHg (Fig.1.c). At 7T, the additional SNR gain (2.8 fold increase) allowed for higher spatial resolution. The dynamic recovery of PCr in the diabetic patient was much longer compared to the normal volunteers (Fig.2).

Conclusion: 3D spectral-selective TSE methods can be used to study PCr kinetics both at 3T and 7T with enough temporal resolution and can give similar recovery rates to the more established non-localized methods.

References: [1] Haseler, L.J., et al. Am J Physiol Regul Integr Comp Physiol, 2007, 293: p R2046-R2051. [2] Greenman, R. and Smithline, H.A., Acad Radiol, 2011, 18: p 917-923. [3] Magland, J. and Wehrli, F.W. Proc ISMRM 14th Scientific Meeting (2006).

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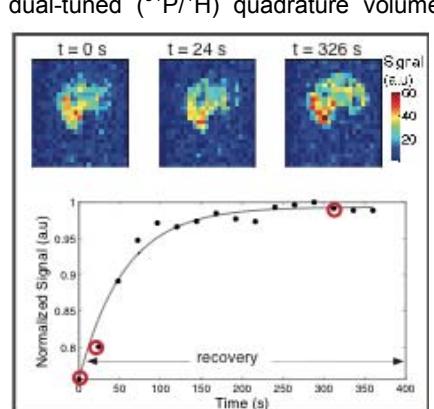


Fig. 2. PCr recovery of a diabetic patient at 7T. The recovery rate constant is 53.5 s.

