Measurement of Post-Exercise Phosphocreatine Recovery Kinetics in Muscle Using 31P RARE MRI

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Introduction: Post-exercise phosphocreatine (PCr) recovery kinetics reflect mitochondrial oxidative metabolism capacity in skeletal muscle. They are generally calculated from unlocalized phosphorus-31 (^{31}P) magnetic resonance spectroscopy (MRS) data using a surface coil. That method is necessary to achieve sufficient temporal resolution, but severely limits spatial localization. The acquisition of spatially localized PCr recovery information from a cross-sectional image of a human limb may provide insights into the functional states of individual muscles simultaneously. The rapid acquisition with relaxation enhancement (RARE) MRI pulse sequence produces PCr images with improved spatial and temporal resolution compared to standard localized ^{31}P MRS methods.[1-3] The purpose of this study was to evaluate the ^{31}P RARE MRI pulse sequence to measure post-exercise PCr recovery kinetics of a well-defined region in the human forearm.

Methods and Materials: PCr image data were acquired at 3T using a double-tuned (^{31}P/^{1}H) birdcage RF coil. A single-shot RARE acquisition, modified for PCr imaging, was prescribed with a 20 x 20 acquisition matrix, resulting in a voxel size of 1.5 X 1.5 X 2.5 cm. A ^{1}H image was acquired for anatomical reference. A single-shot PCr image was acquired prior to exercise. A digit flexion exercise protocol was performed until the subject reported fatigue. PCr images were acquired after the exercise protocol had ended at 6-second intervals for four minutes. The exercise protocol was repeated and post-exercise spectra were acquired at 6-second intervals using MRS with a pulse-and-acquire free induction decay (FID) sequence and a surface coil. The surface coil was placed at the ulnar surface of the forearm (bottom of images shown in Figure 1). Intensity data from the PCr RARE images were matched to the same anatomic region sampled using MRS. Matching was confirmed by using ^{1}H anatomic images and RF flip angle maps of the surface coil that was used for the MRS acquisition[4]. MRS PCr recovery was measured as the area under the PCr spectral peaks. PCr recovery curves were fitted to Changing Rate Utilization Resource (CRUR) functions and recovery rates were calculated[5].

Results: The RARE PCr images showed nearly complete depletion of PCr in the lower (ulnar) region of the forearm immediately following cessation of exercise (Figure 1b). The image intensity in the same region gradually increased to nearly pre-exercise levels within 4 minutes. The RARE image intensity and MRS PCr peak area data are plotted in Figure 1c. The calculated recovery rates for the MRS data are 72 (tau1) and 90 (tau2) seconds; and for RARE image data are 74 (tau1) and 90 (tau2) seconds. These recovery values are consistent with previously published results[5] using unlocalized spectroscopy. The Spearman correlation for the MRS and RARE image recovery data is 0.8, p<0.01.

Discussion: PCr can be measured using a RARE pulse sequence with a temporal resolution of 6 seconds and a voxel size of 5.6 cm^{3} on a 3T MRI scanner. This method allows for measuring post-exercise PCr recovery kinetics in well-defined muscle regions with a spatial resolution superior to current currently used dynamic MRS methods. Changes in exercise physiology as measured by this technique can be used as an outcome measure for clinical trials and has the potential to guide therapeutic interventions for specific patients.
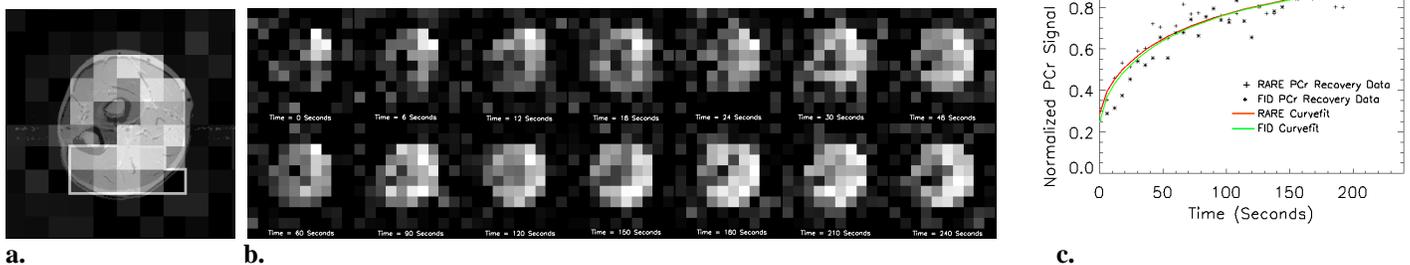

a.   b.   c.

Figure 1. A PCr image of resting muscles, acquired in 6 seconds and superimposed onto a ^{1}H anatomical image is shown in a. The outlined box indicates the voxels that correspond to the sensitive region of the surface coil used for the MRS acquisitions. PCr images showing post exercise recovery of PCr at selected time points from end exercise to 4 minutes are seen in b. A plot of recovery data and CRUR curve fits is shown in c.

References:
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