Gated 31P Chemical Shift Imaging of Phosphocreatine Changes During Single Muscle Contractions

R. A. Meyer[1,2], J. M. Slade[3], T. F. Towse[1], M. C. DeLano[2]

[1]Physiology, Michigan State University, East Lansing, MI, United States, [2]Radiology, Michigan State University, East Lansing, MI, United States, [3]Osteopathic Manipulative Medicine, Michigan State University, East Lansing, MI, United States

Introduction

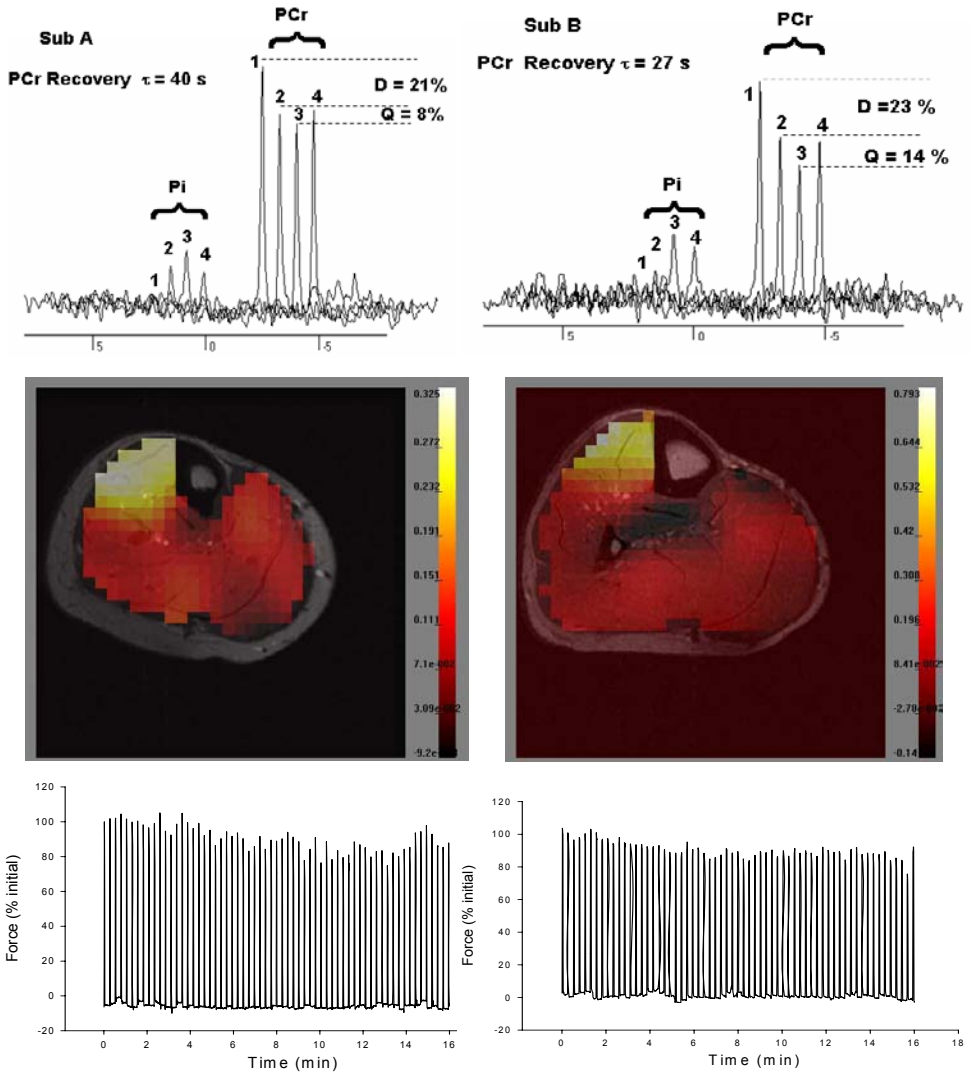
Dynamic ^{31}P-MRS studies of skeletal muscle enable measurement of contractile phosphocreatine (PCr) utilization and PCr recovery rate by acquiring serial spectra during and after a bout of repetitive exercise (e.g., 1). Because of the need for time resolution in these dynamic studies, they are typically performed using surface coils, without any other spatial localization. The application of ^{31}P chemical shift imaging (CSI) to dynamic muscle studies has been limited because of the method's intrinsically poor time resolution. A previous report (2) showed that both the PCr cost of muscle contraction and the time constant for phosphocreatine recovery can be measured during a gated exercise protocol, in which brief, 2 s duration contractions are performed at intervals sufficiently long to allow for partial PCr recovery, and the MRS acquisitions are gated to times before and during recovery after the contractions. The gated protocol was shown to yield estimates of PCr recovery time constant similar to those measured in the same subjects after a conventional repetitive exercise bout. However, in contrast to repetitive exercise protocols, the gated protocol can be performed in a steady-state for long periods, without fatigue, and without muscle acidification (2). This report demonstrates that ^{31}P CSI data can be acquired during the gated exercise protocol, yielding spatially-resolved measurements of muscle contractile PCr cost and PCr recovery time constant.

Methods

Adult subjects (30-55 yrs) performed 2 s duration, maximum isometric ankle dorsiflexion contractions at 15 s intervals for 17.5 min (total 70 contractions). Starting after the sixth contraction, ^{31}P 2D-CSI spectra (51.7 MHz, 2500 Hz sweep, 1024 points, 1 NEX, TR 2.142 s, 15 cm field-of-view, 8x8 acquisition matrix, 3 cm slice) were acquired on a GE Excite 3T system (GE Medical Systems, Milwaukee, WI) via a flexible volume coil wrapped around the lower leg. Seven acquisitions were acquired at each phase-encode step, yielding 7 complete CSI data sets acquired at times corresponding to immediately before, and at 2.142 s intervals after the contractions. In addition, CSI spectra were acquired from the same location at rest, before the gated study. The force of ankle dorsiflexion was continuously recorded on a custom-built ergometer throughout the studies. CSI data were filtered (10 Hz), zero-filled (2K frequency, 32x32 spatial), and Pi/PCr maps generated using the 3DiCSI package recently described by Zhao et al (3). The time constant for PCr recovery (τ) was computed from $\tau = -\Delta t / \ln(D/[D+Q])$, where Q is the PCr decrease during contration, D is the additional steady-state drop in PCr below rest, and Δt is the interval between contractions (13 s).

Results and Discussion

Representative results from two subjects are shown at right. Top panels are Pi and PCr regions of single voxel spectra from anterior tibial muscle at rest (labeled #1), and during the gated protocol at times before contraction (#2), immediately after contraction (#3), and at the end of the recovery interval (#4). (Spectra are successively shifted approximately 1 ppm to the right to illustrate the changes in peak amplitude.) The Pi/PCr ratio maps (Middle) computed from the post-contraction data show that these contraction-induced changes are confined to the anterior compartment muscles. Force (Bottom) was maintained above 80% of initial force throughout the 16 min protocol. This gated CSI method may prove useful for studies of patients with peripheral vascular occlusions or focal muscle denervation, for whom more intense, repetitive exercise protocols may not be appropriate.



References:

1) Conley, KE, et al, Med Sci Sports Exerc. 34:1719, 2002.

2) Slade, JM, et al, Proc. Intl. Soc. Mag. Reson. Med. 13: 348, 2005.

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