Correlation between T2 and diffusion coefficient in exercised muscle

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Introduction: Previous MRI studies have demonstrated increases in the transverse relaxation time, T2, of skeletal muscle following rigorous exercise (1-4). The phenomenon has potential medical applications such as assessing myopathies, sport training regimens, physical therapies, and, in general, muscle recruitment during different exercise regimens (1-4). The underlying biophysical mechanisms which cause T2 increases in exercised muscle are poorly understood, motivating further studies of the phenomenon. Possible explanations for the effect include water shifts from intra- to extracellular spaces, increases in extra-cellular and/or vascular fluid volumes, and/or changes within the intracellular water volume itself whereby exercise results in more "free" and less macromolecular "bound" water. We hypothesized that such would also increase the trace water diffusion coefficient D and tested this hypothesis by interleaving T2 measurements with D measurements in calf muscles of healthy volunteers before and for several minutes after flexion exercise of the tibialis anterior (TA) muscle. A very strong correlation between increases in T2 and D throughout the time course of the experiment is observed for initial increases of T2 and D from baseline of approximately 35 % and 13 %, respectively.

Methods: Six healthy adult males aged 24-48 years participated in the study following the guidelines of the local institutional review board. Experiments were performed with a 3 T system (General Electric Medical Systems, Milwaukee, WI) using a quadrature knee coil positioned about the mid lower portion of the right leg. A single 4 mm thick axial slice through the TA muscle was selected for both T2 and D measurements. A Carr-Purcell-Meiboom-Gill imaging sequence (10 ms echo spacing, 16 echoes, 1 s TR, 128 x 64 matrix, 22 cm^2 FOV) with a scan time of 64 s was used to acquire T2 data. A line scan diffusion imaging sequence (2.1 s effective TR, 40 ms TE, 128 x 128 matrix, 22 cm^2 FOV) with three directional diffusion sensitization sampling was (5 and 500 s/mm^2 b-factors) used to acquire trace D data from the same slice in a scan time of 30 s. Thus both T2 and D measurements were acquired in approximately 90 s intervals before and for approximately 10 minutes after flexion exercise which was accomplished by dynamic ankle flexion for one to two minutes against a 3.5 kg non-magnetic weight attached by string to the subject's foot and suspended from the end of the gantry table. The T2 and D values were evaluated at each time point with monoexponential analyses of signal decays with echo time and b-factor, respectively.

Results: Figure 1 shows D maps of the imaged slice of one volunteer pre- and immediately after exercise. The post-exercise D map shows increased D values within the TA as well as an increase in muscle volume. From all six subjects, the mean ± SD D values pre- and post-exercise were 1.52 ± 0.15 $\mu m^2/ms$ and 1.72 ± 0.13 $\mu m^2/ms$. During the next 10 minutes, D was observed to decrease to approximately 1.6 μm2/ms, remaining above baseline at the last time point. Similarly, from the T2 relaxation studies, the mean ± SD T2 values pre- and post-exercise were 32 ± 1.55 ms and 43 ± 2.5 ms, respectively with a gradual decrease towards baseline observed but still above baseline at the last time point. Figure 2 is a plot of T2 vs D for all six subjects at all time points. The solid line through the data is a linear regression fit with a correlation coefficient r^2 of 0.98 and where T2 (ms) = aD – b with a = 51.6 $ms^2/\mu m^2$ and b = - 46 ms.

Discussion: Exercise induced changes in the T2 relaxation time of skeletal muscle have been extensively reported though the physiological mechanism behind the phenomenon is not fully understood (1-4). The relatively short T2 of muscle in general is indicative of restricted water mobility and the lengthening of T2 with exercise can arguably be rationalized as an overall increase in water mobility. If so, then the water diffusion coefficient would also be expected to rise after exercise. In this work we have shown this to indeed be the case and, further, that a strong correlation exists between T2 and D for several minutes after exercise while the muscle remains in the "activated" state. The implication is that any biophysical model which is to be employed for describing T2 lengthening in exercised muscle must take into account proportional increases in water diffusion coefficients as well.

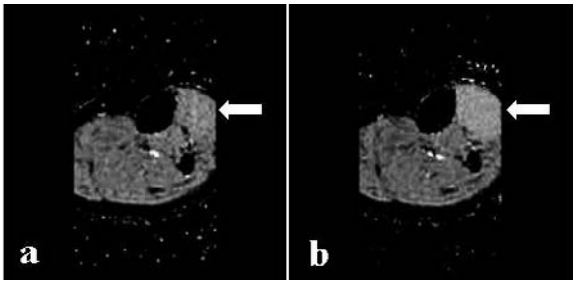

Figure 1: A trace ADC map of a subject before (a) and immediately after (b) exercise.

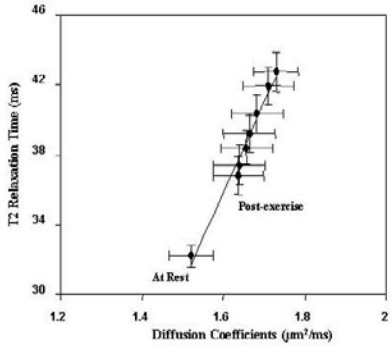

Figure 2: Plot of the interindividual mean and standard error of the mean for T2 relaxation vs diffusion coefficient for 10 minutes after exercise

References:

1. Lori L, Ploutz-Snyder, Sven Nyren, Thomas G. Cooper, E. James Potchen, Ronald A. Meyer. MRM 37:676-682 (1997).
2. J. L. Fleckenstein, R. C. Canby, R. W. Parkey, R. M. Peshock. Am. J. Roentgenol. 151, 231-237 (1988).
3. M. J. Fisher, R. A. Meyer, G. R. Admas, J. M.. Foley, E. J. Potchen. Invest. Radiol. 25, 480-485 (1990).
4. G. Yue, A. L. Alexander, D. H. Laidlaw, A. F. Gmitro, E. G. Ungar, R. M. Enoka. J. App. Physiol. 77, 84-92 (1994).