Acute Effects of Exercise on Quantum Filtered Sodium Spectroscopy in Human Calf Muscle

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Target audience: Researchers and clinicians who are interested in skeletal muscle physiology and quantum filtered sodium spectroscopy

Purpose: Sodium plays a pivotal role in carrying out cellular processes during muscular contraction. A number of studies have used sodium MRI to study the effects of exercise on total sodium concentration (TSC) [1-3], which includes both extra- and intracellular sodium concentrations. However, the knowledge of how the intracellular sodium content is affected by exercise would provide a better understanding of how myocyte physiology is altered in normal and diseased skeletal muscle, but at the cellular level. Triple quantum filtered (TQF) sodium MRI would be able to spatially map out the intracellular content of skeletal muscle. However, it requires long imaging times that makes it very hard to study acute changes in muscle physiology. Contrary to TQF sodium MRI, QF sodium MR spectroscopy would be sensitive to acute effects of exercise due to its high temporal resolution. The purpose of this work was to demonstrate how exercise could affect the QF sodium spectrum in human calf muscle.

Methods: MRI experiments were performed using a GE MR750 3T (General Electric Healthcare, Milwaukee WI) and an in-house-made 6-inch diameter transmit/receive sodium surface coil. An in-house-made MRI compatible ergometer was used to allow ankle plantar flexion exercise in the bore of the magnet concurrent with spectroscopy scans. A 28-year old healthy male subject was tested lying supine in the magnet bore with one leg positioned in the ergometer pedal and the surface coil positioned under the calf muscle belly. The leg and coil were immobilized using a strap tied to the two sides of the MR bed. First, a total of 682 TQF sodium spectra (Creation (τ) /Evolution (σ) time = 3/0.156 ms, TR=0.1 s, Phase Cycles=6) were acquired taking a total time of 6 minutes and 50 seconds. The subject started performing ankle plantar flexion one minute into the scan for a period of 2 minutes at a frequency of 0.5 Hz pushing against a load of 30% of maximum voluntary contraction (MVC). Following the TQF spectroscopy, the subject remained at rest in the magnet for 30 minutes to let the muscle return back to its resting state. During the rest period the TQF scan was repeated 3 more times without exercise to monitor how the TQF signal evolved post exercise. Then, a total of 2046 single quantum filtered (SQF) sodium spectra (FIDCSI sequence, TR=0.1 s, NEX=2) were acquired with the same exercise protocol as the TQF scan. The same SQF spectroscopy was repeated 3 times to observe how the signal recovers post exercise. Sodium peak areas at each time point were calculated and normalized to time=0.

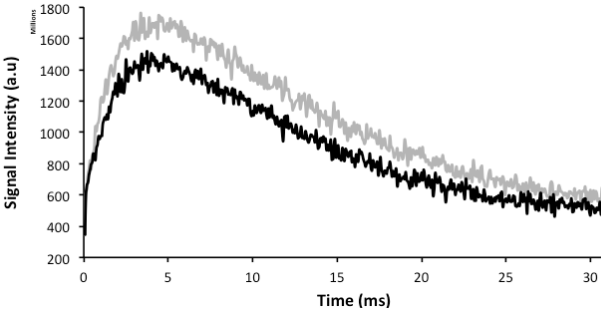

FIG. 1. Sodium TQF FIDs acquired from human calf muscle. The gray line represents the average of collected FIDs during the first minute of scan (i.e. rest) and the black line represents the average of collected FIDs during the second minute of the scan (i.e. 1st min of exercise).

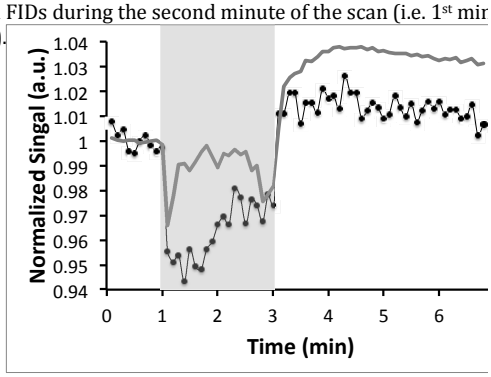

FIG. 2. Normalized Spectral Area of SQF (gray) and TQF (black dotted) sodium MR spectroscopy of human calf muscle acquired over a period of about 7 minutes. The exercise is marked by shaded area.

Results: Figure 1 shows a subset of acquired FIDs during rest and exercise. Figure 2 shows how the area of the SQF and TQF signals change over the time course of the scanning. All the areas were normalized to the average of the data acquired in the first minute prior to exercise. Each time-point was the average of acquired spectra over 6 seconds. As evident in figure 2, both TQF and SQF areas were increased immediately after cessation of exercise, relative to that of the initial baseline rest period. The increased levels of TQF and SQF areas return to baseline at about 15 and 20-minute time-point, respectively (figure 3).

Discussion: The slow recovery of the SQF signal is expected and is lower than reported value (i.e. a 30-minute half-life) reported by the previous TSC MRI studies done on exercising calf muscle [1-3]. The increase in the FID area could be well due to increase in T_2 relaxation time of the sodium in the exercising muscle as a result of alteration in water content of the muscle, which is also suggested by other studies [4,5]. The TQF signal mostly comes from the sodium interacting with macromolecules especially inside the cells. During exercise, the intracellular fraction of restricted water molecules decreases [6] and hence intracellular space becomes more, so to speak, diluted leading to decrease in the sodium macromolecular interactions and in TQF signal. This could explain why the TQF levels decrease during exercise. As the exercise terminates, cellular homeostasis will restore the cell back to resting state and the TQF signal goes back up. According to our results, the rate of recovery of the TQF signal is much more rapid than the SQF. One reason could be that intracellular processes are much more tightly regulated than extracellular processes as intracellular homeostasis is vital to cellular viability. Another reason could be that the extracellular space is also in interaction with other things like blood flow and perfusion and that is why it is slower in going back to rest state. Our QF scan results suggest that both TQF and SQF signal recover much faster than signal intensity recovered in sodium MRI after exercise. This points to robustness of QF spectroscopy as compared to normal sodium MRI in the study of effects of exercise on sodium MR signal.

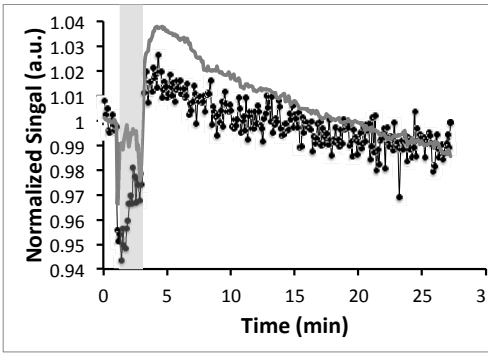

FIG. 3. Normalized Spectral Area of SQF (gray) and TQF (black dotted) sodium MR spectroscopy of human calf muscle acquired over a period of about 28 minutes. The exercise is marked by shaded area.

Conclusion Our results demonstrate how exercise affects SQF and TQF sodium spectroscopy in skeletal muscle. TQF shows a more robust response to acute effects of exercise and how it recovers to the baseline. Although TQF does not have as good spatial resolution as sodium MRI techniques it offers a very high temporal resolution for studying acute effects such a exercise on intercellular physiology in the skeletal muscle. This property of TQF would make it a powerful technique in the study of muscular diseases that affects the muscle intracellular physiology.

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