Rapid Volumetric T2 Measurements in Muscle Pre- and Post-Exercise using Quantitative DESS

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Introduction: The evaluation of muscle for medical and research applications is enhanced by MR techniques that acquire morphological and biochemical tissue properties from the entire muscle volume. T2 relaxation time in muscle increases after activity. Unfortunately, conventional spin echo (SE) techniques used to acquire two-dimensional (2D) T2 maps suffer from long acquisition times, blurring, artifacts, and incomplete coverage. A quantitative three-dimensional double echo steady state (qDESS) sequence, capable of acquiring accurate 3D quantification of T2 without artifacts, was recently validated *in vivo* in the articular cartilage [1]. Several studies have investigated the effects of exercise on T2 changes in muscle; most demonstrating an increase in T2 value after exercise at .35T-1.5T in several muscles. None have yet done so with 3D methods in a 3.0T system [2-5]. We evaluated the effect of exercise upon the diffusion properties of muscle using a 3D qDESS sequence at 3.0T *in vivo*.

Methods: All images were acquired in the coronal plane in a GE MR 750 3.0T MRI scanner (GE Healthcare, Milwaukee, WI) with a torso array coil. Bilateral images of volunteers' calves were imaged with 3D qDESS sequences. Imaging parameters were: spoiler gradient duration: 2ms, matrix: 256×256, receiver bandwidth: ±62.5kHz, FOV: 36×36cm^2, slice thickness: 4mm, TR: 29ms, and TE for the S+ readout: 10ms and S-readout: 48ms. We obtained a first data set (lower diffusion sensitivity) with FA: 35° and spoiler gradient strength: 0.5G/cm for the frequency and phase directions and 1.0G/cm for the slice direction, and a second data set (higher diffusion sensitivity) with FA: 18° and spoiler gradient amplitude: 4.0G/cm for each direction.

Eight healthy volunteers performed six sets of 25 calf raises on their right leg at full body weight outside of the scanner. Bilateral images of volunteers' calves were acquired immediately after exercise and again at 8 and 16 min post exercise with 3D qDESS sequences. We calculated the mean and SD of the estimated T2 values for the medial and lateral gastrocnemius (mGCM and lGCM) and the tibialis anterior (TA) values before exercise and at each post exercise time. T2 relaxation times were estimated within a region-of-interest consisting of each entire muscle from a representative slice and were estimated by numerically comparing the measurements to a wide range of values predicted by a theoretical model [6]. We calculated the difference between the right (exercised leg) and the left (unexercised leg) at each time period. Paired t-tests were used to calculate significant differences for each muscle between each post exercise time point and the pre exercise time point. Mean percent changes in T2 relaxation time were calculated at each post exercise time point in each muscle.

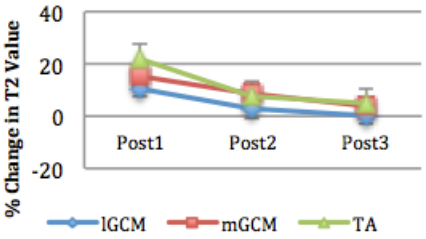

Figure 1: Percent change from baseline of T2 relaxation time in the exercised leg by post exercise time period and muscle (±SE).

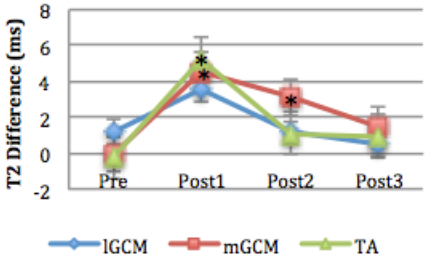

Figure 2: Difference in T2 relaxation times between the exercised leg and unexercised leg by post exercise time period and muscle (±SE). Significant changes ($p<0.05$) are seen in the first and second time points in the mGCM and first time point in the TA compared to pre-exercise. (asterisks)

Results: The 3D qDESS T2 values estimated *in vivo* in muscle are within the ranges of previously reported values [2-5]. The T2 values and average percent change of T2 value from baseline of all exercised muscles peaked immediately after exercise and subsequently decreased back to the baseline T2 value (Figure 1). As a measure of repeatability of the method, T2 relaxation times of each unexercised muscle only varied by ±0.8ms (lGCM), ±1.0ms (mGCM), and ±2.0ms (TA). On T2 maps, increased T2 values of muscle after exercise were observed as shown by differences in measured T2 values between the exercised and unexercised leg (Figure 2) and in representative subjects (Figures 3,4). Although increases were seen in the difference between T2 values in all muscles immediately post exercise, differences were only significant in the medial gastrocnemius immediately post exercise and eight minutes post exercise and the tibialis anterior immediately post exercise ($p<0.05$).

Conclusion: High-resolution, 3D morphological images of the entire muscle and accurate T2 maps can be produced using qDESS acquisitions in <8min without distortion or blurring. The rapid acquisition times and volumetric coverage allow for examination of the entire muscle at multiple time points. Exercise induced T2 changes in skeletal muscle, which are most likely indicative of increased water mobility, are most evident immediately after exercise. Mapping of the entire muscle activation volume after exercise may be helpful in exercise studies and creation of computational models of muscle motion during human activity.

References: [1] Staroswiecki E et al., *ISMRM* [abstract #:500], 2011.[2] Fleckenstein JL et al., *AJR Am J Roentgenol*, 1988. [3] Morvan D et al., *Magn Reson Imaging* 1995. [4] Hayashi M et al. *Acta Med Okayama* 1998. [5] Nygren AT et al., *Eur Radiol* 2002. [6] Wu EX et al., *JMR* 1990.

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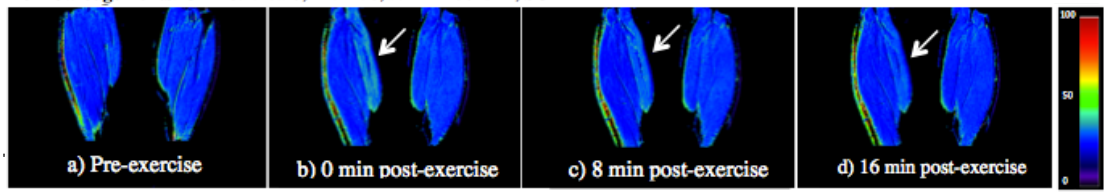

Figure 3: 3D qDESS maps of T2 relaxation times in the medial and lateral GCM (a) pre-exercise, (b) immediately post, (c) 8 min post, and (d) 16 min post exercise. Increase in T2 is seen in the right medial GCM (arrows), most significantly immediately and 8 min post exercise.

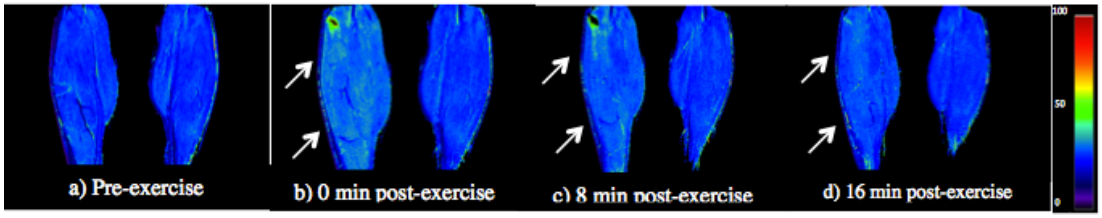

Figure 4: 3D qDESS T2 maps of medial and lateral GCM and GCM (a) pre-exercise, (b) immediately post, (c) 8 min post, and (d) 16 min post exercise. Increase in T2 can be visualized in right lateral GCM (arrows), most significantly immediately and 8 min post exercise.