Visualization of exercise-induced activation of rotator cuff muscles using muscle functional MRI

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Introduction

Measurement of exercise-induced muscle activity is essential in sports medicine and rehabilitation medicine. Strengthening of the rotator cuff muscles is an integral part of rehabilitation programs for athletes with shoulder injuries who must perform throwing motions during sport. Magnetic resonance imaging (MRI) can evaluate muscle activity; the transverse relaxation time (T2) of exercised muscle is increased compared to that of rested muscle [1]. Therefore, evaluation of muscle activity using T2–weighted MRI facilitates identification of the most effective exercises for strengthening the rotator cuff [2]. However, B0 inhomogeneity can affect MR image quality of the shoulder by reducing the spin-to-noise-ratio (SNR) to below that necessary for calculation of the T2 from MR images obtained using pulse sequences of ultrafast imaging (except when used with a spin echo sequence). In spite of this, it is necessary to have high temporal resolution to detect the slight and transient impact on the MR signal induced by acute exercise [3]. Ultrafast imaging has been shown to allow visualization of exercise-induced muscle activity in the trunk [4]. The purpose of this study was to evaluate visualization of the activation of muscles of the rotator cuff induced by acute exercise.
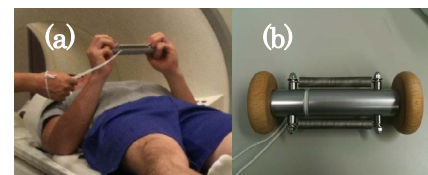

Figure 1: External rotation exercises of the shoulders were repeated 50 times per set starting from a neutral position. (a) The exercise environment, (b) training equipment.

Methods

The right rotator cuffs of eight male subjects (21.6±0.8 years, 172.7±4.9 cm, and 64.5±8.1 kg) were scanned at rest and after exercise using a 1.5T whole body scanner (Magnetom Symphony; SIEMENS AG, Erlangen, Germany) with a small Shoulder Array Coil. Two protocols were employed: (a) true fast imaging with steady precession (TrueFISP) with repetition time (TR) 4.72 ms, echo time (TE) 2.36 ms, matrix size 256×256, flip angle (FA) 50, bandwidth (BW) 501 Hz/Px, acquisition time 12 seconds; and (b) multi-shot spin-echo echo planar imaging (MSSE-EPI) with TR 2000 ms, TE 20, 30, 40, 50 ms (4 echoes), matrix size 128×128 interpolated into 256×256, FA 90, BW 1392 Hz/Px, acquisition time 30 seconds (for 1 echo). Slice thickness 5mm, field of view (FOV) 240mm×240mm, and NEX 1 were common factors. The signal gain of the MR signals was not changed between the rest and post-exercise scans. A single exercise set consisted of the subject performing external shoulder rotation 50 times using training equipment (Arm Twista; Sanriki Corporation, Tokyo, Japan) while lying supine on a bed with the elbow flexed at 90 degrees (Figure 1). Subjects performed 10 sets of the exercise. Areas of interest were set at multiple locations in the subscapularis (sub), supraspinatus (sup), infraspinatus & teres minor (inf & ter), and deltoid (del) muscles. T2 relaxation times were calculated using Interactive Data Language (IDL: ITT Visual Information Solutions, Boulder, CO, USA) with mono-exponential linear least-squares regression of MSSE-EPI images. For visualization of the area of activated muscle, we used the fast-mfMRI technique [4, 5].

Results and Discussion

Figure 2 shows representative MR images of the right shoulder after 10 sets of exercise. Inf & ter show slight changes of signal intensity (SI) after exercise, however, it is difficult to quantify the SI difference (Fig.2a). Additionally, though TrueFISP images were superior in spatial resolution, the identification of the activated muscle using the change of SI in subtracted images is difficult (Fig.2c). On the other hand, MSSE-EPI images improve the image contrast of the activated muscle (Fig.2b). And the subtracted images (Fig.2d) can depict the identification of the activated muscle that is inf & ter. This may be due to B0 inhomogeneity, which commonly occurs in images of this region of the shoulder. However, T2 images are less affected by inhomogeneity of B0 [3], making T2-weighted imaging the superior technique for identification of activated muscles of the shoulder, including the rotator cuff, as shown in figure 2d. Figure 3 shows the fusion images generated using the fast-mfMRI technique. This technique can facilitate visualization of muscle activation induced by exercise. As is shown in the figure, this technique is applicable even in the rotator cuff region, which is susceptible to B0 inhomogeneity. Additionally, muscle activation due to mild exercise can be detected if we use MSSE-EPI to obtain excellent T2 measurements in relation to temporal resolution. Therefore, we suggest that when a site is susceptible to B0 inhomogeneity, T2 calculation using MSSE-EPI can resolve the problem of image distortion.
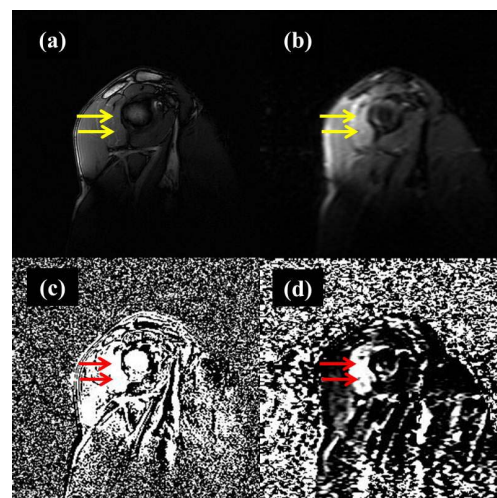

Figure 2: Representative right shoulder MR images after 10 sets of exercise. (a) TrueFISP image, (b) MSSE-EPI image, (c) Subtracted TrueFISP images from after 10 sets to at rest, (d) Subtracted T2 image from after 10 sets to at rest. In (b), the echo is 50 ms. Arrows denote the activated infraspinatus & teres minor (inf & ter) muscles.

Conclusion

In this study, we demonstrate the utility of T2 calculated from MSSE-EPI images for visualization of activation of individual muscles of the rotator cuff. In addition, we show that muscle activity in a region such as the shoulder, which is susceptible to B0 inhomogeneity, can be easily detected using this technique.
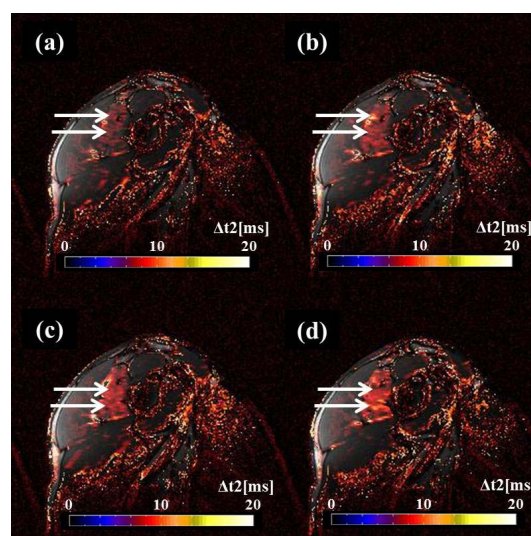
Acknowledgements

Figure 3: Fused image using fast-mfMRI obtained after 2 sets (a), 4 sets (b), 6 sets (c), 8 sets (d) of exercise. The color bar shows differences in T2 (Delta t2). Arrows denote the activated infraspinatus & teres minor (inf & ter) muscles.

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