Changes of transverse relaxation time (T2) of the exercised skeletal muscle by ultrafast imaging

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Aims and objectives

Quantitative evaluation of exercised muscle activity is essential in sports medicine, rehabilitation medicine and exercised physiology. In order to evaluate this activity, Magnetic Resonance Imaging (MRI) is one of the useful methods. MRI can estimate not only the superficial muscle but also the deep muscle. The previous study [1] used muscle functional magnetic resonance imaging (mfMRI) in 1988 has shown the acute effects of exercise on muscle Transverse relaxation time (T2). Therefore, T2 for assessing exercised muscle activity is an essential part of the sports medicine, rehabilitation medicine and exercised physiology.

Generally speaking, T2 calculation method, spin echo (SE) and multiple spin echo (MSE) sequence has been used with acquisition time of a few minutes. As a result of the acquisition time for calculating T2 is long; the exercise-induced acute behavior of muscle is not assessed. It is necessary to reduce the acquisition time for calculating T2 in regard to evaluate muscle activity. In addition, the setting for the parameters of the imaging condition is different for each report for each, in these reports, discussion of setting there is little in the many previous studies which it has been reported in sports medicine and rehabilitation medicine. In the analysis using T2-weighted images instead of T2 images, It is especially also possible that the parameters to be set, using data that does not reflect the characteristic of the T2 image data to be used.

As the temporal resolution for improving the acquisition time in exercised physiology, Ultrafast MR imaging, spin-echo echo-planar-imaging (SE-EPI), has been applied for muscle activity analysis, with signal intensity (SI) changes only [2, 3, 4]. These methods using SI changes cannot be applied for a follow-up examination or the comparisons between subjects. Therefore, it is necessary to verify whether it is possible to calculate T2 or not by SE-EPI.

The purpose of this study was to indicate the feasibility of ultrafast imaging by SE-EPI for quantitative evaluation of acute changes of exercised skeletal muscle.

Methods and materials

Subjects and exercise protocols

Four male healthy subjects (20.5±1.7 years, 174.8±8.7 cm, 59.0±2.7 kg) were invited to participate in this study. All Subjects performed 200 times of right ankle planter flexion using the training-gum-belt (Thera-Band, U.S.A). All exercise was carried out in the MRI
examination room (Figure 1). The institutional Ethics Committee associated with our Institute approved the study, and all participants took an informed consent.

**Imaging protocol**

The all right calf before and after exercise was examined on a 1.5T whole-body MRI Scanner (Magnetom Symphony, Siemens AG, Erlangen, Germany) with the extremity coil. The protocol for all measurements was identical and consisted of an MSE sequence using 15 echoes for the standard T2 calculating method and the SE-EPI approach. For exact comparability, slices were positioned identically for both sequences. SE-EPI was performed with TR 2000 ms, TE 30, 45, 60, ..., 240 ms (15 echoes), matrix size 256×256, FA 90, BW 1392 Hz/Px, slice thickness 10mm, FOV 240mm×240mm, NEX 1 and acquisition time 2.0 sec for a one echo, total of 30 sec. MSE was performed with TR, TE, matrix size, FA, slice thickness, FOV and NEX were equal to SE-EPI, BW 130 Hz/Px, acquisition time 4:20 minutes. The MRI data before exercise was collected by MSE and SE-EPI. Up to 15 minutes later after every 30 sec from after exercise immediately, The MRI data after exercise was collected by SE-EPI only. Signal gain during the image acquisition time was set to be the same at all.

**Image analysis**

Region of interests (ROI) in muscle were placed in tibialis anterior (TA) muscle from the SE-EPI and the MSE images. T2 relaxation time was calculated using mono-exponential linear least-squares by using the SE-EPI and the MSE images. Calculated T2 were generated using Interactive Data Language software (IDL: Exelis Visual Information Solutions, Boulder, CO, USA). The exercise-induced muscle activity was analyzed by signal intensity (SI) and T2.

First, it was compared for characteristics of T2 decay between the MSE and SE-EPI using T2 relaxation curve in this study. It evaluated the feasibility of calculating T2 using the SE-EPI by this comparison. Second, it validated about the temporal alteration of muscle T2 after exercised immediately. Third, Similar to the T2, it was also evaluated for changes related to the muscle MR signal (= SI).

**Images for this section:**
Fig. 1: Figure 1: Exercise schema. (a) Schematic view, (b) Ankle planter flexion.
Results

In the MR images' acquisition after the exercise, that could collect 30 seconds per by using the SE-EPI.

Figure 2 shows the T2 relaxation curve of TA from the MSE and the SE-EPI. SI from the SE-EPI was correlated with that from the MSE in short TE (< 75 ms). SE-EPI in the short range of TE can be applied for the calculating the muscle T2, instead of the MSE in it. Figure 3 shows MR images of the right calf before and after exercise. The TA was predominantly activated with elevated SI. T2-weighted MR images can visualize for muscle the change in muscle water content due to exercise.

Exercise induced muscle by MR signal was shown in Figure 4. In TE of all, Muscles SI on 2 minutes later from the end of exercise was higher than that on 1 minute. The MR signal of muscle raised by the exercise, 19.3% in 5 minutes, 41.5% in 10 minutes, 55.9% in 15 minutes, was reduced respective. Figure 4 was shown the changes of Exercise induced muscleT2. Muscle T2 rose by the exercise, 11.4% in 5 minutes, 22.6% in 10 minutes, 42.5% in 15 minutes, was reduced respective.

The tibialis anterior (TA) was mainly activated with evaluated SI and T2, by comparing before and after exercise skeletal muscle. The changes of TA were gradually decreased according to the muscle changes of SI and T2.

Images for this section:
Fig. 2: T2 relaxation curves from SE-EPI and from MSE. In shorter TE (<75ms), signal intensities from SE-EPI are correlated with that from MSE.
Fig. 3: Figure 3: MR images of lower leg at rest (a) and immediately after-exercise (b). TA is predominantly activated (arrow).
**Fig. 4:** Figure 4: Each TE's MR signal of before \( (t = 0) \) and after exercise. (a) TE = 30 ms. (b) TE = 45 ms. (c) TE = 60 ms. (d) TE = 75 ms.
Fig. 5: Figure 5: T2 changes from before (t = 0) and after exercise.
Conclusion

The findings of Figure 2 in this study suggest that SE-EPI can be applied for the calculating the muscle T2, instead of the MSE in it. One of the reasons that the signal of the MSE and the SE-EPI do not match exactly, SE-EPI is conceivable to make the fat suppression as pre-pulse. Muscle MR signal of SE-EPI is a signal intensity in which fat signal is suppressed. Nevertheless, the previous study reported that the T2 measurement by MR image using the 1.5T MRI units, separation of intramuscular fat is impossible [5]. These results may indicate that if the MR signal is in a short TE (< 75 ms), it is possible to interpret SE-EPI and MSE that are equivalent.

Muscle function evaluation induced exercise by T2 is a useful technique. However, it was reported that the temporal resolution of T2 measurement is low, there may not be able to evaluate the muscle function induced exercise properly. This study considered these factors on the relationship between the temporal resolution of T2 measurement and the changes of muscle T2 after exercise. These results by Figure 4 and 5 shows that MR signal increased by the exercise is reduced at an early time from the end of exercise immediately. The findings from this study suggest that the most important of the data acquisition in muscle function evaluation need high temporal resolution. In addition, the findings by Figure 4 and 5 show that decreasing degree was different in between the T2 and T2-weighted MR signal in muscle after exercise. Accordingly, it seems that the muscle function assessment using MRI should be applied T2.

In conclusion, ultrafast imaging by SE-EPI can shorten the plot interval into as fast as 30 seconds, and calculate T2 of the excised skeletal muscle. This method indicates that the immediately after exercise-induced rapid changes within the muscle can be detected.

Personal information

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