Rapid estimation of muscle transverse relaxation time (T2) based on ultrafast magnetic resonance imaging at 3.0 Tesla

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Introduction

Exercise-induced muscle activity is essential in sports medicine and rehabilitation medicine. 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 specific muscles. Akima *et al*. proposed the muscle functional magnetic resonance imaging (mfMRI) technique [2] for visualization of muscle activity. However, for calculating the T2 mfMRI uses the spin echo (SE) sequence, which requires several minutes of acquisition time. This limits the utility of mfMRI to the limbs. On the other hand, the spin-echo echo-planar-imaging (SE-EPI) sequence is useful for ultrafast imaging for calculating T2 in regions such as the trunk. Therefore, it has previously been shown that using SE-EPI for T2 measurements with a 1.5 Tesla (T) MRI scanner can greatly reduce the acquisition time needed [3,4]. Furthermore, Welch *et al.* reported T2 estimation from double-echo-steady-state (DESS) sequence echoes, which provide both high temporal and high spatial resolution, to be useful for assessment of cartilage morphology [5]. The aim of this study was to assess the utility of SE-EPI and DESS pulse sequences for T2 measurement at 3.0T by comparing them with multiple spin echo (MSE) sequences in order to determine which protocol would best reduce the image acquisition time for the calculation of muscle T2. In addition, this study was assessed about the muscle T2 affected from intramuscular lipids, too.

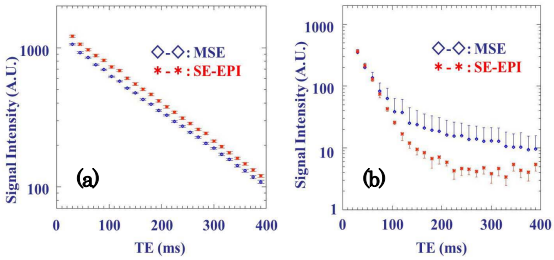

Figure 1: T2 relaxation curve. (a) PVA, (b) Semi. In (a), the slope of the T2 relaxation curve of the PVA is the same for SE-EPI and MSE sequences. In (b), with shorter TE (<75ms), the signal intensities of semi from SE-EPI correspond well with those from MSE.

Methods

Comparison data were obtained using the same 3.0 Tesla whole body scanner (Magnetom Verio; SIEMENS AG, Erlangen, Germany) with an eight-channel knee coil (Invivo, Gainesville, FL). Pulse sequence types were compared over three experiments: (A) comparison between MSE and SE-EPI; (B) comparison between SE-EPI and DESS; (C) comparison between fat suppression (fs) and non fs in MSE and DESS. Three scan protocols were employed: (a) MSE with repetition time (TR) 2000 ms, (echo time) TE 30, 45, 60, …, 390 ms (25 echoes), matrix = 256×256, flip angle (FA) 90, bandwidth (BW) 130 Hz/Px, acquisition time 4:20 minutes. (b) SE-EPI with TR and TE as for MSE, matrix size 128×128, FA 90, BW 1392 Hz/Px, acquisition time 2 seconds (for 1 echo). (c) 3D-DESS [5] with TR 19.9 ms, TE 4.2 ms, voxel size 0.6×0.6×5 mm, matrix = 320×320, FA 33, BW 355 Hz/Px, acquisition time 30 seconds for 6 slices. The 3D-DESS sequence was SIEMENS's work-in-progress (W.I.P.). Common conditions over all scans were: prepared slice thickness 5mm, field of view (FOV) 200mm×200mm, and NEX 1. In comparison A, a PVA-gel phantom (PVA) and the right thigh of five male subjects (25.5±6.8 years, 173.2±6.4 cm, and 65.0±6.4kg) were scanned. In comparisons B and C, the other right thighs of 5 other male subjects (29.2±5.9 years, 166.7±3.5 cm, and 58.0±4.6 kg) were scanned. In comparison C, the MSE image data from subjects in comparison A and the DESS data from subjects in comparison B were used. Regions of interest (ROI) were placed in m. semitendinosus (semi) for the MSE, the SE-EPI and the DESS images. T2 was calculated using mono-exponential linear least-squares of the MSE and SE-EPI MR images with TE = 30, 45, 60, 70 ms. Muscle T2 was calculated from DESS images as described previously [4]. It has been reported that the change of the T2 does approximately 10% of changes even if it is in the same muscle [4]. Therefore, in comparison A the T2 values between the pulse sequence types were compared directly and by a T2 relaxation curve. In comparisons B and C, significance of differences was assessed using the Student's t-test and were considered significant at p-values < 0.05.

Table 1: Comparison of T2 between MSE and SE-EPI

	MSE (ms)	SE-EPI (ms)
PVA	138.0±1.2	146.3±1.5
semi	31.5±2.1	28.5±1.1

PVA: PVA-gel phantom. Semi: m. semitendinosus. Even though the slope of the T2 relaxation curve was the same, there was a difference of 6% in the PVA T2, and 9% in the muscle T2, between sequence types.

Results and Discussion

Figure 1 shows the T2 relaxation curve of PVA and semi calculated from the MSE and the SE-EPI images. In Figure 1(a), the slope of the T2 relaxation curve of the PVA was the same for both SE-EPI and MSE with a 6% difference in signal intensity between the pulse sequence types. In Figure 1(b), signal intensities from the SE-EPI corresponded with those from the MSE with short TE (< 75 ms). This indicates that it is possible to calculate T2 from SE-EPI if the TE is short, but that errors may arise with longer TE values. The semi T2 differed by 9.2% between pulse sequences types as shown in Table 1. Semi T2 by DESS was 29.9±1.9 ms, and semi T2 by SE-EPI was 28.6±1.0 ms (Table 2); this difference was not significant, as was expected based on our previous report [4]. Additionally, as shown in Table 2, there was no significant difference in T2 with and without fat suppression (semi T2 by MSE was 30.2±0.6 ms and 31.1±0.8 ms with and without fs, respectively). This suggests that MR images using 3.0 Tesla MR units cannot detect intramuscular lipids. SE-EPI can largely reduce the acquisition time of images suitable for calculating T2, however its spatial resolution is limited. On the other hand, image data by DESS cannot only be acquired as a three-dimensional image, but also has high spatial resolution. Nevertheless, DESS has inferior temporal resolution to SE-EPI. As a result, it was shown that two the ultrafast imaging T2 method was higher temporal resolution than MSE that is traditional T2 method. It has been previously reported that evaluation of muscle activity using T2 values calculated from ultrafast imaging is effective, even in a region such as the shoulder, which is susceptible to B0 inhomogeneity [6]. Therefore, we suggest that the ultrafast imaging T2 method can be creatively used with each sequence type depending on the reason for performing the scan.

Table 2: Comparison of MSE-T2 and ultrafast imaging T2 methods

	DESS fs (ms)	DESS (ms)	SE-EPI (ms)
semi	28.5±2.1	29.9±1.6	28.6±1.0
P value	0.084	0.070	
	MSE fs (ms)	MSE (ms)	
semi	30.2±0.6	31.1±0.8	
P value	0.069		

Semi: m. semitendinosus. There was no significant difference in T2 between SE-EPI and DESS, and there was no significant difference in T2 with and without fat suppression (fs).

Conclusion

In this study we demonstrated the feasibility of calculating T2 values using ultrafast imaging. The muscle T2 calculating using 3 Tesla MRI units were uninfluenced by intramuscular lipids. The ultrafast imaging T2 method can be creatively used with each sequence type depending on the reason for performing the scan.

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