T_1 and T_2 relaxation times of the human calf at 7 Tesla

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Introduction:

The aim of this work was to measure the T1 and T2 relaxation times of muscle and subcutaneous fat tissue in the human calf at 7 Tesla and to validate the corresponding values at 3 Tesla. For 7T the relaxation times of the human calf muscle tissue were still unknown.

Materials & Methods:

Three healthy volunteers (two male (25, 34 years) and one female (24 years)) were examined on 7T and 3T whole body MR systems (Magnetom 7T / Magnetom Trio, Siemens Healthcare, Erlangen, Germany) using a 28 channel Tx/Rx knee coil (QED, Mayfield Village, Ohio, USA) at 7T and a 8 channel Tx/Rx knee coil (Invivo, Gainesville, Florida, USA) at 3T.

T1 relaxation time measurements:

A saturation recovery sequence was employed with five non-selective 90 degree preparation pulses followed by spoiling to obtain homogeneous saturation. To sample the relaxation curve 16 TI times were used. TI was non-equidistantly adapted to an assumed T1 of 2000 ms (1400 ms at 3T) in muscle and 500 ms (360 ms at 3T) in fat to get a linear sampling on the magnitude axis. For muscle TI ranged from 70 to 4150 ms at 3T, from 100 to 5950 ms at 7T, for fat from 50 to 1050 ms at 3T, from 50 to 1450 ms at 7T. The other parameters are FA 7°, TE 4.16 ms at 3T and 3.31 ms at 7T, for TR the shortest possible duration was chosen (depending on TI), BW 340 Hz/Px at 3T and 800 Hz/Px at 7T, resolution 1.25 mm × 1.25 mm, slice thickness 4 mm on 3T and 2.5 mm on 7T. The lower bandwidth and higher slice thickness at 3T was used to achieve a similar chemical shift and signal to noise.

T2 relaxation time measurements:

A standard spin-echo (SE) sequence with 16 echo times TE was chosen. The spacing of the TEs was optimized (as TI above) for the assumed relaxation times. For muscle imaging TE ranged from 8 to 90 ms at 3T, from 8 to 75 ms at 7T, for fat from 8 to 150 ms at 3T and 7T. The sequence parameters were: TR 1000 ms, BW 340 Hz/Px at 3T and 797 Hz/Px at 7T, resolution 1.25 mm × 1.25 mm, slice thickness 4 mm at 3T and 2.5 mm at 7T.

In all measurements it was ensured that muscle and fat received proper excitation by selecting the resonance frequency of the tissue of interest (i.e. one measurement was performed on the water frequency and one on the fat frequency). This was done, since the narrow bandwidth of the preparation pulses can result in improper preparation of one tissue type. This is in particular relevant at 7T, where the chemical shift of water and fat is about 980 Hz. However, to ensure consistency the same type of excitation was also performed at 3T.

Regions of Interest were drawn manually for muscle and fat tissue. The data was fitted voxelwise in MATLAB (The MathWorks, USA) by using a nonlinear least square algorithm with consideration of noise and flip angle imperfections. The relaxation times were determined by creating a histogram of the relaxation time map and then obtaining the maximum of the distribution. The full width half maximums of the distributions were taken as the uncertainties of the mean values.

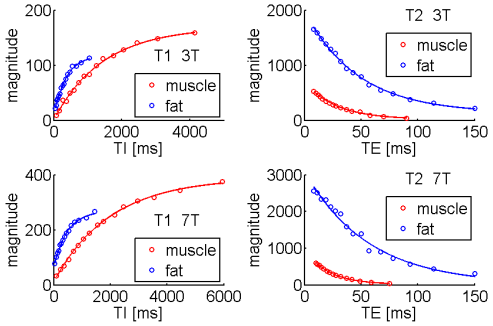

Fig.1: Signal intensities for muscle and fat as a function of TI / TE plotted for the position of the white dot marked in Fig.2 and 3. Solid lines show the fits for relaxation times.

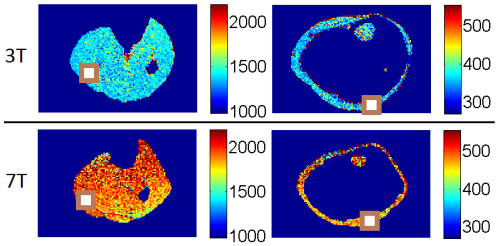

Fig.2: T1 maps in milliseconds for one volunteer separately in the calf muscle (left) and fat tissue (right) for 3T (top) and 7T (bottom). For signal values of the white dot see Fig.1.

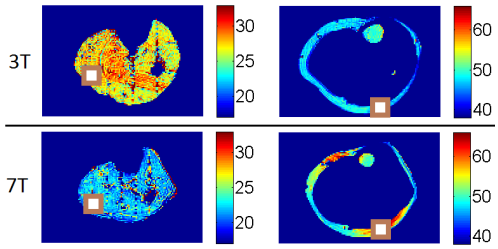

Fig.3: T2 maps in milliseconds for one volunteer separately in the calf muscle (left) and fat tissue (right) for 3T (top) and 7T (bottom). For signal values of the white dot see Fig.1. Interestingly, the soleus muscle in the center of the leg shows increased values compared to the other muscle groups.

Results:

In Fig.1 the fit curves for both tissue types are shown. It is visible that the non-linear sampling of the relaxation curves matches to the individual signal behavior. An increase of the T1 relaxation times with field strength is clearly detectable for both water and fat tissue (Fig. 2). The values for T2 are mapped in Fig.3 and show a decrease in T2 relaxation for muscle tissue, while the values for fat increase slightly with higher field strength. An overview of the T1 and T2 relaxation times is given in Table 1.

Discussion & Conclusion:

The relaxation times of muscle at 3T are in agreement with the values presented in [1]. The T1 values for fat at 3T are in accordance with [1] and [2]. Our SE T2 results for fat are slightly lower than in [2], where a fast SE was used. We confirmed their detected increase of T2 for fat with field strength. In the T2 map of muscle tissue in Fig. 3 the soleus muscle can be distinguished by increased values.

To our knowledge, the relaxation times of muscle tissue at 7T have not been investigated to date. For fat tissue there exist spectroscopy relaxation time values in [3], which agree for the main component (methylene protons) of the fat with our results. In the T2 map in Fig. 3 appear different values for fat which is likely to be an influence of an imperfect flip angle that results in lower signal to noise and an instable fit.

The histograms of the T1 or T2 map show a spreading, that is represented by the errors in Table 1. It is due to the occurrence of different tissue contributions in the muscle like vessels or connective / supporting tissue between muscle groups, which makes the tissue inhomogeneous. Another reason is the B1 inhomogeneity that is more present at 7T than at 3T.

T1 and T2 relaxation times of the human calf were measured in-vivo at 7T and 3T. This will be useful for pulse sequence optimization for calf muscle imaging.

	T1 [ms]				**T2** [ms]			
	muscle	literature	fat	literature	muscle	literature	fat	literature
3 T	1391 ± 193	1420 ± 38 [1]	364 ± 58	382 ± 13 [2]	27 ± 5	32 ± 2 [1]	48 ± 5	68 ± 4 [2]
7 T	1864 ± 243	-	451 ± 66	530 ± 40 [3]	22 ± 4	-	53 ± 10	63 ± 5 [3]
Δ%	+ 25.4		+ 19.3		- 18.5		+ 9.4	

Table 1: Relaxation times T1 and T2. The values are averaged over the three volunteers. The errors represent the FWHM of the histograms of one value type. Additionally, the literature values of the references are given.

References:

[1] G.E. Gold *et al.*, Am J Roentgenol, **183** (2004); [2] C.M. de Bazelaire *et al.*, Radiology, **230** (2004); [3] J. Ren *et al.*, J Lipid Res, **49** (2008);