B0 and B1 Correction of High Field T2 Maps of Human Calf Muscle

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Introduction: Quantitative T2 mapping is conceptually straightforward, but in practice obtaining accurate T2 measurements is challenging especially on high field clinical MR scanners, such as 3 Tesla, that suffer from increased static (B0) and RF transmit (B1) field inhomogeneity. Time efficient multi-slice, multi-echo (MSME) turbo spin echo (TSE) sequences are commonly available, but conventional MSME TSE sequences often are not optimized for T2 mapping. The primary shortcomings of a standard MSME TSE protocol for T2 mapping arise from (1) too small thickness ratio of the refocusing versus excitation slice and (2) inadequate crusher scheme used to eliminate stimulated echoes created by imperfect refocusing pulses. A refocusing slice that is too thin or an insufficient crushing scheme both lead to elevated T2 estimates. If the slice thickness and crushing issues are addressed, the observed T2 values will be diminished due to the refocusing inefficiency of imperfect π pulses. The diminished observed T2 values can be corrected with knowledge of the B0 and B1 fields [1-2]. In this work, the performance of a MSME TSE was tested on water and oil phantoms and in the human calf muscle at 3 Tesla. The standard MSME TSE sequence was altered to include an improved refocusing slice selection and crusher scheme properties. Finally, B0 and B1 maps were acquired to correct the observed T2 values.

Methods: Phantom and human images were acquired on a 3 Tesla Philips Achieva scanner (Philips Healthcare, Best, The Netherlands). Phantoms included a 1.9L doped-water bottle (2g/L $CuSO_4$-$5H_2O$, 4.5g/L NaCl) and a 2L mineral oil bottle, with ∅=12cm for both. After obtaining informed consent under a protocol approved by the Vanderbilt University Medical Center Institutional Review Board, a 32 year-old healthy male subject underwent calf imaging. An 8-channel receive-only knee coil (Invivo Inc., Gainesville, FL) was used to acquire MSME TSE data along with corresponding B0 and B1 maps. The 10 echo MSME TSE sequence acquired 18 7mm slices as two separate 9 slice packages to minimize slice cross-talk. Other parameters of the MSME sequence were: TR\TE\BW = 3000ms\10*15ms\200Hz/pix, in-plane FOV = $(192mm)^2$, 240×191 matrix, scan time=10min. Ratios for the refocusing-to-excitation slice thicknesses were either 0.9 (scanner standard) or 2.8 for improved results. The MSME TSE was acquired with the scanner's standard constant-amplitude, constant polarity crushers (dephasing = 4.3π) and with an improved Poon-Henkelman scheme [3] using diminishing amplitude and switching polarity (max strength 20mT/m, duration=2ms, max. dephasing = 53.2π, min. dephasing = 10.4π). B0 maps were collected with a repeated 3D fast field echo (FFE) sequence (ΔTE=1.0 ms). B1 maps were acquired using the pulsed steady-state (PSS) technique [4]. The multi-echo magnitude data were fit to a mono-exponential decay with noise offset term using the *lsqcurvefit* function of Matlab (Mathworks Inc., Natick, MA). B0 and B1 maps along with knowledge of the refocusing pulse (Philips built-in *optimim_echo_2* with 5.384 ms duration) were used to calculate an effective refocusing rotation matrix [1] on a voxel-by-voxel basis. The fractional refocusing efficiency from that matrix was used to correct the observed T2 values according to the method of Sled and Pike [2].

Results: Table 1 reports the observed T2 values for the water and oil phantoms as well as for the tibialis anterior (TA) and soleus (SO) muscles of the human calf. For all species, T2 values are elevated when using the standard sequence's thin refocusing slice (90% excitation slice thickness). The decay profiles when using a thin slice (not shown) also exhibit non-exponential decay. With a thicker refocusing slice, the T2 values decrease, but the decay curves still show signs of unwanted stimulated echo signals because of inadequate crushing. With a proper crushing scheme [3], the T2 values reduce further. Correction using B0 and B1 maps [1-2], increases the T2 values to a varying degree as a function of B0 and B1 inhomogeneity. Figure 1 shows the importance of the B0/B1 correction for the water and oil phantom. For the water phantom, B1 inhomogeneity is significant enough to create large fluctuations in estimated T2 across the profile of the phantom. Correction for both the B0 and B1 fields significantly improves the uniformity of the T2 map. In the case of the mineral oil phantom, B1 inhomogeneity is much less. The corrected T2 values for the TA and SO muscles reported in Table 1 agree with previously published 3T values based on a spectroscopy method [5] of 28.4 ± 0.7 and 31.3 ± 1.2 respectively. The importance of the B0 and B1 correction is supported by muscle results. Before correction, the SO muscle had an estimated T2 of less than the TA muscle. After correction, values are much closer to published values and have the correct relative magnitude.

	0.9 slice ratio / default crushers	2.8 slice ratio / default crushers	2.8 slice ratio / Poon-Henkelman [3] crushers (B0/B1 corrected by method of [1-2])
1.9L doped water bottle	164.0 ± 3.1	154.4 ± 2.3	126.4 ± 10.1 (132.9 ± 5.6)
2L mineral oil bottle	46.0 ± 0.4	38.9 ± 0.5	37.3 ± 0.4 (38.5 ± 0.4)
human calf: tibialis anterior	39.6 ± 5.5	32.2 ± 1.5	26.0 ± 1.2 (26.4 ± 1.2)
human calf: soleus	34.6 ± 0.8	30.4 ± 1.5	25.1 ± 2.9 (30.0 ± 5.0)

Table 1. Mean ± σ T2 values (ms) for phantoms (100x100 ROI) and tibialis anterior/soleus muscles (10x10 ROI)

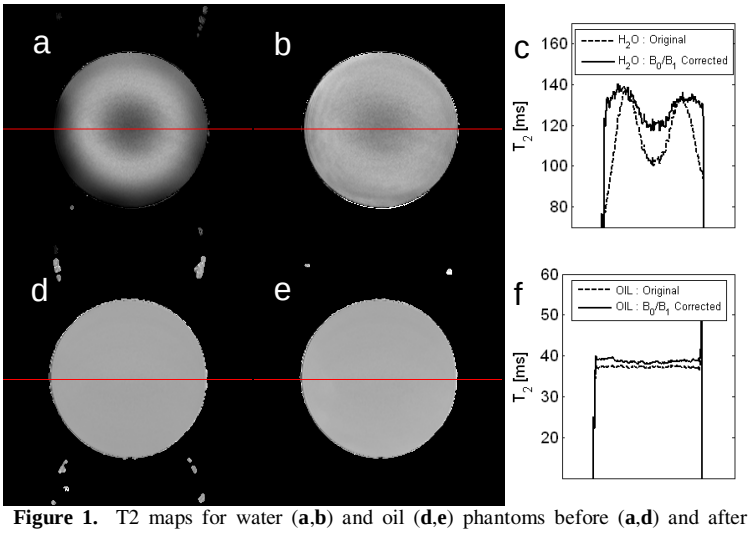

Figure 1. T2 maps for water (**a**,**b**) and oil (**d**,**e**) phantoms before (**a**,**d**) and after B0/B1 correction (**b**,**e**). Correction improves uniformity of the water phantom (**c**). The oil phantom uniformity (**f**) is already good, but correction shifts the T2 values.

Conclusions: Rigorous T2 mapping using a MSME TSE sequence is possible, but attention must be paid to refocusing slice properties and to signal crushing. At high static field, B0 and B1 inhomogeneities affect T2 estimates, but such effects can be corrected. After these steps, image-based T2 maps should agree with results obtained from other non-image-based T2 measurements such as single voxel selective spectroscopy.

References: 1. Simbrunner JMR (1994) 109:117-120 2. Sled et al. MRM (2000) 43:589-593 3. Poon et al. JMRI (1992) 2:541-553 4. Yarnykh MRM (2007) 57:192-200 5. Moser et al. MAGMA (2004) 16:155-159