A B_1 Insensitive qMT Protocol

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INTRODUCTION: Quantitative magnetization transfer (qMT) imaging requires several additional measurements to correct for instrumental biases (B_0, B_1) and to constrain parameters in the fitting model (T_1). These three extra measurements are typically independent of each other, but certain T_1 mapping techniques also require B_1 maps (e.g. variable flip angle – VFA[1]). In this case, B_1 is used twice before fitting the qMT parameters: to correct the flip angles for T_1 mapping, and to scale the nominal MT saturation powers. Inaccuracies in B_1 would propagate to the fitting of the qMT parameters through two pathways – through errors induced in T_1, and errors in MT saturation powers. This work demonstrates that for the Sled and Pike qMT model[2], certain qMT parameters (F – pool ratio, and T_{2f}) are insensitive to a large range of B_1 inaccuracies when using VFA for T_1 mapping.

METHODS: Three healthy adults were scanned with a 3T Siemens Tim Trio MRI using a 32-channel receive-only head coil. Single slices (2x2x5 mm^3) were acquired parallel to the AC-PC line, superior to the corpus callosum. Whole-brain T_1w MPRAGE images (1x1x1 mm^3) were acquired for image registration and skull stripping. **T_1 maps:** VFA T_1 maps were acquired using an optimally spoiled[3] 3D gradient echo sequence (TE/TR 2.89/15 ms, $\alpha = 3°/20°$, $A_G = 280$ mT•ms/m, $\varphi = 169°$), and the flip angles were scaled voxel-wise with each B_1 map prior to fitting for T_1. Inversion recovery (IR) T_1 data was collected from a four inversion time spin echo sequence (TE/TR = 11/1550 ms, TI = 30, 530, 1030, 1530 ms), using an open source robust inversion recovery fitting methodology[4,5]. **qMT maps:** MT data was acquired using the spoiled gradient echo two-TR (25/60 ms) optimal 10-point protocol for 3T using Gaussian-Hanning MT pulses (the full protocol including the 10 off-resonance frequency and MT saturation power pairs can be found in Levesque et al 2011[6]). qMT parameter maps were fitted using the Sled and Pike model[2]. B_0 was mapped using a two-point phase-difference gradient echo method (TE1/TE2/TR = 4/8.48/25 ms). **B_1 maps:** A double angle (DA) B_1 map was acquired using a turbo spin echo readout (TE/TR12/1550 ms, $\alpha = 60°/120°$). To simulate a wide range of B_1 inaccuracies, flat (homogenous) B_1 maps were simulated for a range of values (B_1 Flat = 0.5, 0.75, 0.9, 1, 1.1, 1.25, 1.5, 2 n.u.). VFA T_1 maps and corrected MT saturation powers were then calculated from these flat B_1 maps to provide a wide range of inaccurate T_1 and MT saturation powers. Note that VFA T_1 calculated with a flat B_1 factor of 1 is equivalent to fitting VFA T_1 maps using the nominal flip angles.

qMT maps were fitted with combinations of B_1 maps using DA and flat B_1, as well as IR T_1 maps and VFA T_1 maps corrected with the corresponding B_1 maps. Voxel data from all subjects were pooled for each qMT/T1/B_1 sets, and linear regressions and correlations were calculated between qMT/T1/(B_1=DA) and qMT/T1/(B_1 Flat) for all B_1 flat maps and both T_1 methods.

RESULTS: Figure 1 shows a comparison between B_1 maps (measured DA and simulated B_1 flat =1, the latter being equivalent to assuming true nominal angles) for a single subject; VFA T_1 maps calculated using each B_1 map; and fitted qMT F maps. Figure 2 shows the pooled whole brain Pearson correlation coefficients (a) and linear regression slopes (b) for qMT F values between the measured DA B_1 maps and simulated flat B_1 maps, for VFA (blue) and IR (red) T_1 maps. Table 1 lists the correlation and linear regression slope for all fitted qMT parameters and both T_1 methods (VFA, IR) between DA and B_1 flat = 1.

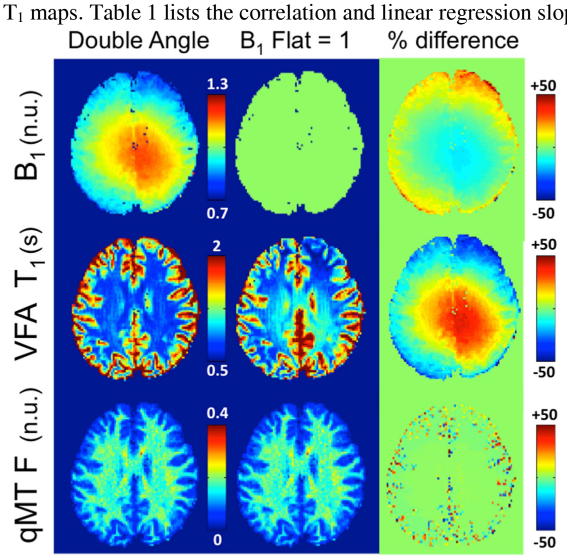

Figure 1: A single subject comparison of qMT F maps fitted using DA and flat (B_1 = 1) B_1 maps and VFA T_1 maps corrected using the corresponding B_1 map.

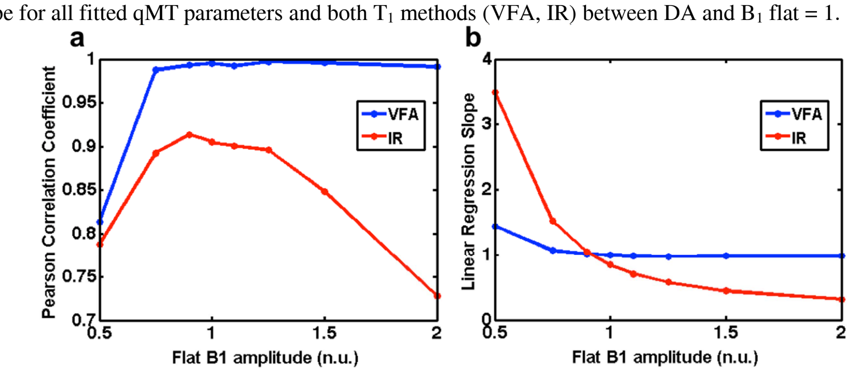

Figure 2: Pooled (all subjects) whole brain Pearson correlation coefficients (a) and linear regression slopes (b) for qMT F values between the measured DA B_1 maps and simulated flat B_1 maps.

		F	k_f	R_{1f}	T_{2f}	T_{2r}
DA B_1, VFA T_1 vs Flat B_1 = 1,VFA T_1	**Pearson ρ**	**0.99**	0.32	0.81	**0.99**	0.92
	Slope	**0.99**	0.31	0.98	**0.95**	0.90
DA B_1, IR T_1 vs Flat B_1 = 1, IR T_1	**Pearson ρ**	0.90	0.36	0.99	0.96	0.90
	Slope	0.84	0.37	0.97	1.16	0.89

Table 1: Pooled (all subjects) whole brain Pearson correlation coefficients and linear regression slopes for qMT F values between the measured DA B_1 maps and simulated flat B_1 maps.

DISCUSSION: As can be observed from Fig. 1, processing qMT F maps using a flat B_1 map (nominal flip angle assumption, large B_1 inaccuracies) and the corresponding VFA T_1 map results in nearly identical qMT F maps using DA B_1 maps, except for cortical regions where partial volume with CSF is present due to the voxel size (2x2x5 mm^3). Severe overestimation of B_1 is better tolerated than severe underestimation for the qMT parameter F (Fig. 2). As expected, inaccurate B_1 values lead to severe qMT parameters errors when IR T_1 maps are used (Fig. 2 and Table 1). Poor correlation in R_{1f} values for VFA, and strong correlations for IR R_{1f} (Table 1), can be easily explained because the measured T_1 is used to constrain the fitted R_{1f}[2].

The exact origin of the erroneous B_1 and VFA T_1 nearly cancelling out in qMT F maps remains to be clarified, and simulations may provide a better understanding this insensitivity. It may be possible that k_f, which has the lowest correlation (Table 1 - VFA), is absorbing some errors instead of F during the fitting procedure, when the effects of inaccurate B_1 and T_1 compensate each other. F has been observed to be the best qMT correlate with myelin content using histology[7], and some qMT methods have recently been developed to fix most qMT parameters except F to reduce the number of acquisitions[8]. A likely source of the insensitivity of F and T_{2r} to B_1 may also be that the measured MT signal is inversely proportional to the MT saturation powers, while measured MT signal is proportional to T_1, and it can be seen from Figure 1 that B_1 and VFA T_1 are inversely proportional. qMT protocols with different TRs or parameter constrained methods[8] may be more sensitive to B_1 inaccuracies than the protocol presented in this work.

CONCLUSION: We have demonstrated that qMT F maps fitted using VFA T_1 can be insensitive to B_1 inaccuracies. Thus, faster and lower resolution B_1 maps can be used without sacrificing qMT F accuracy or precision when VFA T_1 maps are used. More work in simulating the effects of B_1 and VFA T_1 inaccuracies on qMT parameter estimation is needed to have a clearer understanding of the limitations of this observation.

REFERENCES: [1] Deoni S. et al, MRM 49:515-526 (2003) [2] Sled J. and Pike G. B., MRM 46:923-931 (2001) [3] Yarnykh V., MRM 63:1610-26 (2010) [4] Barral J. et al, MRM 64:1057-1067 (2010) [5] http://www-mrsrl.stanford.edu/□jbarral/t1map.html (Accessed: October 2012) [6] Levesque I. et al, MRM 66:635-643 (2011) [7] Schmierer K. et al, JMRI 26:41-51 (2007) [8] Yarnykh V., MRM 68:166-178 (2012)