Impact of three B1 mapping techniques on variable flip angle T1 measurements

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Introduction: Variable flip angle (VFA) T1 mapping has become a popular tool to estimate T1 times *in vivo* due to its time-efficient high-resolution 3D coverage. For accurate T1 estimates at 3 Tesla, the acquisition of a B1 map is essential to correct the nominal flip angles. B1 maps are typically acquired at a low resolution (~4 mm) since the B1 field is slowly varying. For accurate T1 measures of cortical grey matter (GM), the B1 mapping method must also be accurate for long T1 and T2 relaxation times due to partial volume effects of GM and CSF. This work evaluates the impact of 3 published B1 mapping techniques (the double angle method (DAM), actual flip angle imaging (AFI) and Bloch-Siegert shift (BS)) to correct VFA T1 measurements in phantoms that mimic GM and CSF. VFA measurements were performed with standard and optimized spoiling. Gold standard inversion recovery (GS IR) T1 measurements (not requiring B1 measurement) are included for reference.

Methods: Two uniform phantoms were designed to mimic the dielectric and relaxation properties of GM (H_20, 85.5mM NaCl and 65µM $MnCl_2$) and CSF (H_20 and 85.5mM NaCl). All images were acquired on a Siemens TIM Trio 3 T scanner with a 32-channel receive only head coil at an isotropic resolution of 4 mm, 64×54 matrix size and 52 slices for 3D acquisitions. We acquired a reference B1 map using the 2D single slice DAM with turbo spin echo readout (TI/TE/TR= 14/12/2000ms, α=33°/66°) [1]. We also acquired 3D B1 maps using AFI (TE/TR_1=3.53/20ms, N=5, α=60°) with optimal spoiling parameters (gradient moment A_G=450mT•ms/m, phase increment φ_0=39°) [2], and BS (TE/TR=11.5/50ms, α=19°, 8ms Gaussian pulse of 500° at ±4kHz off-resonance) [3]. VFA T1 measurements were acquired using the Siemens product SPGR implementation with TE/TR=2.48/15ms and α=3°, 10°, 20°. The VFA measurements were repeated with optimal spoiling parameters (A_G=280mT•ms/m, φ_0=169°) [2]. The VFA T1 estimates were computed from a linear fit to the SPGR signal equation. GS IR T1 measurements were acquired with TE/TR=11/5000ms and TI=50, 400, 1100, 2000 ms, and the complex data was fitted using custom software [4].

Results: Intensity profiles of the B1 maps across the GM and CSF phantoms are illustrated in Figure 1. The BS and AFI B1 maps are lower than the reference DAM method, the BS B1 map is particularly low for CSF. The maximum difference between the AFI/BS B1 profiles and the DAM are 3.4/5.3% for the GM phantom and 5/11.9% for the CSF phantom. Histograms of the T1 times for the GM and CSF phantoms are shown in Figures 3 and 4, and the mean T1 times are listed in Table 1. The most accurate T1 mapping method is the optimally spoiled VFA with DAM B1 correction, resulting in less than a 1% difference in mean T1 time relative to the GS T1 measurements for GM and CSF, albeit with some broadening of the histogram peaks. The standard VFA method with DAM B1 correction results in 1.53/5.47% (GM/CSF) higher mean T1 estimates than the GS. The fast 3D BS and AFI methods cause an overestimation of the mean T1 time by 8.28/17.54% and 5.69/5.40%. The spoiled VFA T1 measurements with BS B1 correction are also characterized by a much broader histogram in comparison to the other methods investigated.

Discussion: The optimally spoiled VFA T1 mapping technique with DAM B1 correction yields the most accurate results; however, whole brain coverage using the DAM method is not possible within reasonable scan times. Incomplete spoiling will impact the AFI and VFA methods that are based on SPGR magnitude images. The errors in B1 and T1 mapping are therefore enhanced for the long T1 and T2 relaxation times of CSF. Although the optimally spoiled VFA method with AFI B1 correction is characterized by a relatively sharp T1 histogram, the T1 times are overestimated. The BS gradient echo sequence, implemented according to [3], could be improved for 3D applications by optimizing the design of the off-resonance BS pulse. The trade-off between SAR, direct saturation and phase accrual during the BS pulse will impact B1 map accuracy and SNR. The errors in the 3D fast B1 mapping techniques investigated here result in broadening and/or shifting of the T1 histogram.

References: [1] Sled & Pike, MRM 43: 589–593 (2000) [2] Yarnykh, MRM 63: 1610-26 (2010) [3] Sacolick *et al.*, MRM 63: 1315-22 (2010) [4] Barral *et al.*, MRM 64: 1057-67 (2010)

Figure 1: Profile of B1 maps in GM and CSF phantoms

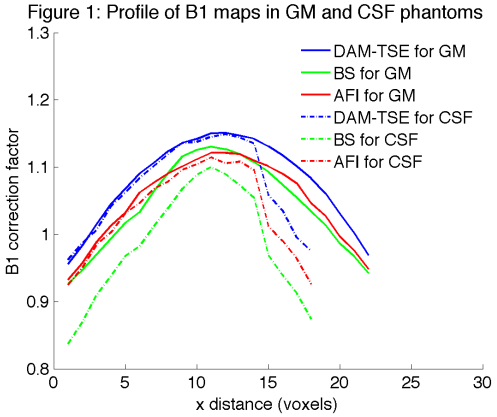

Figure 2: Histogram of T1 times in GM phantom

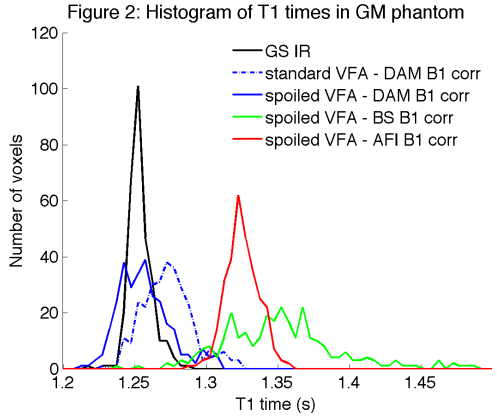

Figure 3: Histogram of T1 times in CSF phantom

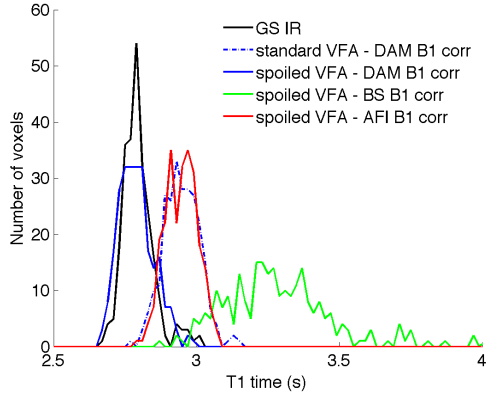

Table 1: T1 times of GM and CSF phantoms

Acquisition procotol	$T1_{GM}$ (ms)	$T1_{CSF}$ (ms)
GS IR	1 252	2 786
Standard VFA + DAM	1 270	2 938
Spoiled VFA + DAM	1 254	2 780
Spoiled VFA + BS	1 355	3 275
Spoiled VFA + AFI	1 323	2 936