A Comparison of B_1 Mapping Methods for T_1 Mapping at 3T

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INTRODUCTION: B_1 maps are an essential part of most quantitative MRI protocols, including Variable Flip Angle (VFA) T_1 mapping. To achieve whole brain quantitative imaging in reasonable scan times, several novel rapid B_1 methods have been inroduced[1,2]. Recent works have compared several novel B_1 mapping methods used at 3T in simulations[3], phantoms[4], and in vivo[5]. Accelerating B_1 mapping can also be done through fast k-space trajectories, such as EPI, but are sometimes dismissed due to the possibility of distortions associated artifacts[6], particularly for brain imaging. The aim of this work was to compare VFA T_1 maps in white matter (WM) produced with four B_1 methods: Reference double angle (DA), Bloch-Siegert[2] (BS), Actual Flip-Angle Imaging (AFI), and DA using a stock scanner spin-echo EPI readout sequence (EPI-DA).

METHODS: Six healthy adult subjects were scanned with a 3T Siemens Tim Trio MRI using a 32-channel receive-only head coil. Axial slices (2x2x5 mm^3) were acquired (or extracted from 3D volumes) parallel to the AC-PC line above the corpus callosum. A reference DA B_1 map was acquired using a turbo spin echo readout with TE/TR 12/1550 ms and α = 60°/120°. Whole brain 3D optimally spoiled[7] AFI B_1 maps were acquired with TE/TR1 3.53/20 ms, N = 5, α = 60°, spoiling gradient moment A_G = 450 mT•ms/m and RF phase increment φ = 39°. Single slice BS B_1 maps were acquired with TE/TR 15/100 ms, α = 25°, 8 ms Fermi Pulse of 500° at ±4kHz off-resonance and K_{BS} = 74.01 rad/G^2. Interleaved multi-slice spin-echo EPI-DA whole brain B_1 maps were acquired with TE/TR 46/4000 ms, α = 60°/120°, EPI Factor = 9 and echo spacing = 4.18 ms. To further investigate possible distortion artefacts in EPI-DA B_1 maps, a left-hemisphere sagittal slice B_1 map for both DA methods was acquired for one subject. VFA T_1 maps were acquired using an optimally spoiled[7] 3D gradient echo sequence (TE/TR 2.89/15 ms, α = 3°/20°, A_G = 280 mT•ms/m, φ = 169°), and the flip angles were scaled voxel-wise by each B_1 map prior to fitting for T_1. Whole-brain T_1w MPRAGE images (1x1x1 mm^3) were acquired, and tissue classification maps (WM, GM, CSF) were provided via INSECT[8] with the ICBM-152 atlas. WM tissue masks were resampled to a 2x2x5 mm^3 slice using a majority voting analysis; GM and CSF were not included because of partial volume effects due to the voxel size.

RESULTS: Single slice B_1 maps and WM T_1 maps for a single subject are shown in Fig.1. Figure 2 displays histograms for single slice WM T_1 data that was pooled for all subjects. Linear regression analysis of pooled WM T_1 for each B_1 relative to the reference is shown in Table 1. Figure 3 compares reference DA and EPI-DA sagittal B_1 maps for a single subject. No significant B_1 maps distortions were observed in axial or sagittal EPI-DA B_1 maps.

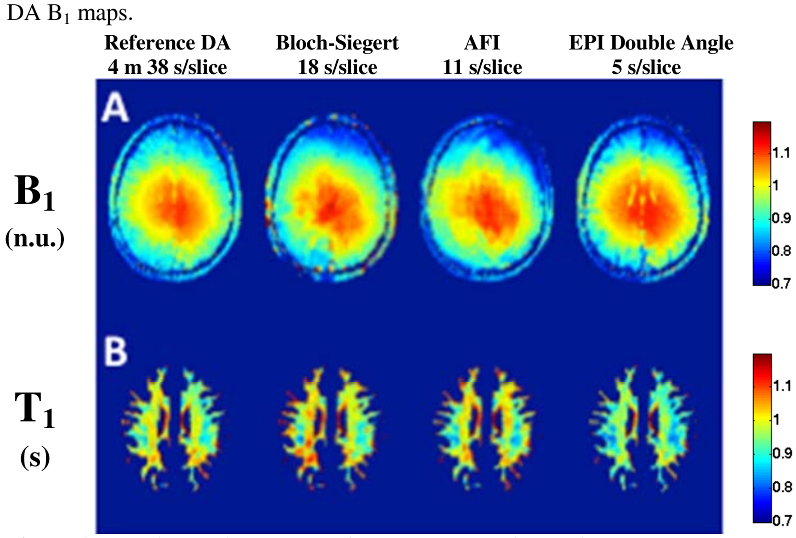

Figure 1: (A) Single slice B_1 maps from a representative subject. (B) WM VFA T_1 maps using flip angles corrected with each B_1 map.

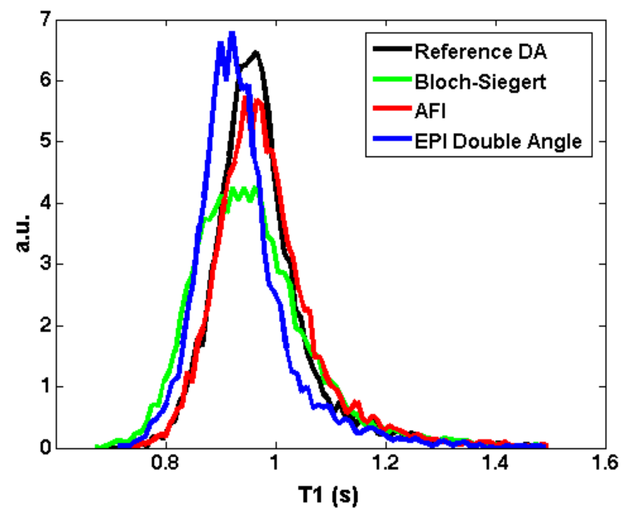

Figure 2: Normalized pooled histograms of single slice WM T_1 values for 6 healthy subjects (bin width = 10 ms).

	Ref. DA	BS	AFI	EPI-DA
Pearson ρ	---------	0.963	0.972	**0.984**
Fit slope	---------	0.993	**1.002**	0.981

Table 1: Linear regression analysis of the pooled WM T_1 values (6 subjects) for each B_1 method relative to the reference DA B_1 method.

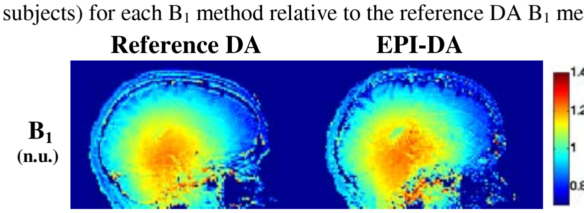

Figure 3: Sagittal (left hemisphere) B_1 maps for a single subject using the reference and EPI double angle methods.

DISCUSSION: All B_1 methods provided comparable B_1 and VFA T_1 maps. EPI-DA, the fastest of the B_1 maps (5 s/slice), had no observable B_1 artefacts (Figs. 1 and 3), due to careful sequence planning (low EPI factor, long echo spacing). Strong correlations were observed between VFA T_1 maps using all three rapid methods compared to Ref. DA (Table 1). T_1 maps using EPI-DA B_1 maps underestimated T_1 by ~4% (Fig 2., Table 1), but strongly correlated to the Ref. DA.

Transmit B_1 in the brain is typically observed to be a slowly varying function. Interpolating or blurring B_1 maps has been used for both transmit[1] and receive[6] B_1, and could remove structural information from the B_1 maps, particularly for maps measured using novel (BS, AFI) or k-space accelerated (EPI-DA) methods. For multi-site or multi-scanner studies requiring whole-brain B_1 maps, EPI-DA could be a good alternative to novel methods, which are not available as stock-sequences on most scanner platforms.

CONCLUSION: All B_1 methods resulted in comparable WM T_1 maps, and all rapid methods strongly correlated with the reference DA map. EPI-DA, the fastest of the techniques derived from a stock scanner sequence, correlated the best with Ref. DA with no observable distortion artefacts. As B_1 maps are expected to be smooth, blurring[2] or spline smoothing[9] could be beneficial at improving B_1 maps for quantitative MRI methods (e.g. spline interpolation would remove visible anatomical regions such as the sulci and ventricles in EPI-DA B_1 maps (Fig. 1)).

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