Direct calculation of $B1^+$ and $B1^-$ from two point variable flip angle data for quantitative T1 and PD mapping

Simon Baudrexel[1,2], Ulrike Noeth[2], Sarah Reitz[1,2], Johannes Christian Klein[1,2], and Ralf Deichmann[2]

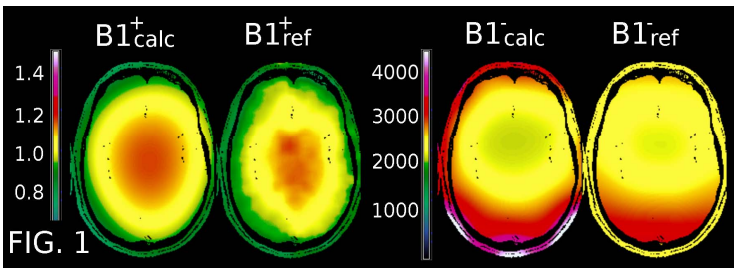
[1]*Department of Neurology, Goethe University Frankfurt, Frankfurt am Main, Germany,* [2]*Brain Imaging Center (BIC), Goethe University Frankfurt, Frankfurt am Main, Germany*

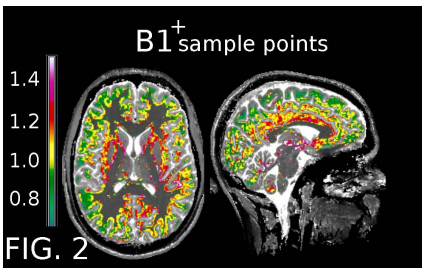
Introduction: Quantitative techniques for mapping T1 and the proton density (PD) are of increasing clinical interest as they provide information on basic physical properties of tissue. Several methods are based on the acquisition of standard spoiled gradient echo (GE) data with two excitation angles (i.e. the variable flip angle method, VFA [1]). However, this technique requires knowledge of the transmitted radio frequency (RF) field ($B1^+$) and the receiver sensitivity profile ($B1^-$) [1,2]. Several methods for $B1^+$ and $B1^-$ mapping have been proposed which, however, often require additional scans with sequences not routinely implemented on standard MRI systems [3]. A $B1^+$ mapping technique without further measurements is based on bias field correction [4]. However, although very accurate, this method depends on the correct choice of algorithms and parameters. The purpose of this work was to overcome these problems by developing a method for simultaneous $B1^+$ and $B1^-$ mapping directly from VFA data, which (i) does not require additional measurements, and (ii) is based on a simple and easy to implement postprocessing algorithm.

Theory: For TR << T1, TE << T2*, and $\alpha \ll 1$ (α: nominal flip angle), the signal S in spoiled GE data is given by the simplified Ernst equation: $S = (B1^-)\cdot PD\cdot\alpha\cdot(B1^+)/N$ (eq.1), with $N = 1 + T1_{app}\cdot\alpha^2/(2\cdot TR)$, where $T1_{app} = T1\cdot(B1^+)^2$ is the apparent T1 value obtained via VFA without $B1^+$ knowledge, assuming $B1^+ = 1$. Using Fatouros' approximation $1/PD \approx K_1 + K_2/T1$ (eq.2) [5] with $K_1 = 0.858$ and $K_2 = 522$ ms [6], eq.1 yields: $1/PD = K_1 + K_2\cdot(B1^+)^2/T1_{app} = (B1^+)\cdot(B1^-)\cdot\alpha/(S\cdot N)$ (eq.3). Replacing $Y = K_1\cdot(S\cdot N/\alpha)$ and $X = -K_2/T1_{app}\cdot(S\cdot N/\alpha)$ in eq.3 yields: $Y = (B1^+)\cdot(B1^-)+(B1^+)^2\cdot X$ (eq.4), where both Y and X can be obtained without knowledge of the RF coil bias. As $B1^+$ and $B1^-$ are slowly varying in space, both fields can be considered constant within a small volume element V (e.g. 3x3x3 mm^3). Thus, by sampling of pairs of X and Y from voxels within V, $B1^+$ and $B1^-$ values in V can be derived from linear fitting of eq.4. The following restrictions apply: (i) Since Fatouros' approximation is only valid in grey (GM) and white (WM) matter [5], voxels containing CSF have to be omitted from the fitting procedure. (ii) A certain amount of signal variability within V is necessary for reliable fitting, requiring WM/GM partial voluming in V which is fulfilled for voxels located at GM/WM borders. Thus, $B1^+$ and $B1^-$ can be calculated for certain sample points, and whole brain $B1^+$ and $B1^-$ maps may be derived via low order 3D-polynomial fitting.

Materials and Methods: In 12 healthy subjects, spoiled GE imaging was performed using a FLASH-EPI hybrid readout technique with TR/TE/FA1/FA2=16.4ms/6.7ms/4°/24°], FoV=256x224x160 mm^3, isotropic resolution 1 mm [6]. Reference $B1^+$ mapping was performed as described in [3]. Reference $B1^-$ maps were calculated via bias field correction [2]. The new algorithm for $B1^+$ and $B1^-$ calculation consisted of the following steps: 1. Sampling of X and Y within volumes V of size 3x3x3 voxels. Center voxels were located within a GM/WM mask (see below for a description of the calculation of this mask). 2. Linear fitting according to eq.4 and calculation of the correlation coefficient cc(X,Y). 3. For cc(X,Y)>0.7, derivation of $B1^+$ and $B1^-$ for the respective center voxel. $B1^+$ values >1.3 or <0.7 and $B1^-$ values >5000 or <1000 were considered outliers and excluded. 4. Second order (in case of $B1^-$ fourth order) 3D-polynomial fitting across sample points, yielding whole brain $B1^+$ and $B1^-$ maps. The initial GM/WM mask was derived via an initial run of this algorithm yielding an approximate $B1^+$ and thus an approximate T1 map. This map was thresholded according to 500ms<T1<2000ms. For reliable exclusion of CSF, the mask was further reduced in size by eroding all surface voxels.

Results: Calculated and reference $B1^+$ and $B1^-$ maps from axial slices through the thalamus are presented in Fig. 1. Figure 2 shows respective B1+-sample points with cc>0.7, most of them being located at GM/WM borders. Absolute deviations of calculated $B1^+$ and $B1^-$ from reference values (i.e. $|B1_{calc} - B1_{ref}|/B1_{ref}$ averaged across the whole brain) were similar for both fields and amounted to 3% only (all subject average).





Discussion and Conclusion: The presented technique produced accurate $B1^+$ and $B1^-$ maps in a sample of 12 subjects, as required for subsequent correction of T1 and PD maps. The method only employs the original VFA data acquired for T1 and PD mapping and is thus independent of any special MRI techniques for measuring $B1^+$ and $B1^-$ that may not be available on standard scanners. Thus, it holds promise to contribute to quantitative MRI applications in the clinical setting.

References:

1. Venkatesan R et al. Accurate determination of spin-density and T1 in the presence of RF-field inhomogeneities and FA miscalibration. MRM 1998;40:592-602
2. Volz S et al. Correction of systematic errors in quantitative proton density mapping. MRM 2012;68:74-85
3. Volz S et al. A fast B1-mapping method for the correction and normalization of magnetization transfer ratio maps at 3 T. Neuroimage 2010;49:3015-3026
4. Weiskopf et al. Unified segmentation based correction of R1 brain maps for RF transmit field inhomogeneities (UNICORT). Neuroimage 2011;54:2116-2124
5. Fatouros PP et al. In vivo brain water determination by T1 measurements: Effect of total water content, hydration fraction, and field strength. MRM 1991; 17:402-413
6. Volz S et al. Quantitative Proton Density Mapping: Correcting the Receiver Sensitivity Bias via Pseudo Proton Densities. Neuroimage 2012;63:540-552