A simple method (eMoS) for T1 mapping is more accurate and robust than the Variable Flip Angle (VFA) method

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Purpose: The variable flip angle (VFA)[1,2] method for quantitative T1 mapping requires a minimum of two 3D- spoiled gradient echo (SPGR) scans acquired with flip angles, α_1 and α_2. T1 is calculated from the signal intensities $S_{i=1,2}=S_0(1\text{-}E1)\sin\alpha_i/(1\text{-}E1\cos\alpha_i)$, where $E1=\exp(-TR/T1)$ and S_0 encompasses TE, T2*, proton density and coil sensitivity. In its most common implementation[1-4], the data points are transformed: $(X_i, Y_i)=(S_i/\tan\alpha_i, S_i/\sin\alpha_i)$ for i=1,2 and T1 can be extracted from the slope of the line defined by these points. Here, this implementation will be referred to as the VFA method. Recently, an efficient method of slopes (eMoS) has been proposed for B1 and T1 mapping[5]. This method also relies on two low flip angle SPGR signals to get T1 while using two other signals, sampled at high flip angles, for B1 mapping. Quantitative methods that rely on SPGR signal require accurate knowledge of flip angles thus accurate B1 mapping is essential. The effects of noise and errors in flip angles have been studied for VFA[1-4,6], with different B1 mapping methods across studies. Studies show that both an underestimation of B1 and increased noise levels can cause an overestimation of T1 with VFA. This may explain the observed overestimation of T1 resulting from VFA when compared to the gold standard inversion recovery (IR) experiment[6]. The goal of this work is to introduce a simplified version of eMoS for T1 mapping that results from investigating the effects of noise and B1 errors on the T1 result. Ultimately, we aim to explain the differences observed when comparing T1 maps of the human brain resulting from the VFA and eMoS methods and demonstrate that eMoS results in more accurate and robust T1 values in vivo.

Methods: eMoS solves for B1, T1 and S0, in stages. First, a B1 map is obtained via extrapolation to signal null. Next, T1 is determined using two data points, (S_1, S_2) , acquired at low flip angles, 3˚ and 14˚, respectively. Here, we propose to solve for S0 first, using an approximation: $S0=S_1/B1\cdot\alpha_1$. T1 can then be solved analytically using S_2 and the aforementioned SPGR signal equation (given B1 and S0). This is a more simple version of eMoS that eliminates data fitting. Simulations were used to assess the effect that errors in the computed B1 maps will have on the resulting T1maps calculated by both VFA and eMoS. For this, the relative error in T1, $\delta T1_{rel}$, was plotted as a function of the relative error in B1, $\delta B1_{rel}$. Simulations were also used to study the effects of noise on the T1 computations using VFA and eMoS. To test the results of T1 mapping in vivo, (S_1, S_2) were obtained for four healthy volunteers on a 3T scanner (GE MR750 Discovery) (scanning parameters: Sag FSPGR, whole volume excitation, TR/TE=5ms/10.7ms, 1mm isotropic resolution, ASSET=2). B1 maps were determined using the eMoS. The same data and B1maps were used for VFA and eMoS T1 calculations. A single slice IR experiment was performed as per ref.7 for comparison.

Results: It has been shown that for VFA, $\delta T1_{rel}$ is almost uniquely dependent on $\delta B1_{rel}$, regardless of absolute T1 and B1 values[3]. The results of our simulations reproduce this result and also show that for the eMoS, $\delta T1_{rel}$ depends not only on $\delta B1_{rel}$ but also on the absolute values of B1 and T1 (Fig.1). However, over a given range of $\delta B1_{rel}$ values < -10%, $\delta T1_{rel}$ is smaller for MoS than for VFA for a relevant range of T1 (grey matter (GM)=1600ms and white matter (WM)=800ms) and B1 values. Furthermore, the addition of noise greatly affects the $\delta T1_{rel}$ vs $\delta B1_{rel}$ relation for VFA while eMoS is more robust. Fig.2 shows that for $\delta B1_{rel}$ = -10% (vertical dotted line in Fig.1), noise causes $\delta T1_{rel}$ to increase as T1 increases, more for VFA than for eMoS. Whole brain histograms are used for T1 map comparisons of VFA and eMoS (single slice for IR) (Fig.3). Table 1 summarizes the shift of the WM T1 peak (relative to the IR WM peak) and the spread of the histograms (T1 range at normalized # voxels=0.02).

Discussion and Conclusions: T1overestimation (e.g., shift of the WM peak towards greater T1) for VFA and eMoS could be the result of B1 underestimation, i.e.,$\delta B1_{rel} < 0$. The spread of the T1 histograms can be explained as a result of the effects of noise. In conclusion, given the same data: (S_1, S_2) and B1 map, solving for T1 with the proposed eMoS yields more accurate results than if the VFA is used. Investigations into the underestimation of B1 resulting from eMoS (and other B1 mapping techniques) are underway.

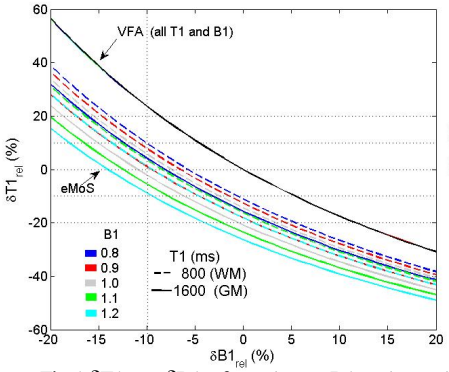

Fig.1 $\delta T1_{rel}$ vs $\delta B1_{rel}$ for relevant B1 (color-coded) and T1 (line type) values. Spread only occurs for eMoS. All VFA lines are superimposed.

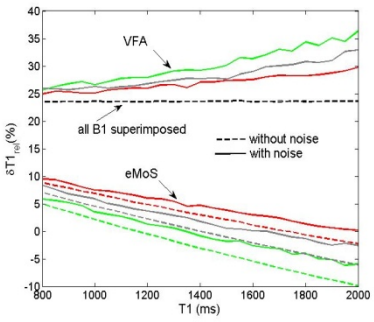

Fig.2 T1-dependence of noise effects on $\delta T1_{rel}$ for $\delta B1_{rel}$= -10% (B1 color-coded as per Fig.1) . "Without noise" is equivalent to Fig.1.

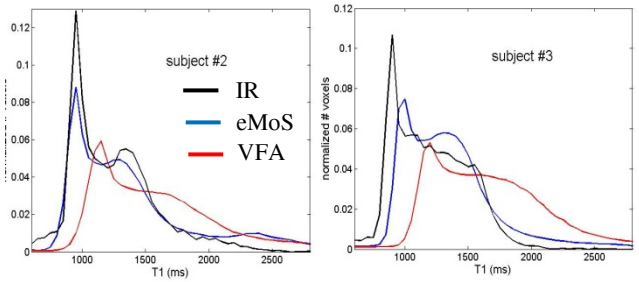

Fig.3 Normalized T1 histograms comparing results of VFA (red) and eMoS (blue) against the gold standard IR (black) for subjects #2 & #3.

Table 1. Results of T1 histogram comparisons

Subject #	WM peak shift		T1 spread (ms) (at norm #voxels=0.02)		
	VFA	eMoS	IR	VFA	eMoS
1	+42	+16	875-1675	1120-2050	925-1650
2	+21	0	850-1625	1000-1950	825-1600
3	+33	+11	800-1700	1075-2125	875-1700
4	+47	+18	750-1650	1100-2050	925-1650

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