# Simultaneous Quantitative Mapping of $T_1$, $T_2$*, and Magnetic Susceptibility with Multi-Echo MP2RAGE at 7 T

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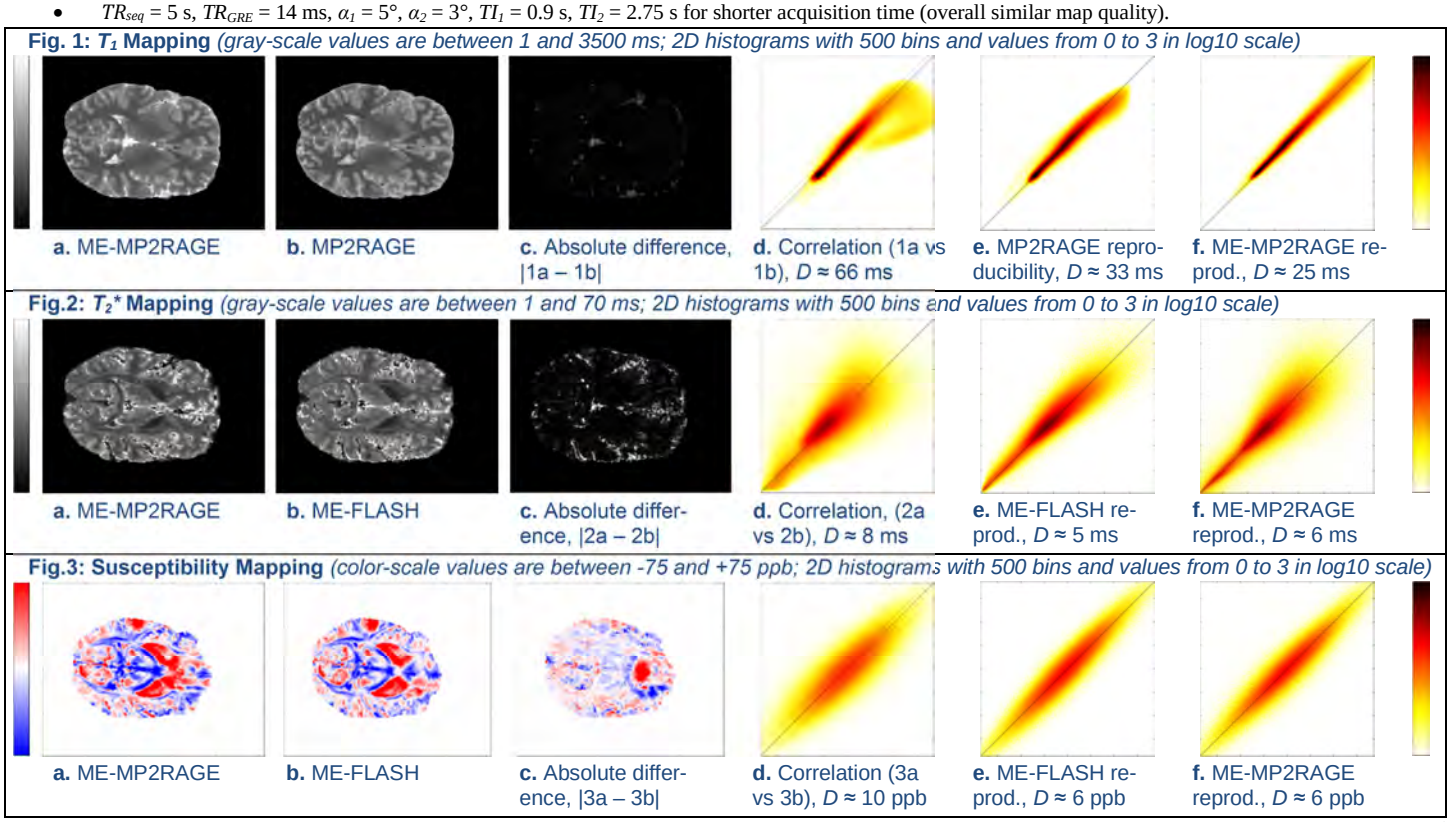
**Target audience**: Researchers and clinicians interested in quantitative MRI, in particular relaxometry and susceptibility.

**Purpose**: Knowledge of relaxation times is essential for understanding the biophysical mechanisms underlying image contrast, and can be related to tissue composition [1]. Quantitative MRI experiments may permit a more reliable interpretation of contrast variations in longitudinal studies or multi-centric comparisons. However, they often require longer acquisition times. To address this limitation, we demonstrate the possibility of simultaneously recording relaxation-time and susceptibility maps with a prototype Multi-Echo (ME) MP2RAGE sequence.

**Methods**: The MP2RAGE pulse sequence is the preferred method for obtaining $T_1$ maps. This technique is relatively insensitive to $B_1^+$ inhomogeneities, provided that the acquisition parameters are properly chosen. Several different combinations of the sequence parameters yield equivalent $T_1$ maps [2]. It is possible to modify the MP2RAGE by including multiple readouts gradient echoes after each inversion time, resulting in ME-MP2RAGE. The multi-echo images can then be used to calculate $T_2^*$ and susceptibility maps. Since higher signal-to-noise ratio (SNR) is expected to lead to better mappings, we used simulations of the Bloch equations with variable acquisition parameters for maximizing SNR, while still achieving sufficient insensitivity to typical $B_1^+$ variations across the 3D scanning volume for the $T_1$ estimate. We also selected a different set of parameters leading to a shorter acquisition time. These parameters were then used to acquire in vivo $T_1$ maps (0.9mm isotropic nominal resolution) in five healthy volunteers, using a MAGNETOM 7T (Siemens AG, Erlangen, Germany), from the two inversion times as well as $T_2^*$ and susceptibility maps calculated from the signal magnitude and phase of the ME readout after the second inversion time. Quantitative Susceptibility Maps (QSM) were obtained using SHARP and SDI techniques [3]. Voxel-by-voxel correlations with results from gold-standard reference scans were used to asses the reliability of the maps: $T_2^*$ and susceptibility maps were compared against analogous maps calculated from images acquired using a ME-FLASH sequence, while $T_1$ maps were compared to standard MP2RAGE scans. To assess reproducibility, we used the averaged Euclidean distance, $D$ (i.e., the distance of a correlation point, i, from the identity line), defined by: $D = \frac{1}{\sqrt{2}N}\sum_{i=1}^{N}|x_i - y_i|$.

**Results**: The figures show the parameter maps, difference maps and voxel-by-voxel correlations between the reference scan and the optimized ME-MP2RAGE scan. Test-retest reproducibility of results obtained with ME-MP2RAGE (Figs. 1f, 2f, 3f) and with the standard techniques (Figs. 1e, 2e, 3e) in subsequent scans are also shown. The ME-MP2RAGE acquisition parameters leading to these results were:

- $TR_{seq}$ = 8 s, $TR_{GRE}$ = 14 ms, $\alpha_1$ = 5°, $\alpha_2$ = 10°, $TI_1$ = 0.9 s, $TI_2$ = 2.75 s for better image quality (images shown in Figs. 1-3 acquired with this setting);
- $TR_{seq}$ = 5 s, $TR_{GRE}$ = 14 ms, $\alpha_1$ = 5°, $\alpha_2$ = 3°, $TI_1$ = 0.9 s, $TI_2$ = 2.75 s for shorter acquisition time (overall similar map quality).




**Discussion**: As indicated by the simulations, experimental results show that ME-MP2RAGE yields equivalent $T_1$ maps as MP2RAGE with an appropriate choice of acquisition parameters. Moreover, the simultaneously obtained $T_2^*$ and susceptibility maps were comparable to those obtained with ME-FLASH. Averaged Euclidean distance values for ME-MP2RAGE were consistent across subjects and within their standard deviation when compared to $D$ values obtained for the reference experiments. ME-MP2RAGE acquisition times were comparable to those required for corresponding MP2RAGE scans. This has been achieved as a trade-off between image resolution and the timing restrictions for the ME readout. An additional advantage for ME-MP2RAGE is that the obtained maps are intrinsically co-registered.

**Conclusion**: Using the ME-MP2RAGE acquisition scheme, we simultaneously obtained accurate and co-registered $T_1$, $T_2^*$ and susceptibility maps *in vivo* at 7T.

**References**: [1] Stüber, et al., NeuroImage 93: 95-106 (2014); [2] Marques, et al., NeuroImage 49:1271-1281 (2010); [3] Schweser, et al., MRM 69:1581-1593 (2013).

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