# Native T1 Contrast Enhancement at 4.7, 11 and 17.6 T for Neuroimaging

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**Introduction:** The push to higher magnetic field strengths has necessitated the re-evaluation of standard MR protocols to account for changes in image contrast mechanisms. Of particular interest has been the degradation of T1 relaxation contrast at high fields due to the increase in tissue T1s. Recently, several methods have been proposed to recover T1 contrast above 3 T. Among these techniques, the Modified Driven Equilibrium Fourier Transform (MDEFT) preparation (1-3) has proven to be especially useful in human neurological imaging because it provides T1 contrast enhancement over a wide range of T1 values and is less sensitive to B1 inhomogeneities. In this study, the MDEFT preparation is compared to standard saturation recovery (SR) and inversion recovery (IR) techniques at three ultra-high magnetic field strengths (4.7, 11 & 17.6 T) that are pertinent to high resolution, morphometric imaging. To assess the benefits and drawbacks of each T1 preparation technique, physiologically relevant phantoms were constructed for the three field strengths (Figs. 1 & 2). The phantoms cover a range of field dependant T1 values matched to measurements from the brains of normal C57BL6/J mice. Using these phantoms, optimal preparation times were determined for the three T1 contrast techniques at the three field strengths to provide optimal contrast enhancement over a range of T1 values. These optimal values were utilized to generate enhanced MDEFT images of *in vivo* mouse and rat brains for comparison to standard imaging protocols.

**Method:** *Fabrication of T1 phantoms*: To determine biologically relevant T1 values, living C57BL6/J mice were scanned at the three field strengths using a SR multi-slice spin-echo sequence in which the recovery time (TR) was incremented to sample longitudinal relaxation. White matter (WM) in the corpus callosum, gray matter (GM) in the cortex and CSF in the ventricles were segmented to provide a range of T1 values. T1 values for structures in the mouse brain are provided in Figure 4 as a function of field strength. Phantoms covering a range of T1s were created through the use of copper sulfate-doped deionized water.

*MR parameters*: Phantoms were imaged using SR, IR and MDEFT techniques. The MDEFT and IR sequences made use of a non-segmented gradient echo acquisition (NEX = 2; MTX = 128x128; TE/TE = 5/50 ms; Slice = 2 or 0.5 mm; $\alpha = 22.5^{o}$; FOV = dependent on magnet) that utilized adiabatic hyperbolic secant pulses during the preparation period. To assess contrast enhancement, the preparation time ($\tau$) was incremented (0.05-5 sec) for MDEFT acquisitions, the inversion time (TI; 0.05-5 sec) was incremented for IR acquisitions, and the TR was incremented (0.05-5 sec) for SR gradient-echo acquisitions.

*Data analysis*: Regions of Interest (ROIs) were placed in each of the sample containers. The mean signal from each ROI ($X_{signal}$) was recorded as a function of the total acquisition time (for MDEFT: $T_{acq}$ = PE*(TR+ 2*$\tau$)). The signal-to-noise ratio (SNR) was determined by: $SNR = X_{signal} / (\sigma_{noise} \sqrt{T_{acq}})$, where $\sigma_{noise}$ is the standard deviation of a noise ROI. The contrast to noise ratio (CNR) was determine by taking the absolute difference of the SNR of different ROIs. CNR curves (Figs. 1 & 2) that represent phantom-equivalent WM, GM and CSF T1 values are presented below as a function of $T_{acq}$. Simulated data are displayed for comparison at 4.7 T (Fig. 2).

*Mouse/Rat experiments*: To test the optimal values for $\tau$ determined from phantom experiments, animals were imaged using the three acquisition methods at the three field strengths. Mice (or rats) were anesthetized using isoflurane/95% $O_2$. SR, IR and MDEFT images were acquired over a range of acquisition times (Fig. 3).

**Results and Discussion:** There is excellent agreement between the experimental and analytical results for SR, IR and MDEFT (Fig. 2). Although the MDEFT sequence is effectively a special case of IR, one of the benefits of the MDEFT sequence may be its relative insensitivity to B1 inhomogeneities (2), which may account for the closer agreement of simulation and test results. Overall, *in vivo* MDEFT images displayed superior image contrast for a wider range of structures up to at least 17.6 T. Future work will include (i) the incorporation of fast spin echo (FSE) imaging with MDEFT to reduce magnetic susceptibility artifacts and (ii) dynamic contrast studies. Also, we plan to assess the benefits of MDEFT with respect to RF homogeneity at high magnetic fields. As frequencies head toward 1 GHz, preparations like MDEFT may be essential to maintain contrast and RF homogeneity in high resolution *in vivo* imaging.

***Fig. 1*** *(A, B) Phantom images for SR & MDEFT @ 17.6 T (C, D) CNR vs. $T_{acq}$ for SR & MDEFT @ 17.6 T*

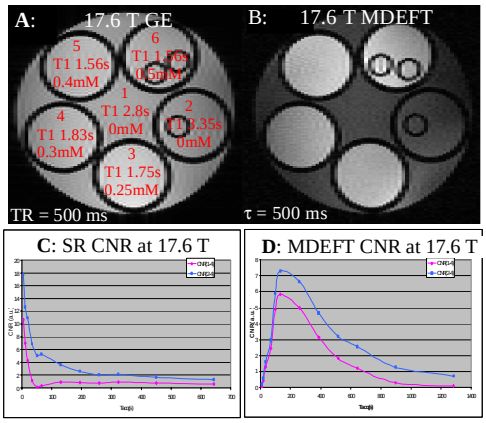



***Fig. 2*** *(A, B) Experimental Phantom CNR Curves for IR & MDEFT @ 4.7 T (C, D) Simulated CNR Curves for SR & MDEFT @ 4.7 T*

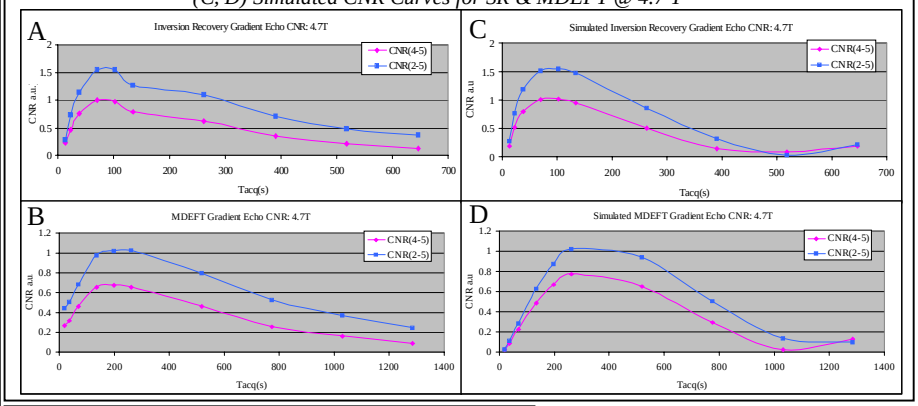



***Fig. 3:*** in vivo *Rat Images @ 4.7 T – (a,c) MDEFT; (b,d) SR* in vivo *Mouse Images @ 11 T – (e) MDEFT; (f) SR*

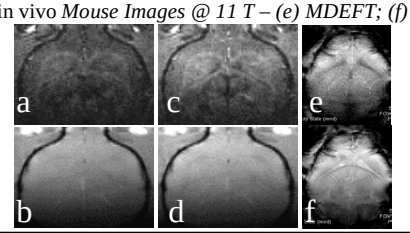
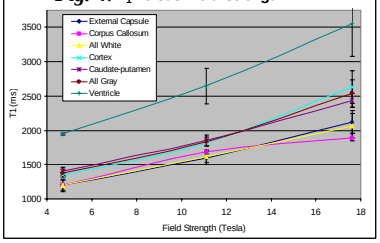



***Fig. 4:*** **$T_1$ versus Field Strength**




**References**

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