T1 mapping of MT effects in bSSFP

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Introduction: Recent work has presented the concept of magnetization transfer effects in balanced SSFP (bSSFP) acquisitions [1] for calculating MTR maps [2]. These works use a pair of bSSFP experiments: One has a short RF pulse as is commonly used to minimize TR, thus with a high RF power deposition on-resonance. The other stretches the RF pulse to up to 10 times longer, reducing the pulse's power deposition up to 100-fold, yet also lengthening TR. From this pair of experiments, MTR is calculated using $(M_{long}-M_{short}) / M_{long}$, where M_{long} is the long-pulsewidth, long-TR, low power experiment's steady-state signal, and M_{short} is the short-pulsewidth, high saturation experiment's steady-state signal.
Another quantity of interest in MT research is the variation of T1 relaxation of the free pool under varying saturation of the bound pool. When a bSSFP train is prefaced with an inversion pulse, and the transient magnetization is sampled as it progresses towards steady-state, the on-resonance spins relax towards steady-state with an apparent rate constant known as T1*. Indeed, when flip angles are moderate (< ~50°), or when T2/T1 approaches unity, the T1* value has been used as a surrogate for underlying T1, for rapid T1 relaxometry with bSSFP [3]. The T1* quantity can be related to the underlying T1 by also measuring the initial (S0) and final (Sstst) signal levels as the magnetization progresses towards steady-state [4]. In our approach, after inversion a segmented phase encode acquisition is used to acquire data until the magnetization reaches steady-state. The process is repeated until a full set of k-space data have been acquired. Because no longitudinal recovery time is required [5], very rapid T1 mapping is possible, with a constant RF saturation. This process is then repeated using stretched RF pulses of lower power, but equal slice profile and flip angle. The collection of at least two such data sets makes it possible to rapidly estimate $T1_{sat}$ and MTR values.

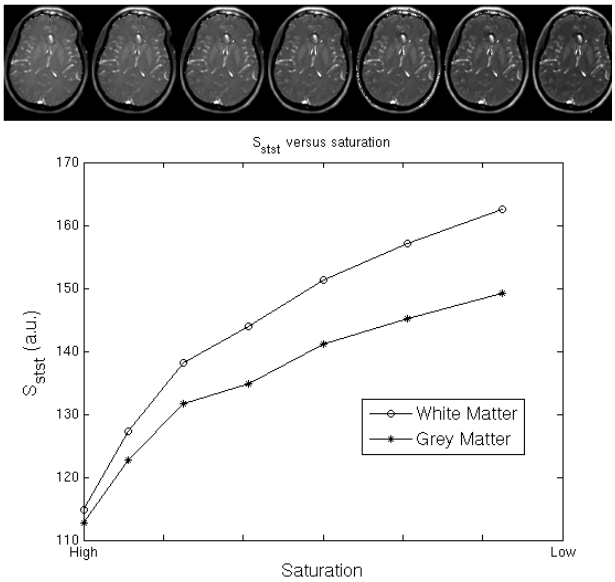

Figure 1. (top) Steady-state maps from IR-bSSFP using on-resonance RF power deposition of (left to right) 16, 20, 25, 33, 44, 64, and 100% of the unscaled RF pulse. (bottom) Mean values in an ROI in the WM and GM are plotted.

Materials and Methods: T1 mapping was performed using a 2D spiral sequence that included an inversion recovery pulse. Four interleaves of a spiral readout (80 total interleaves, readout length = 2600µs, 192x192 matrix) in a 6ms TR acquired 120 timepoints over 3s per inversion in a total scan time of 63s. The 50° flip angle was stretched from its original width of 800µs to 1000, 1200, 1400, 1600, 1800, and 2000µs. The same TR was used for all experiments to remove any concerns of TR influence. Fitting to the characteristic equation was performed [4] and T1 values were calculated.

Results: Steady-state magnetization maps fitted from the recovery curve in a volunteer experiment which measured 8 different RF powers are presented in Fig 1. The increasing RF power from left to right greatly changes the gray matter (GM) to white matter (WM) contrast. Inflowing blood spins appear bright, due to the single slice excitation. The steady-state value (Sstst) in GM and WM ROIs are plotted below in Fig 1, better illustrating the greater change in WM signal over GM signal. Apparent relaxation during the magnetization's progression towards steady state (T1*) is plotted in Figure 2. T1* depends only on the flip angle, T1, and T2. As the T2 and flip angle do not change between experiments, the decrease in T1* seen in Fig 2 is indicative of decrease in the underlying T1 with increasing saturation. Although underlying T1 values could be calculated, they showed a deviation at higher saturations, due to a marked increase in the initial (post inversion) magnetization levels, S0, without a concomitant increase in steady-state levels, as seen in Figure 3. Inflow effects, which are greater in GM than in WM, may not explain this increase, as inflow should be similar in all experiments. The S0 magnitude is determined by the amount of longitudinal magnetization left during the steady-state. Thus, in higher saturation experiments, an unaccounted for increase in the longitudinal magnetization may be related to the decreased transverse magnetization. A model that accounts for this change may be able to better quantify underlying T1.

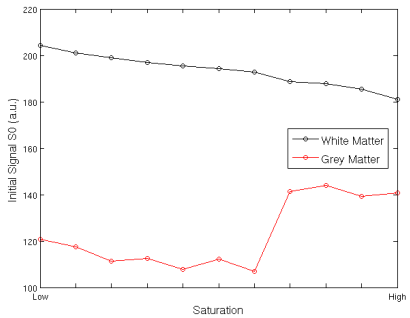

Figure 3. A marked increase in initial magnetization at the highest levels of direct RF power deposition is seen in all subjects. Here, an extreme example.

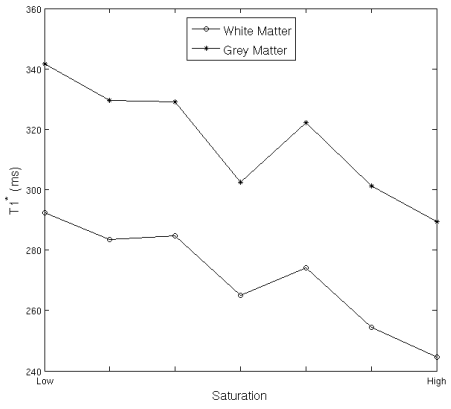

Figure 2. Apparent T1 relaxation (T1) decreases with increasing saturation, implying underlying T1 is decreasing.*

Discussion: bSSFP sequences have recently been shown to produce a measure of an MTR. As bSSFP can also quantify T1, it was natural to investigate how T1 varies with the direct RF saturation innate to bSSFP. With increasing on-resonance saturation, steady-state values decreased, as shown previously, and apparent T1 values also decreased. However, accurate quantitation of the underlying T1 was hampered by a variation in the initial magnetization levels. Further modeling may be able account for this effect.

References: 1) Bieri MRM 2006;56:1067-1074. 2) Bieri MRM 2007;58:511-518. 3) Scheffler MRM 2001;45:720-723. 4) Schmitt MRM 2004;51:661-667. 5) Gulani Invest Radiol 2004;39(12),767-774.
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