Dependance of the apparent T_1 on Magetization Transfer

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Purpose of study: To investigate the dependence of inversion recovery on inversion pulse parameters.

T_1 contrast has been widely used to study brain anatomy and pathology and is strongly affected by tissue myelin content [1,2]. Myelin increases R_1 ($=1/T_1$), as its bound (non-water) protons have a relatively high R_1, and while MRI invisible, exchange their magnetization with the MRI-visible (more mobile) water protons. Thus, quantitative measurement of T_1 through analysis of inversion recovery (IR) may provide an opportunity to infer local myelin content. Unfortunately, the IR is dependent on the initial magnetization difference between bound and mobile protons [3,4], and thus on the details of the pulse sequence. Here, we studied the IR dependence on inversion pulse power, with a focus on white matter.

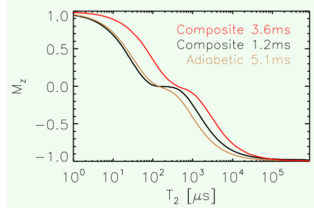

Figure 1. Simulated effect the inversion pulses used in this experiment on the magnetization for a range of T_2 values.

Theory

Because of their short T_2 (<100µs), the longitudinal magnetization (M_z) of bound protons is saturated rather than inverted by the inversion pulse of the IR experiment. Through magnetization transfer, the resulting M_z difference between bound and mobile protons affects the IR of the mobile protons in a inversion time (TI) dependent manner: at short TI, a higher apparent R_1 is expected. Importantly, initial bound proton magnetization (M_z^b), and thus initial R_1 increase are strongly dependent on the details of the inversion pulse.

Methods

IR characteristics were investigated for three inversion pulses, a 5.1ms adiabatic inversion, with 800Hz peak B_1, and two composite (90_x-180_y-90_x) pulses of total length of 1.2ms and 3.6ms. B_1 energy (time-integral of B_1^2) was 859, 833 and 277Hz respectively. Simulations indicated a strong dependence of bound proton saturation on RF pulse type: for example for a T_2 of 20µs, M_z^b was 0.47, 0.52 and 0.80 for the 3 pulses respectively (Fig. 1).

To investigate the effects on IR, 5 healthy subjects were scanned under local IRB approved protocol on a 3T scanner (Siemens Skyra). IR-EPI was used with TI times ranging from 9 to 600ms and 240x180mm^2 FOV, 144x108 resolution, five 2mm slices (1.5mm gap), sense rate 2 (with external gradient echo based reference), 4s TR, 30ms TE, fat suppression by adding two scans with 115µs difference in TE, 5 averages. The slices were acquired sequentially following the inversion pulse with the slice positions rotating through five of the TIs (as in [5]). Two averages were acquired without inversion to estimate M_0. The instantaneous apparent T_1 was calculated from M_z-M_0 at each pair of adjacent TIs. In addition, the IR of the average signal in a region of the myelin rich splenium of the corpus callosum was fitted to a two-pool exchange model in order to estimate T_1 and the effect of the inversion pulse on magnetization levels of bound and mobile protons (M_z^b and M_z^m).

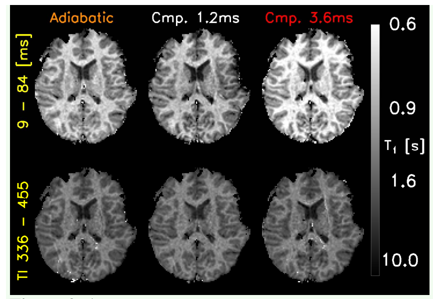

Figure 2. Apparent T_1 early (top row) and late (bottom) in the IR,for the three inversion pulses. The relaxation rate is TI dependent and more so for the shorter, higher B_1, inversion pulse.

Results & Discussion

MRI results confirmed the notion of an exchange induced shortening in apparent T_1 at short TI (Fig. 2). Furthermore, this effect was substantially larger for the low B_1 energy inversion (right column Fig. 2). Further confirmation of this effect is obtained from comparison with the exchange model, showing a close correspondence between simulated and measured IR characteristics (Fig. 3). An excellent fit with was obtained on all five subjects ($1-R^2 < 6 \cdot 10^{-5}$), with T_1 averaging 913±28ms. The bound pool fraction was found to be constrained between 11% and 14.5% by the limits on M_z^b (between 0 and 1). Magnetization levels at a 14% bound pool fraction [6] are reported in Table 1. The difference in saturation between low and high power inversion pulses suggested a (average) bound pool T_2 around 30µs. The bound pool lifetime was found to be 100±27ms. Note that this value includes exchange through the myelin water pool [7], a process that was not captured with this MRI experiment and the 2-pool model.

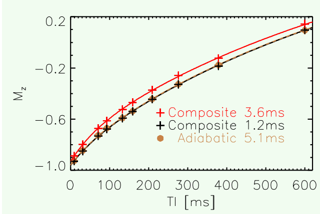

Figure 3a. IR data for the average signal in a splenium ROI, for 3 different inversion pulses. The shape and the starting point of the curves varies with pulse type. The symbols indicate data points, the curves are the result of a two-pool model fitting.

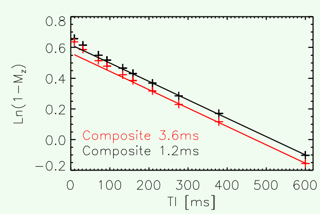

Figure 3b. The log of the data from Fig. 3a, with a line fit based on the last 3 T_i points (276-600ms), showing that the decay is deviating from mono-exponential and that this deviation is larger with a lower B_1 pulse.

Conclusion

The experiments described here confirm non-single exponential T_1 decay in white matter and its origin in the differential effect of the inversion pulse on bound and mobile proton magnetization. Strongly accelerated T_1 relaxation is observed immediately following inversion, and this acceleration is strongest for low power inversion pulses. These effects should be taken into account when attempting to quantify T_1, and will affect T_1 values obtained with techniques such as MP2RAGE when data within several times the exchange time constant of bound proton magnetization is included. Conversely, study of the IR characteristics and its dependence on pulse power provides an opportunity to estimate the exchangeable bound pool fraction and its magnetization transfer charateristics.

Table 1. Average (and SD) of the M_z-levels resulting from the two-pool fitting.

Pool\Pulse	Adiabatic	1.2ms	3.6ms
M_z^m	-0.94 (0.03)	-0.94 (0.04)	-0.91 (0.05)
M_z^b	0.17 (0.09)	0.24 (0.12)	0.85 (0.02)

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