Enhanced Slab Selective Brain Imaging at 3T using Wide Band Tailored RF pulses

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Introduction

T1 weighted brain imaging at 3T for both clinical and neuroscience applications is often done using slab selective MPRAGE [1] sequences that provide flexible 3D coverage. RF field (B_1) non-uniformity is an inherent problem for high field MRI and for this type of sequence results in variable image contrast. In order to compensate for this, various B_1 inhomogeneity mitigating RF pulses have been proposed, and for slice or slab selective imaging the most popular are the so-called "spokes" or "fast k_z" [2,3] pulses. These consist of a train of slice/slab selective pulses ("spokes") which are individually modulated to produce the desired excitation. Parallel transmission (PTx) can be incorporated into this framework, by applying different pulses on each RF coil. We designed and tested an enhanced PTx-spokes implementation of a clinically used slab selective MPRAGE protocol for at 3T.and have explored the relative merits of simple RF shimming, single channel spokes operation and full PTx with spokes.

Methods

The spatial domain small tip angle approximation RF pulse design [4] framework was used to formulate the problem **m(r) = A b(k)** where m = target excitation (uniform), A = system matrix including details of the k-space trajectory and measured fields and b = RF pulse samples. For a transverse slab the spokes are along k_z. The relevant spatial domain **r** = (x,y,ω) includes only in-plane spatial variables but is extended to include frequency since RF pulses of this type are inherently spectrally as well spatially selective [5]. Similarly the k-space trajectory is $k(t) = (k_x,k_y,k_\omega)$ where k_ω=t-T (T=pulse duration). The frequency response of the pulse was considered over two bands: fat = -435 Hz and water = -100,-50,0,50,100 Hz. Inclusion of the fat response protects against producing spatially nonuniform excitations in fat [6] while the wide bandwidth of the water band makes the response robust against off resonance. A relative weighting parameter W_{fat} for the fat band was included in the pulse calculation in order to investigate the influence of the fat band in the optimization. The problem was solved using magnitude least squares (MLS) optimization [7] ($b = \arg_b \min\{ \|\, |A\,b| - m\|^2_w + \lambda\|b\|^2 \}$) where λ is a regularization parameter and w represents weightings applied. A short RF pulse is required for compatibility with rapid imaging sequences; a five spoke trajectory was used, with each subpulse separated by 0.5ms. A symmetric k-space trajectory was used: $k_x(t) = \{-\Delta k,0,\Delta k,0,0\}$, $k_y(t) = \{0,\Delta k,0,-\Delta k,0\}$ (similar to that in [3]) with Δk=7.5 cycles/m, resulting in a modulation of ~1 cycle over the head. In order to fully quantify the local SAR, estimates of the electric fields are required. However an estimate of the relative RF power can be obtained from EQ1, in which $\theta_{c,p}$ is the flip angle for pulse p on coil c, θ_{nom} is the nominal flip angle and N_c is the number of coils.

$$\text{EQ1} \quad P = \sum_{c,p} \left|\theta_{c,p}\right|^2 \Big/ N_c \times \theta_{nom}^2$$

This study used a whole-body 3T Achieva MRI system (Philips healthcare, the Netherlands) with an 8 element parallel transmission body coil [8] and an 8 channel SENSE head coil for signal reception. The body coil can emulate a quadrature coil using predefined amplitude and phase settings. For the pulse calculation, slice selective B_1 maps were acquired using Actual Flip angle Imaging [9,10] with the array mapping described in [11] and a B_0 map was acquired using a dual echo sequence; total field mapping time was 1m50s. A standard 3D MPRAGE protocol with isotropic resolution 1.2 mm^3 was used for imaging: T_I=1250ms, 199 echoes per readout, TR=12ms TE=4.6ms, flip angle 8°, interval between inversion pulses 4000ms, SENSE factor 2, scan time 5 min. adiabatic inversion pulses were used with the body coil in quadrature mode; the rapidly applied slab selective small flip angle pulses were substituted for the tailored RF pulse described above.

Results & Discussion

Using acquired field data for one volunteer, pulse optimisation was performed for different values of W_{fat}; Figure 1 summarises the results. If fat is excluded from the optimization (W_{fat}=0) there is a strong spatial modulation of the excitation at he fat frequency, however this error rapidly drops even for very small values of W_{fat}. Excitation uniformity for water is almost independent of W_{fat} ,but increasing this weight does increase the relative RF power required. Based on these findings a value of W_{fat}=0.1 was used for all studies. Acquired MPRAGE images for a healthy volunteer are given in figure 2. The contrast between grey and white matter is improved when using the tailored RF pulse, and this leads to better visibility of deep grey matter structures. In this examination the relative power of the tailored RF pulse was 1.0 – i.e. the same as for the control pulse. The sequence ran at only 4% of the maximum allowable SAR (estimated using total RF power) – while local E-fields were not accounted for there was a large margin to accommodate undesirable effects. With parallel transmission, another possible approach is to use RF shimming – i.e. alter magnitude and phase for each channel but only use one pulse; conversely it is also possible to make a spokes pulse with a single channel system. Figure 3 compares optimal excitations obtained by these approaches. RF shimming requires relative power 1.5 and does not perform well since the coils are far from the head, in fact a spokes pulse using quadrature mode performs better and requires relative power 1.15. Spokes in conjunction with parallel transmission leads to lowest error and lowest power. This study shows that parallel transmit can provide an effective mitigation for RF inhomogeneity in slab selective brain imaging improving tissue contrast without increasing the applied RF power.

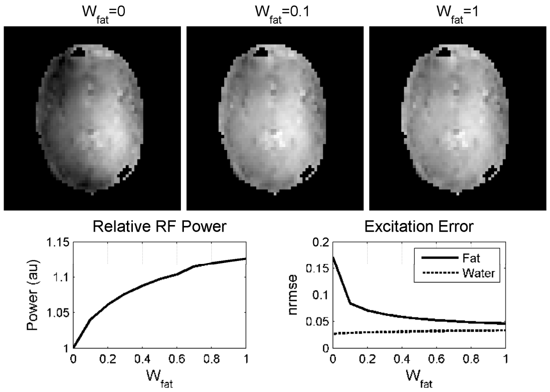

Fig 1 **Top:** Simulated excitations at the Fat frequency for different values of W_{fat} ; **Bottom:** Graphs showing variations of power and error with W_{fat}

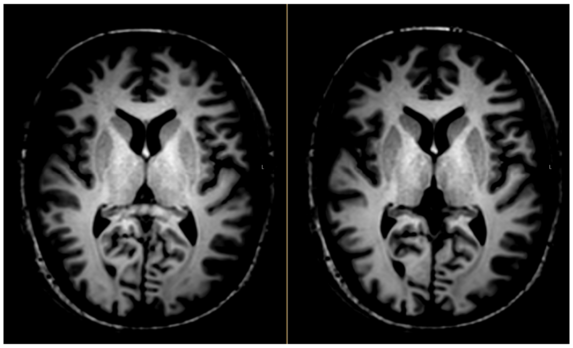

Fig 2: MPRAGE image using standard pulse (left) and tailored pulse (right)

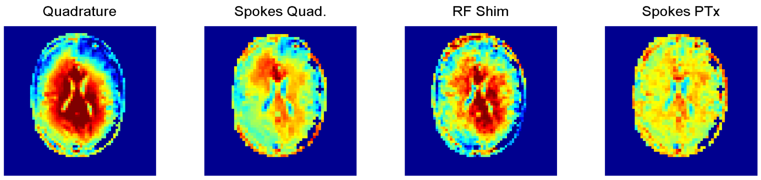

Fig 3

References

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