Comparison of Current B1-Mapping Techniques

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Introduction:

In recent years the deleterious effects of B1 inhomogeneity has become increasingly apparent in high field human MR images. As stronger main field magnets are used, dielectric effects distort the RF field, leading to image intensity gradients and incorrect values in quantitative maps, in particular in fast T1 and T2 mapping methods such as DESPOT1 and DESPOT2 [1]. As a result, there is a strong need to develop techniques to rapidly and accurately map the distortions in the B1 field. In the past few years several new B1 mapping techniques have been introduced, but to date none has emerged as a standard. The goal of this work was to quantitatively compare some of these known B1 mapping techniques on the basis of accuracy and signal-to-noise efficiency.

Methods:

The sequences analyzed were the standard double angle method, Cunningham's modification of the double angle method [2], Yarnykh's pulsed steady-state method [3], and Morrell's phase sensitive technique [4]. The standard double angle method is a long TR acquisition [5], whereby an image is acquired at a prescribed flip angle, α, and then twice that, 2α, from which the trigonometric double angle formula can be used to determine the true flip angle. Two criticisms may be made of this technique: that it is slow due to the requirement for long TR, and that it must be assumed that actual flip angle scales linearly with prescribed angle. Cunningham addressed the first of these by using a saturation pulse and an EPI readout. The saturation pulse ensures the same Mz is achieved before the α and 2α pulses negating the need to wait for full relaxation to avoid T1 bias, and the EPI readout speeds up the acquisition. Yarnykh proposed another steady-state technique not based on the double angle method. He used a dual steady state using two interleaved TR values (TR1 and TR2), and so long as TR1<TR2<T1 there is minimal T1 related error. Morrell used yet another steady state approach using a nominal inversion pulse immediately followed by a nominal 90 degree pulse, and the phase of the resulting signal would provide information on the accuracy of the nominal 180. This technique can be generalized to arbitrary flip angles. If two orthogonal pulses of arbitrary, identical flip angle, are applied in quick succession the flip angle would be given by $\alpha = \arccos(\tan(\beta))$ where β is the phase of the resulting image. We used numerical simulations, with additive noise, to calculate the bias in estimating the true flip angle, and the signal-to-noise efficiency, for each of the above four methods. Signal-to-noise efficiency was defined as the signal-to-noise ratio in the B1 map (which we call the alpha to noise ratio, ANR, α/σ_α), normalized by the square root of the scan time: efficiency = ANR/sqrt(scantime). The effective scantime was taken to be an appropriate function of TR. For example the effective TR for Yarnykh's method would be TR1+TR2, and for the double angle method it would be 2TR. Low bandwidth and an EPI readout can be used in both the double angle method and Cunningham's modification to improve SNR or speed without changing TR. Yarnykh and Morell's methods on the other hand are fast steady state techniques and as such cannot make use of EPI without changing TR, and a compromise would have to be reached between bandwidth, EPI train length and TR. For the purposes of this initial comparison, EPI acceleration (or any other form of readout acceleration) was not considered. Also, the optimal imaging parameters depend on the T1 of the tissue, as well as on the target flip angle. A target of T1=800 ms was chosen for optimization, but T1 = 400 ms and T1 = 1600 ms were also analyzed. The noise was set at a fixed proportion of M_0 ($\sigma_{noise} = 10^{-4} M_0$), and T2 effects were ignored (i.e. echo time the same for all sequences).

Results:

For the double angle method, any TR < 2.5T1 leads to significant distortion of α across the range of α observed, as can be seen when T1 = 1600 ms in Figure 1 (top right), and this proved to be the limiting factor in optimization (TR = 2000 ms at T1 = 800 ms for this sequence). Interestingly, Cunningham's modification of the standard double angle method shows nearly identical ANR/sqrt(scantime), but does not have the T1 bias problem. The fact that a long TR value (TR = 2000 ms) is still required for optimal performance is due to the fact that significant time must still be given for Mz to recover. While the double angle method and Cunningham's modification achieve an optimal ANR/sqrt(scantime) uniformly for different α's, Yarnykh and Morell's methods can be optimized for either large or small target α values. For Yarnykh's method these optimal values were TR2/TR1 = 4, TR1 = 5 ms for low flip angle optimization, and TR1 = 100 ms for high flip angle optimization, and for Morrell's method TR = 10 ms for low and 100 ms for high angle optimization. When using large flip angle optimization, all the techniques appear to have similar SNR efficiency, however when optimized for low flip angles, Yarnykh and Morrell's methods provide an order of magnitude improvement in ANR/sqrt(scantime) over the double angle techniques at low flip angles (<10 deg), with Morrell's method appearing to perform better than Yarnykh's method.

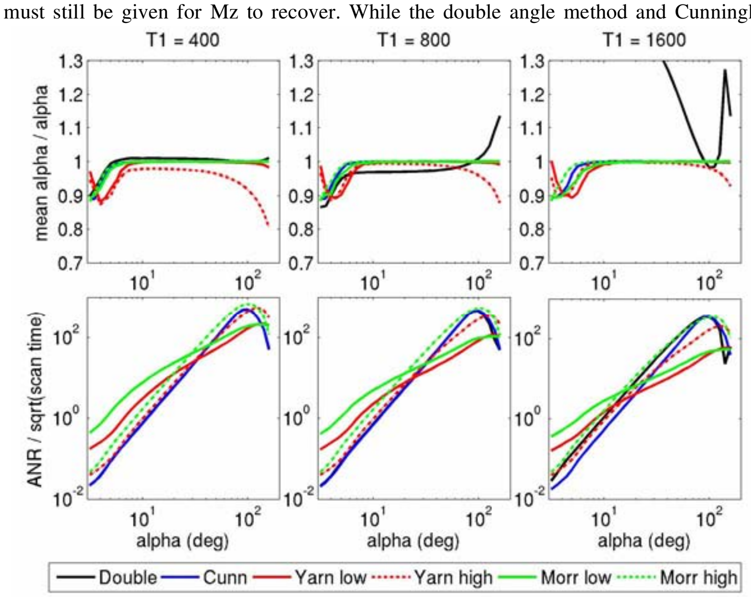

Figure 1: Comparison of noise sensitivity of four B1 mapping methods over a range of flip angles (3-180 deg) and different T1 values.

Conclusion:

This comparison shows that Morrell and Yarnykh's techniques can outperform the double angle methods at low flip angles with Morrell's phase sensitive method providing the highest SNR efficiency at low flip angles. EPI can be used to increase SNR efficiency, though comes with associated artifact and distortion problems, and is unlikely to result in the order of magnitude efficiency increase required to bring the double angle methods up to equal or exceed Morrell's method. Morrell's method is sensitive to B0 inhomogeneity, which is handled either with additional imaging acquisitions or by using custom, short RF pulses. Yarnykh's method, on the other hand, should work with any arbitrary RF pulse and does not rely on the double angle method or the assumption of transmitter linearity.

References:

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