Generating Flip Angle maps by nonlinear estimation from the initial non-equilibrium EPI signal

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Introduction: One problem facing MRI and MRS is the spatial variation in the flip angle. This arises from non-uniformities in the B_1 field which in turn arise from inhomogeneous radio frequency (RF) coils [1] and from the effects of sample loading [2]. The net result is a non-uniform distribution of power throughout the sample which manifests itself as a spatial variation in the flip angle.

This study introduces a new method for mapping flip angle distributions by using the initial transient in echo planar imaging (EPI) time course series. The technique employs a nonlinear estimation, on a voxel-wise basis, of the EPI signal as it approaches equilibrium during initial RF excitations.

Methods: The behaviour of the longitudinal magnetization can be described by iterating the equations:

$$M_-^{new} = (1 - e^{(-TR/T_1)}) * M_0 + e^{(-TR/T_1)} * M_+^{old}$$
$$S_0^{new} = \sin\phi * M_-^{new}$$
$$M_+^{new} = \cos\phi * M_-^{new}$$

These equations are used by a nonlinear fitting routine as an estimate to the time course of the signal (S_0). T_1, equilibrium longitudinal magnetization (M_0) and flip angle (ϕ) are left as free parameters to be estimated by the fitting routine. M_- and M_+ represent the longitudinal magnetization before and after successive RF pulses, respectively.

Data were collected from both phantom (a cylinder, 16.5cm in diameter and filled with a 0.075M NaCl and 0.005M $CuSO_4$ solution) and human subject scans at several flip angles between 30° and 90°. The scans were performed on a Bruker Biospec 3T system using a torque-balanced three-axis gradient coil with an end-capped bird-cage RF coil. Scan parameters were TR = 100ms, TE = 30ms with the image resolution set at 32x32. Each acquisition lasted 10 seconds.

Results: The data were analyzed using the "Nonlinear Fit" subroutine within AFNI [3]. Figure 1 shows the flip angle maps generated from the phantom and human images, both taken at a nominal 45° flip angle.

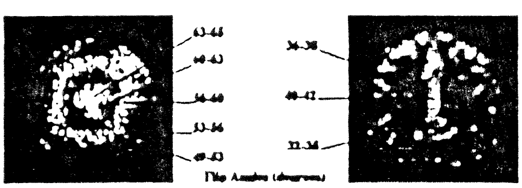

Figure 1: Phantom and Human Flip Angle Maps

The observed variations in the flip angle are consistent with predictions made by Yang et al. [2], i.e., because of dielectric resonance, the B_1 field is stronger at the center of the object and the flip angle there will be greater than at the periphery. However, the flip angle map in the anatomical images appeared to have a very similar pattern to the white and grey matter pattern in the anatomical image.

Simulations were also performed to determine the extent of coupling between any of the parameter pairs. All three parameters were varied in a predetermined fashion with different SNR (between 20 to 50). Figure 2 shows the results of the simulation where the flip angle was varied down the FOV and M_0 was varied across the FOV. This image implies that the estimate of the flip angle is not strongly coupled to variations M_0. An identical picture was obtained when the simulation to determine the coupling to T_1 was performed.

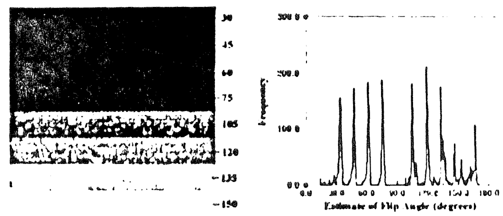

Figure 2: Simulated variation of M_0 and Flip Angle

The value of flip angles in these simulated images varied between 30° to 150° at an SNR of 50. The graph shows the distribution of the estimated flip angles generated by the algorithm. The results imply the algorithm provides very reasonable estimates of the flip angle, even with large variations in M_0 and T_1. The "leakage" at higher flip angles may be due to the errors that result in the algorithm trying to fit rapid oscillations of the magnetization.

Discussion: The estimation of flip angle from the initial magnetization transient has proven to be very robust and accurate, even with large variation in T_1 and M_0 values. This is very useful as it allows mapping of the flip angle from the data already collected, and does not require additional scans or pulse sequences.

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