OPTIMIZATION OF FLIP ANGLES IN SPGR IMAGING FOR QUANTITATIVE T_1 MAPPING OF THE CERVICAL SPINAL CORD AT 3.0 T

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Introduction

Image contrast in MRI is based on the intrinsic relaxation properties of different tissues. Quantitative mapping of the longitudinal relaxation time constant, T_1, allows for optimization of pulse sequences to yield high contrast between tissues and allows for further tissue characterization and classification. Recently there has been a shift from traditional methods for T_1 mapping, such as inversion-recovery (IR) and saturation-recovery (SR), to faster volumetric methods employing Spoiled Gradient Recalled Echo (SPGR) or Fast Low Angle Shot (FLASH) sequences acquired with two or more flip angles at constant repetition time (TR). Increased precision and accuracy of the estimated T_1 values is achieved by the choice of flip angles and TR. Here, we propose optimized flip angles for accurate T_1 measurement of the cervical spinal cord at 3.0T under the presence of noise in a Monte Carlo simulation using the Driven Equilibrium Single Pulse Observation of T_1 (DESPOT1) sequence [1]. The accuracy is validated using the traditional IR method for T_1 mapping.

Theory

DESPOT1 employs SPGR sequences acquired with two (or more) flip angles with constant TR. Therefore the SPGR signal equation in its linear form is given by

$$\frac{S_{SPGR}}{\sin\alpha} = \frac{S_{SPGR}}{\tan\alpha}\left(e^{-TR/T_1}\right) + \rho\left(1-e^{-TR/T_1}\right) \qquad [1]$$

where S_{SPGR} is the SPGR signal intensity associated with flip angle α, and ρ is a factor proportional to the equilibrium longitudinal magnetization. Therefore by plotting $S_{SPGR}/\sin\alpha$ against $S_{SPGR}/\tan\alpha$, we can calculate $T_1 = -TR/\ln(slope)$, and $\rho = \text{intercept}/(1-slope)$ for each voxel in the image volume. The choice of flip angles can significantly affect the precision and accuracy of the derived T_1 values. In the dual angle limit the precision of the derived T_1 values is maximized by choosing flip angles which provide 71% of the signal associated with the Ernst angle, $\alpha_E = \text{acos}\left(e^{-TR/T_1}\right)$. At high field strengths double flip angle methods based on SPGR sequences are hindered by transmit field inhomogeneity (B_1) resulting in variations in the flip angle profiles and hence affecting the derived T_1 values. We therefore used an inversion recovery SPGR approach [2] called DESPOT1-HIFI involving application of a 180° inversion pulse, an inversion time (TI) delay and a train of low angle RF pulses, separated by a TR, which sample successive *k*-space lines. If the centre of *k*-space is acquired immediately following each 180° pulse, the IR-SPGR signal can be approximated as

$$S_{IR-SPGR} = \rho\left[1-\left(1-\cos k180^\circ\right)e^{-TI/T_1}+e^{-TR/T_1}\right]\sin k\alpha_p \qquad [2]$$

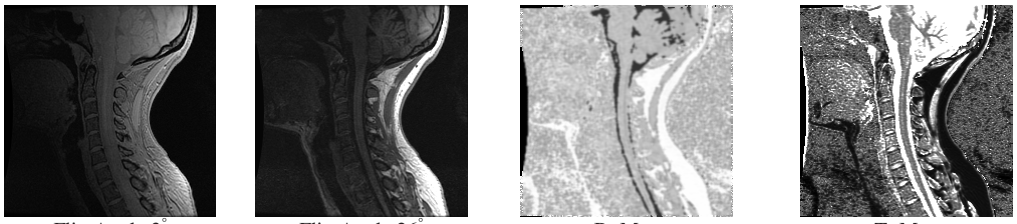
where TR is the time between 180° pulses and *k* denotes the spatially varying flip angle α_τ profile ($\alpha_\tau = k\alpha_p$). A unique solution for T_1, ρ and *k* can then be calculated using least-squares minimization of equations [1] and [2].

Methods

Simulations were performed using 14 test tubes with different concentrations of Gadolinium producing a wide range of T_1 values from approximately 500ms to 1500ms. For the cervical spinal cord a T_1 is approximately 900 ms taken from [3]. The optimum flip angles yielding 71% of the Ernst signal are then 3° and 26°. Generating random noise with a normal distribution and performing a Monte Carlo simulation 10,000 iterations yields a T_1 of 902.2785 ± 49.72 ms. Subsequently 10 healthy volunteers underwent MRI of the cervical spinal cord. All MRI experiments were performed on a 3.0T MRI scanner (Signa Excite HDx, GE Healthcare, Waukesha, WI) using a 16-channel receive-only array cervical spine coil (NOVA Medical Inc,Wakefield, MA). Analysis for the DESPOT data was done in ImageJ (http://rsb.info.nih.gov/ij/) and for the FSE-IR data was performed in MATLAB (Mathworks, Natick, MA). DESPOT1 data were acquired using TE=3.0 ms TR=6.6 ms, RBw=31.25KHz, FOV=210x210mm^2 1.00 mm^3 isotropic voxel and the following specific parameters: SPGR: Flip Angles=3°,26°, Matrix=212x212x176 in 3 min time per flip angle. IR-SPGR: Flip Angle=5° TI=350, 450 ms, with a Matrix=212x106x88 zero-padded to full size prior to Fourier reconstruction. Imaging time for both IR-SPGR was 6 mins. For reference and calibration of the DESPOT1 sequences T_1 maps were calculated from 6 geometrically spaced TI using FSE-IR data acquired as TE=14ms, TR=15000ms (to allow for full relaxation), TI={50,177,432,942,1961,4000}, ETL=16, RBw=15.63KHz, Matrix=256x256, FOV=140x140 mm^2. To avoid intersection modulation effects, a single slice (5-mm thick) through the center of the tubes was imaged. For each TI point the imaging time was 4 mins. T_1 measurements were made using a 3-parameter exponential fit on each voxel as $M_z(TI) = M_0\left[1-2\alpha e^{-TI/T_1}+e^{-TR/T_1}\right]$ where M_z is the longitudinal magnetization (signal intensity), M_0 is the maximum observable signal intensity, and α is the spin-density factor corrected for T_2 losses. The coefficient of variation between the FSE-IR data and the DESPOT1 using 2 flip angles was 3.06%.

Results

The following quantitative maps for the Cervical Spinal cord are produced illustrating the optimization of the flip angles for accurate estimation of T_1 values



Flip Angle 3° | Flip Angle 26° | B_1 Map | T_1 Map

Discussion and Conclusions

DESPOT1 although providing a robust and fast approach to T_1 estimation has shown to be highly sensitive to B_1 inhomogeneities in high fields suggesting that careful selection of acquisition parameters is essential and B_1 correction is essential before it can be used for cervical spinal cord imaging in clinical practice.

References

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