Ultra-High Field Optimization of the Double Inversion Recovery (DIR) sequence: Gray Matter Imaging at 7T

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Target Audience:

Clinicians and scientists who perform gray matter imaging and lesion detection with the DIR sequence.

Purpose:

The goal of this project was to develop an optimized double inversion recovery (DIR) sequence [1] for gray matter imaging at ultra-high field (7 Tesla). Several issues compromise image quality and scanning efficiency when the DIR sequence is used at ultra-high field: SAR limitations, a hyper intense fat signal, and an inhomogeneous B_0 and B_1 field distribution. To overcome these restrictions several improvements were implemented in a 3D-DIR sequence with an extended phase graph based variable flip angle spin echo readout [2]. The proposed modifications enabled whole brain gray matter imaging (resolution = 1 mm^3) in short scan times (~6 min) at 7T.

Methods:

All imaging experiments were performed on a MAGNETOM 7T scanner (Siemens AG, Healthcare Sector, Erlangen, Germany) using a 32 channel head coil (Nova Medical, Wilmington, USA). A 3D non-selective variable flip angle (vFA) DIR-TSE sequence [2] was optimized for ultra-high field application. The variable flip angle calculation was based on the extended phase graph algorithm, and the flip angles were optimized to yield highest possible SNR for a predefined signal shape. As signal shape an exponential decay with an initial plateau was chosen in order to control point-spread function (PSF) blurring. To reduce and keep SAR within specifications, a mechanism was implemented which recalculates the flip angle train with reduced amplitudes, if SAR restrictions were not met. This was done by down scaling the first flip angle of the echo train and recalculating the remaining flip angles for the prescribed signal shape. This procedure was applied iteratively until SAR restrictions were met.

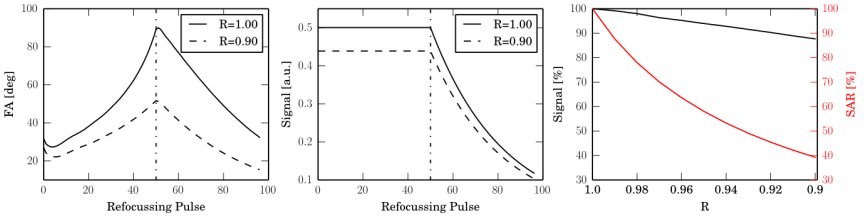

Figure 1: Dependency of flip angle reduction factor R on flip angle train (left), and gray matter signal amplitude (middle). On the right side the signal and SAR are depicted for different reduction factors. A flip angle reduction of approximately 50% decreases the gray matter signal intensity only by ~10%.

Another issue at high field is that the fat signal gets more dominant and degrades image quality significantly, resulting in severe fold over artifacts if parallel imaging is used, see Fig. 1. For that reason we implemented a water excitation (based on binomial pulses) in the sequence to selectively excite the water protons and therefore suppressing the fat signal effectively. The water excitation method was compared to a spectrally selective fat suppression method proposed by Madelin et al. [3]. Moreover, to overcome B_0 and B_1 inhomogeneity issues, and improve inversion efficiency, we implemented HSN pulses with exponents N>1 in the DIR preparation module [4]. Before each imaging session B_1-mapping was performed and the transmitter voltage was optimized for cortical gray matter. Additionally, to get the main magnetic field as homogeneous as possible, we applied a shim over the whole FOV up to the 3rd order.

All experiments were performed in a healthy male volunteer using the following parameters: TI1/TI2/TR = 2364/356/2500 ms, ETL = 100, 1x1x1 mm^3 resolution, matrix size 256x256x160 (whole brain coverage), 2D-Grappa factor 4 (2x2). Total scan time: 6:00 min. Additionally, to demonstrate the feasibility to perform a "sequence driven" segmentation with the DIR sequence the inversion times were changed to acquire white matter (TI_1/TI_2 = 2423/746 ms) and CSF images (TI_1/TI_2 = 1486/432 ms) as well. For white matter and CSF imaging only the inversion times were adapted to suppress the unwanted tissue components. The remaining image parameters were kept similar.

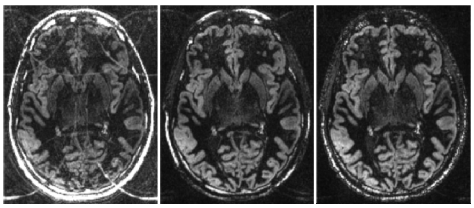

Figure 2: Gray matter images of a healthy subject. Left: No fat suppression applied. Middle: Fat suppression based on frequency selective inversion [3]. Right: Water excitation

Results:

Figure 1 (left and middle plot) shows simulated flip angle trains and signal envelopes for the original FA calculation (flip angle reduction R=1.0) and a SAR reduction of 60% (R=0.90). In the right plot the signal amplitude and SAR change is depicted for different reduction factors. While SAR could be reduced significantly, the image SNR remained almost constant and was less affected. A representative axial slice of a DIR gray matter acquisition is shown in Fig. 2. Signal from white matter and CSF was completely suppressed. Folding artifacts originating from fat (*left*) were significantly reduced by the application of fat suppression. Compared to the chemical shift based inversion method (*middle*) the water excitation acquisition (*right*) shows a more homogenous fat suppression. Furthermore, the SAR slightly decreased in the water excitation acquisition compared to the chemical shift based inversion method were the SAR increased significantly, due to the additional application of an inversion pulse.

Conclusion:

It was shown that high resolution, 3D whole brain DIR imaging in short scan times is possible at 7T. This was achieved by the implementation of a mechanism to reduce SAR dramatically, while maintaining the high image SNR at UHF. This enabled the possibility to shorten imaging time significantly without running into SAR constraints.

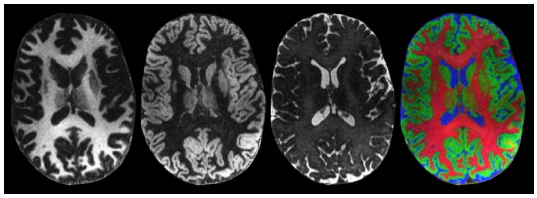

Figure 3: "Sequence driven" tissue segmentation using the proposed method. From left to right: White matter, gray matter, CSF images, and the corresponding composite RGB overlay.

References:

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[4] Tannus A., Garwood, M. NMR in Biomedicine 1997;10, 423–434.