Investigation and Modeling of Magnetization Transfer Effects of conventional and hyperecho TSE sequences at 1.5T and 3T

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Purpose

2D turbo spin echo sequences (TSE) with a large number of slices for good volume coverage find widespread applications in clinical routine MRI examinations. One undesirable side effect of this type of acquisition is that adjacent slices act like an off-resonance excitation pulse (1). This leads to an “artificial” magnetization transfer (MT) effect and, hence, undesired MT contrast (1-5). Low flip angle TSE sequences with constant and varying flip angles have become popular to overcome SAR issues. However, the observed MT effect is related to the submitted RF power which also depends on the refocusing flip angles. Thus, the MT effect for different kinds of multi-slice TSE sequences with constant refocusing flip angles (conventional) and varying refocusing flip angles (hyperTSE: TRAPS (6) and hyperechoes (7)) at 1.5T and 3T was investigated. It will be shown that the quantified MT effect of such TSE sequences highly depends on the refocusing flip angle and that the data can be described by a modified model derived from “classic” MT experiments that usually use continuous wave off-resonance irradiation.

Subjects and Methods

All experiments were performed on, both, a 1.5T and 3T whole-body imaging system (Siemens Sonata and Siemens Trio, Erlangen, Germany). Different schemes of flip angle variations were implemented in a common TSE sequence (TR/TE=5000/80ms, MATRIX=256x208, ESP=6.6ms, slth=5mm): constant flip angles (180°, 150°, 120°, 90°, 60°), hyperechoes (90°, 60°), TRAPS (90° and 60° with linear and sinusoidal flip angle ramps). A protocol with two different echo train lengths (ETL=17, ETL=27) was employed. For MT investigations comparative measurements between single- and multi-slice acquisitions (5 slices, dist.=5mm) were performed. Signal intensities ($I_{single\text{-}slice}=I_{ss}$ and $I_{multi\text{-}slice}=I_{MS}$) were evaluated in ROIs of cerebral WM, GM, CSF, and subcutaneous fat. MT effect was quantified via the attenuation I_{MS}/I_{SS}. For a physical / theoretical description of the experiments the theory for a “classic” continuous wave (cw) MT experiment with a discrete off-resonance frequency $\delta\omega$ described by Eng et al. (8) was adapted to multi-slice imaging with TSE sequences submitting arbitrary flip angles. Though the performed experiments exert a discontinuous spectrum of off-resonance frequencies, the following heuristic approach can be made: The square of the saturating B1 field in MT experiments is a measure for the RF power level which is proportional to the square of the refocusing flip angle α in a generic multi-slice TSE sequence. Hence, $B1^2$ can be replaced empirically by α^2 similar to the model proposed by Melki et al. (1) for TSE180° multi-slice imaging with a varying number of slices. This leads to:

Eq. [1] $I_{MS}/I_{SS} = A + (1-A)/(1+B\cdot\alpha^2)$ with Eq. [2] $A = 1/(1+k_{for}\cdot T1_f)$. Term B denotes the overall spectral effect of the off-resonant slices, k_{for} is the exchange rate constant between the liquid and semisolid proton pool. $T1_f$ signifies the respective T1 relaxation time of the “free” protons. As a result, I_{MS}/I_{SS} vs. α measured in the experiments was fit to Eq. [1] taking A and B as free parameters using a non-linear least squares fit algorithm. The MT pool exchange rate k_{for} for each tissue was then estimated by employing Eq. [2] and the corresponding $T1_f$ relaxation times from Ref. (9).

Results

Figure 1 presents the assessed mean MT effect versus the refocusing flip angles used by the TSE sequences for ETL=27 at 1.5T (upper row) and 3T (lower row). For TSE sequences with varying flip angles the arithmetic mean of the corresponding flip angles was used. The MT effect for WM compared to GM is constantly stronger for each sequence due to the higher content of macromolecules. The attenuation I_{MS}/I_{SS} caused by MT effects is more pronounced at 3T than at 1.5T for identical tissues. Moreover, hyperTSE sequences with their low mean flip angles show a considerable lower MT effect than the common TSE180°. A very good correspondence between the acquired data and the generated respective fits to Eq. [1] for both, conventional and hyperTSE, is demonstrated. In **Table 1** the obtained fit parameters A and the resulting MT transfer constants k_{for} (Eq. [2]) are displayed. The quantified MT effects for CSF and fat were negligible for each sequence at both field strengths. Results for the protocols with ETL=17 were found to be similar (not shown).

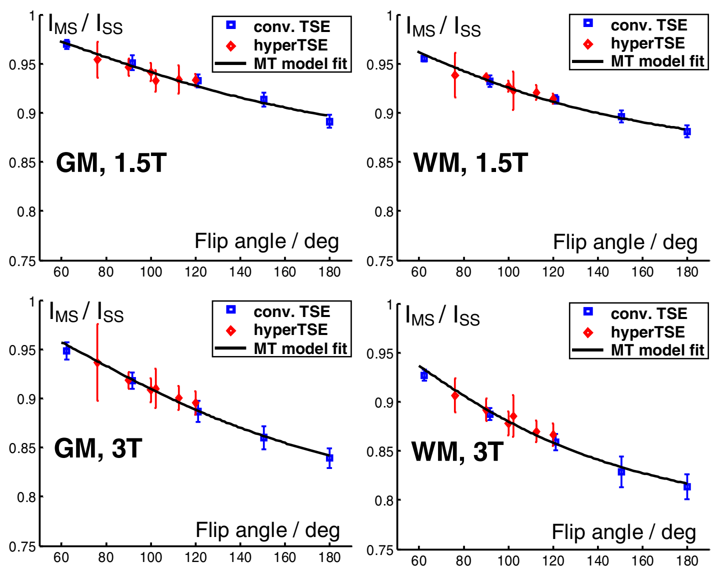

Figure 1: MT effect vs. flip angle for GM and WM at 1.5T and 3T is illustrated (ETL=27). The solid lines through the measured data points were generated by a fit to Eq. [1] (Methods section). For TSE sequences with varying flip angles the arithmetic mean of the flip angles was used.

Discussion and Conclusion

A ; k_{for} / Hz	GM	WM
1.5T	0.84 ; 0.17	0.84 ; 0.24
3T	0.76 ; 0.21	0.76 ; 0.29

Table 1: Fit parameter A obtained for GM and WM and the resulting MT pool exchange rate constant k_{for} derived from Eq. [2] at 1.5T and 3T is shown.

It could be shown that the “artificial” MT effect of TSE sequences with arbitrary flip angles caused by off-resonant slices can be described well using an adapted model from “classic” MT experiments (Eqs. [1] and [2]). For varying flip angles the mean flip angle of the RF pulse train can be employed. The depicted model exploits the rationale that the MT effect is proportional to the RF power exerted by the B1 field (1,4,8) which is proportional to the square of the refocusing flip angle α. The more pronounced MT effect at 3T compared to 1.5T can be explained by the higher RF power required and the prolongation of T1 relaxation times at 3T (Eq. [2], (9)). Yet, the observed k_{for} is much lower than generally investigated by continuous wave (cw) MT experiments (9), suggesting that different physical effects partially participate. One important fact is that multi-slice imaging represents off-resonance excitations with a discontinuous spectrum and time response, whereas in cw experiments high RF power at a discrete off-resonance frequency $\delta\omega$ is applied, establishing a steady-state between the liquid and semisolid pool. Since the observed MT effect in CSF and fat was negligible, cross talk effects between the different slices can be neglected in this respect. In the future, additional theoretical considerations and experimental studies dedicated to the MT effect of multi-slice MRI sequences with low and / or varying refocusing flip angles should be performed.

References

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