Optimizing SAR-reduction for High-Field TSE with Asymmetric Hyperechoes Combined with Partial Fourier Parallel Imaging

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Introduction

One of the most severe problems in morphological imaging at high fields of 3T and more is the considerably increased RF-power leading to serious SAR(specific absorption rate)-problems especially for RF-intensive sequences like TSE. This may severely limit the number of slices in a multislice-experiment, if protocols used at 1.5T are being used. The conservative way to deal with this problem is to use longer refocusing pulses, which will, however, lead to an increased bandwidth at identical echo spacing. At short interecho times ESP of 10 ms or less this will lead to an appreciable loss in SNR. A more efficient way to reduce RF power is to use low refocusing flip angles. Several approaches to optimize signal behaviour at low flip angles including symmetrical (1) and asymmetrical hyperechoes (2,3,4) and others (5,6) as well as variable selective rate encoding (VERSE) (7) have been suggested and lead to SAR-savings by a factor of 3-5 and more. The purpose of this paper is to investigate, how these low-flip angle approaches may be used in combination with incomplete k-space coverage schemes to further reduce SAR without any (or very little) compromise in image quality.

Methods.

For the further discussion one has to distinguish between two parameters, which can be used to characterize RF-power deposition. The total rf-power (tRFP) measures the average RF-power over the sequence, while it is running. It is given by

$$aRFP \sim c \sum_{k=1}^{g*k0} \alpha_k^2 / TAQ \; = \; c \; nex \sum_{k=1}^{ETL} \alpha_k^2 / TAQ \qquad (1)$$

where TAQ is the total acquisition time, ETL the echo train length and nex the number of excitations. Summation over all flip angles is carried out over g*k0 k-lines acquired. g is the reduction factor, g=1 corresponds to a full k-space coverage acquiring all k0 lines necessary for image reconstruction. c is a constant relating to the shape and duration of the pulses used, the Q-factor of the (loaded) coil and other factors relating to pulse transmission.

For SAR-calculation the RF power is averaged over 6 min according to current guidelines, therefore strictly speaking TR and ESP are irrelevant as long as the total acquisition time TAQ of the sequence stays below 6 min. For very fast acquisition (TAQ< 10s) the RF power can be tripled. The longer averaging time is, however, not implemented in the SAR-monitors of most systems, which measure aRFP instead. From Eq.(1) it is apparent, that aRFP will be reduced, if the reduction factor is 'invested' into a shorter ETL or into a longer TR, such that TAQ remains constant at lower nex. If ETL is kept constant and the reduction factor is used to reduce TAQ, then aRFP will remain constant, although SAR may still be reduced as long as TAQ remains below 6 min.

Experimental

Experiments were performed on a 3T system (Siemens Magnetom Trio) and a 4T system (Bruker MedSpec 4T), both equipped with an 8-channel head receiver coil. Various asymmetric hyperTSE-sequences based on TRAPS with ETL=13-256 were used in combination with partial sampling techniques. Partial sampling was accomplished in three different modes: Partial Fourier with 8/8, 7/8, 6/8, 5/8 and 4/8 k-space coverage. This could be combined with parallel imaging using GRAPPA or mSENSE. The reduction factor was 2 and 4, where a variable part of fully sampled k-lines symmetrically around the centre could be specified.

Reduction factors were used to reduce the echo train length up to reduction factors of 2, for lower reduction factors the number of excitations was reduced. SNR was measured as usual as mean signal intensity over the standard deviation within a ROI in the background noise. In order to account for the variation of noise inherent to parallel reconstruction techniques, three noise ROIs were chosen: One each besides the object in the readout- and phase-encoding dirtection respectively and one at the corner of the image. Experiments were performed on phantoms as well as on volunteers.

Results

Fig.1 shows results from a standard TSE-experiment with 180° flip angles(1) throughout compared to a hyperTSE at % SAR and partial k-space coverage hyperTSE-sequences with GRAPPA. TEeff of the asymmetric hyperTSE was adapted to correct for stimulated echo contributions to give identical T2-contrast as the standard TSE (2). Tab.1 shows the SNR of different tissues (dgm=deep grey matter) relative to the TSE-image (PF=partial Fourier reduction factor, g2/10 corresponds to reduction factor 2, full sampling of 50 k-lines at center). HyperTSE at equal TE (2nd column) shows higher SNR due to stimulated echo contributions, further experiments were performed at T2-matched TE of 114 ms (2,3). SNR and also image resolution remain constant for a-c, whereas at higher g-factor SNR and image quality start to suffer.

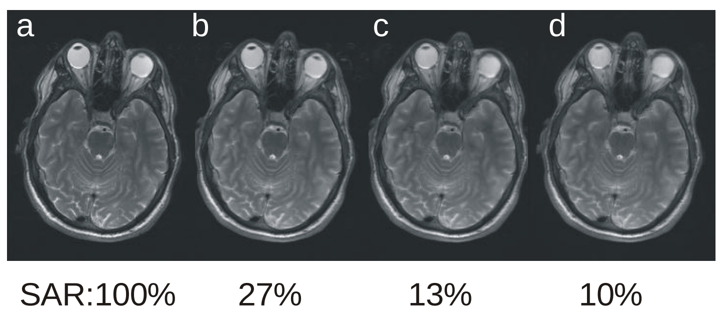

Fig.1 TSE reference image (a), asymmetric hyperecho at full k-space coverage (b) and with GRAPPA and reduction factors 2 (c) and 3 (d). Hyperechoes have been corrected for stimulated echo contribution and read out at T2-equivalent TE (114 ms for b,c,d compared to 83 ms for a) according to (2).

Tab.1	**TSE 83 ms**	hypTSE 83 ms	**hypTSE 114 ms**	PF5/8	PF5/8 g2/50	PF6/8 g2/50	**PF8/8 g2/50**	**PF8/8 g3/50**	PF8/8 g4/50
gray matter	1.00	1.31	1.07	0.89	0.67	1.08	0.89	0.64	0.32
dgm	1.00	1.35	1.08	0.93	0.73	1.13	0.94	0.67	0.37
white matter	1.00	1.36	1.08	0.90	0.69	1.14	0.95	0.70	0.36
csf	1.00	1.09	1.07	0.91	0.70	1.07	0.89	0.64	0.35

Conclusions

Incomplete k-space coverage combined with parallel acquisition leads to a further reduction of SAR by a factor of 1.5-3. Combined with hyperTSE, a SAR-reduction of a factor of 6-10 and more can be reached without any deterioration in image quality. Using the possibility to optimize the point-spread-function afforded by the asymmetric hyperecho and with a moderate g-factor, image quality and SNR is even improved compared to the conventional sequence. At higher reduction factors, the measured SNR starts to deteriorate although image quality may still be perceived as perfectly acceptable.

References:

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