Highly Accelerated Parallel ^{1}H MRSI at 7T with Simultaneous Suppression of Near- and Far-Reaching Signal Leakage

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Introduction

Magnetic Resonance Spectroscopic Imaging (MRSI) at ultra-high fields (≥ 7T) has a great potential to gain insight into physiological processes in the human body by providing spatially-resolved spectroscopic information for a large number of metabolites [1]. Robust acceleration techniques are of outstanding importance in order to make MRSI available as a fast and reliable tool in a clinical setting, since typical examinations are still excessively long due to SAR constraints. Generally, MRSI suffers from the so-called voxel bleeding effect, where the spectrum in a voxel of interest (VOI) exhibits contributions from other spatial regions, which may or may not be obvious. In any case, they are detrimental to reliable metabolite quantification and might even lead to false diagnosis of pathologies. Voxel bleeding is represented by non-idealities in the Spatial Response Function (SRF) which become stronger as spatial resolution decreases. Furthermore, when performing parallel MRSI for acceleration [2, 3, 4], the intra-voxel variation of coil element sensitivities is considerable and causes significant additional contamination if not taken into account by the reconstruction [5]. ***In this work***, we extend the SENSE acceleration technique for MRSI by introducing spatial overdiscretization and combining it with the target based optimization of the SRF presented in previous work [6, 7] to achieve excellent SRF side lobe suppression without the major enlargement of the effective voxel size that would be introduced by conventional ***k***-space apodization methods (e.g. Hamming filtering).

Theory and Methods

Data acquisition: Using a quadrature transmit head coil together with a 16-channel receive array (NOVA Medical, Wilmington, USA), a fully sampled ^{1}H MRSI data set was acquired on a 7T MR system (Philips Healthcare, Cleveland, USA) from a transversal slice (FOV 200 mm x 160 mm, voxel size 10x10x10 mm^3) of a healthy volunteer's brain along with the coil sensitivity maps. Interleaved flip angle-optimized outer volume suppression and VAPOR water suppression with direct acquisition of the free induction decay (FIDLOVS [1]) was employed which resulted in an acquisition time of 42:40 min (*TR*= 8s due to SAR limitations). For improved $\boldsymbol{B}_0$ field homogeneity a localized image based shimming method [8] was extended to choose the best out of 6 shim sets.

Algorithm: The SENSE reconstruction matrix F is calculated as the minimum of the cost function $\Delta_\pi = \|(FE - T)_\pi\|_2^2 + \alpha(F\Psi F^H)_{\pi,\pi}$ where α is a regularization parameter weighting SRF optimization (first term) against noise minimization (second term). E is the encoding matrix, π the index of the VOI and T contains the target functions, all of them newly expressed in a spatial basis up to three times finer than the MRSI grid (overdiscretization). Target SRF functions are centered on the VOI and have either Dirac or Gaussian peak shape. We then extract the raw data from the 16 channels, introduce artificial ***k***-space undersampling by selectively removing data points to simulate SENSE acceleration, and perform unfolding.

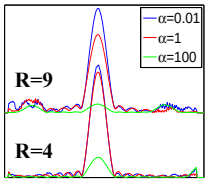

Figure 2*: Cross section in RL direction through the main peak of the resulting SRF with a σ=1.5 Gaussian target*

Results

Fig. 1 gives an overview of the calculated SRF. A Dirac target without overdiscretization (corresponding to standard SENSE reconstruction) leads to the well-known trains of side lobes that transport unwanted signal contributions from large areas of the FOV into the VOI at acceleration factor R=4. For R=9, even residual aliasing peaks are clearly discernible, indicating incomplete unfolding. Spatial overdiscretization in both cases leads to a more favorable result. A Gaussian target SRF with a standard deviation σ=1 (in units of the underlying spatial grid) leads to tremendous widening of the main SRF lobe, corresponding to an increased effective voxel size and therefore a loss of spatial accuracy of the MRSI, which is efficiently alleviated by overdiscretization. Widening of the target curve (Gaussian, σ=1.5) leads to much improved results if overdiscretization is used, combining very efficient side lobe and aliasing peak suppression with an acceptably small increase of the effective voxel size. In Fig. 2 we investigate the choice of regularization parameter. Minimal regularization is desired for SRF shape and unfolding but causes ill-conditioning of the system. We find, in our example, α=1 to be a good compromise. A subset of reconstructed spectra is displayed in Fig. 4 with peaks identified in Fig. 5. It is striking to see how spatio-spectral quality improves over standard SENSE when reconstruction is controlled with optimized SRF on a high spatial grid. Even with the inherently ensuing SNR decrease, unfolding and acceptable spectra are made possible at an extremely high acceleration factor of 9, which would correspond to an acquisition time of only 4.5 min in the presence of severe SAR constraints at 7T. Note that no ***k***-space apodization was performed and the acceleration factors achieved are much higher than with standard SENSE.

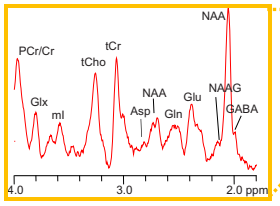

Figure 5*: Enlarged spectrum with peak assignments*

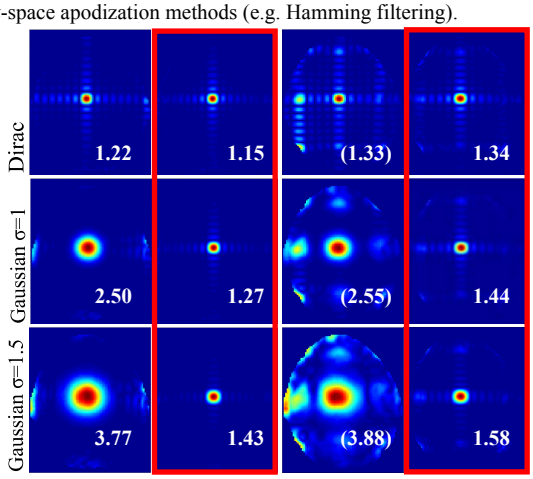

Figure 1*: Resulting SRF for a VOI in the middle of the object without and with (red frames) threefold overdiscretization at 4- (left half) and 9-fold (right half) SENSE acceleration with α=1. The FWHM in RL direction of the main peak is given in multiples of the nominal voxel size (numbers in brackets: unfolding incomplete).*

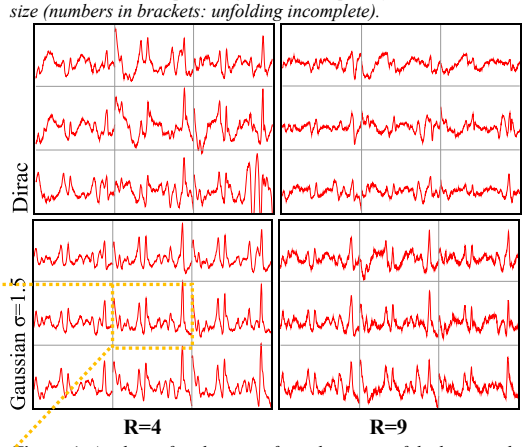

Figure 4*: A subset of real spectra from the center of the brain without (top row/standard SENSE) and with (bottom row/optimized SRF) threefold overdiscretisation. $\boldsymbol{B}_0$ correction, HLSVD residual water peak subtraction and a 2 Hz noise filter were applied.*

Conclusion

We demonstrate up to 9-fold accelerated FIDLOVS MRSI at 7T with intrinsic and efficient suppression of voxel bleeding contributions as well as good maintenance of the nominal spatial resolution. Both of these side effects of standard SENSE reconstruction would otherwise jeopardize reliability in MRSI assessment, particularly in quantitative metabolite studies.

References

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