

Rapid MRSI of the Brain on 7T Using Subspace-Based Processing

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Synopsis

We present here a new method for rapid MRSI of the brain on 7T that combines fast rosette trajectories and subspace-based processing from the SPICE MRSI framework. Results from in vivo experiments demonstrated substantial improvement in spectral quality and SNR achieved by the subspace imaging method over the standard reconstruction of rosette MRSI data. The ability to obtain single-slice rapid MRSI of the brain with an only 1.1 min acquisition was also demonstrated using the subspace-based reconstruction. These results highlight the potentials of integrating subspace imaging and fast acquisitions to push the performance of ultrahigh-field MRSI.

INTRODUCTION

Improvements in SNR, speed and spectral quality are key motivations for developing MRSI on ultrahigh-field systems.¹ In the past few years, a number of sequences and customized instrumentations have been developed for fast, high-resolution MRSI at 7 and 9.4T.²⁻⁷ While these methods have achieved excellent performance, spectral quality problems persist, particularly from nuisance lipid and/or macromolecule signals. Furthermore, better SNRs through advanced processing are highly desired in order to achieve better resolution and speed tradeoffs for fast trajectories.⁸⁻¹⁰ We present a new processing method for brain MRSI at 7T based on the recently proposed subspace imaging approach¹¹⁻¹² to improve the spectral quality of data from fast rosette spectroscopic imaging (RSI).¹⁰ Results from in vivo experiments showed substantial improvement in residual nuisance water/lipid signal reduction and SNR enhancement for 7T RSI data achieved by the proposed method over the standard reconstruction. We also demonstrated the capability of our subspace-based method in producing high-fidelity reconstruction from temporally undersampled RSI data, which can enable further acceleration by reducing the number of temporal interleaves. These results highlight the potentials of synergistic acquisition and processing strategies to advance ultrahigh-field MRSI.

METHODS

Data from five healthy volunteers were acquired on a Siemens 7T Magnetom 8 channel pTx system with the 8x2 transceiver using two RF-shimmed B1+ distributions (homogeneous, ring) as previously described.^{7,13} Outer volume suppression of extracerebral tissue was performed using the B1+ ring spatial excitation. B0 shimming was performed using a high-order shim insert (Resonance Research Inc.), achieving water linewidths of 4-5Hz over a frontal-parietal slice.¹⁴ A J-refocused double-spin-echo sequence was used with TR/TE=1500/34ms (single slice, 2.2min total), which provides excellent retention of coupled spins through longer TEs.¹⁵ Spatial encoding was performed using a circular rosette trajectory with a 216x216mm² FOV, 9mm slice thickness, 44 shots (9x9mm² in plane voxels), two temporal interleaves, and 2500Hz spectral bandwidth. More details for the pulse sequence can be found in a concurrently submitted abstract. Coil combination was performed using an SVD-based scheme (other SNR-optimized strategies can be considered). A MP2RAGE scan was acquired to extract the spatial support of brain and extracerebral tissues for water/lipids removal (NSRM).¹¹⁻¹² B0 maps were also acquired for data processing.

While this acquisition achieves high SNR and good lipid suppression, significant nuisance extra-cerebral signal leakage can remain and result in poor spectral quality, especially for the edge/cortical voxels. The OVS itself can also reduce the SNR at the edge through the imperfect ring distribution, thereby perturbing the intracerebral signal. With the availability of accurate B0 maps and structural images, we address the NSRM and SNR issues using subspace-based processing. Furthermore, given the spectral prior knowledge afforded by a pre-estimated subspace^{11,16}, we demonstrate that with our subspace-based reconstruction, data acquisition can be further accelerated through less temporal interleaves. Specifically, we formulate the reconstruction problem as follows¹⁰⁻¹¹

$$\{\hat{\mathbf{U}}_w, \hat{\mathbf{U}}_f, \hat{\mathbf{U}}_m, \hat{\mathbf{V}}_m\} = \arg \min_{\{\mathbf{U}_w, \mathbf{U}_f, \mathbf{U}_m, \mathbf{V}_m\}} \left\| \mathbf{d} - \mathcal{F}_\Omega \left\{ \mathbf{B} \odot \left(\mathbf{M}_w \mathbf{U}_w \hat{\mathbf{V}}_w + \mathbf{M}_f \mathbf{U}_f \hat{\mathbf{V}}_f + \mathbf{U}_m \mathbf{V}_m \right) \right\} \right\|_2^2 + \lambda_w \|\mathbf{U}_w\|_F^2 + \lambda_f \|\mathbf{U}_f\|_F^2 + \lambda_m \|\mathbf{D}_w \mathbf{U}_m \mathbf{V}_m\|_F^2,$$

where $\mathbf{d}$ denotes (k,t)-space data, $\mathcal{F}_\Omega$ is an encoding operator that maps Cartesian-grid images to the rosette data, $\mathbf{B}$ captures B0 inhomogeneity related phases, and $\mathbf{M}_x$ captures the spatial support information (1's if signal present and 0's otherwise) for water and lipids, respectively. $\mathbf{U}_x \mathbf{V}_x$ are explicit low-rank (subspace) constraints for water, lipids and metabolites, respectively. We solve this problem using a two-step approach. More specifically, we first gridded the RSI data to Cartesian grids (24x24) and performed B0 correction followed by a parametric fitting to estimate the subspaces ($\hat{\mathbf{V}}_w$, $\hat{\mathbf{V}}_f$ and $\hat{\mathbf{V}}_m$).¹¹ We then refit the data to estimate water/lipid signals on a higher-resolution grid (64x64) and removed their contributions from the data. Finally, a joint low-rank and spatially constrained reconstruction was performed to obtain the metabolite spatial-spectral distribution.

RESULTS

We evaluated the proposed method in different scenarios to illustrate its utility for fast 7T MRSI. First, we compare the quality of spatial-spectral reconstruction produced by our subspace method to that by the standard reconstruction (gridding+FFT+coil combination¹⁰). Figures 1 and 2 compare spatially-localized spectra. It is clear that the proposed method yielded spectra with significant reductions of lipid/water contamination and higher SNRs, especially for the edge voxels. Metabolite ratio maps (i.e., NAA/Cr, Cho/Cr and Glu/NAA) from the standard reconstruction and the proposed method are shown in Fig. 3, the latter showing better gray/white matter contrast. Metabolite maps from different subjects are shown in Fig. 4.

To examine the capability of the subspace method in enabling temporal undersampling, we also performed reconstruction using only a single temporal interleave (corresponding to a **1.1min** acquisition). Figure 5 compares the reconstruction from this undersampled data with the full data. Very similar spatially-resolved spectra were produced, demonstrating the capability of subspace-based reconstruction for further acceleration. Note that the subspace used in this reconstruction was pre-estimated from three RSI data with full spectral width other than the one under evaluation. More details on subspace learning can be found in Refs. [11] and [16].

CONCLUSION

We demonstrate that subspace modeling can improve the performance of fast MRSI of the brain at 7T. Further acceleration using subspace-based reconstruction can be achieved. The results obtained highlight the unique potentials of synergistic acquisition and processing strategies to push the limits of

ultrahigh-field MRSI. Future work will include higher-resolution acquisitions, multislice coverage and further optimized reconstruction methods.

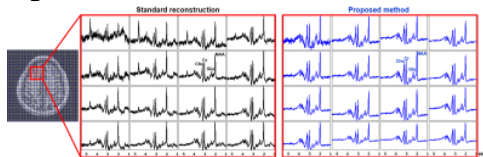
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No acknowledgement found.

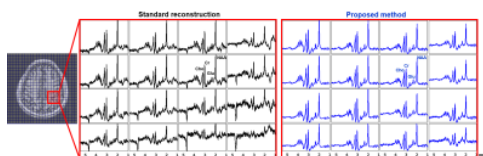
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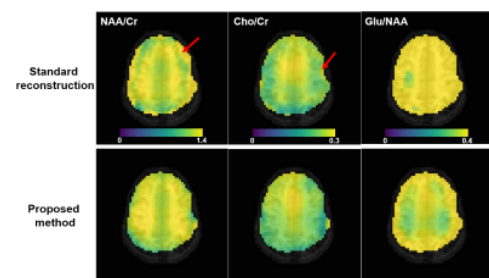
Figures



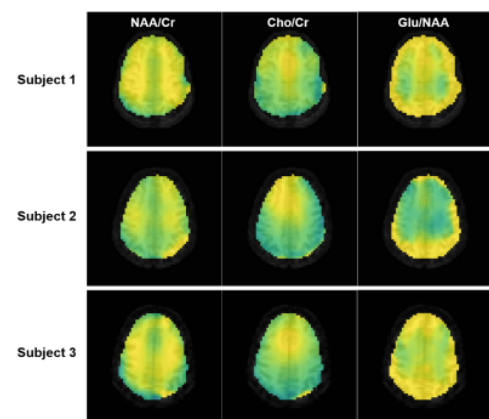
Spatially-localized spectra for a 4x4 voxel array from an anterior brain region are compared, with results produced by the standard reconstruction (see texts) and the proposed method (the blue curves). The location of the region-of-interest is indicated by the red box in the anatomical image on the left with overlaid voxel grids. Significant reduction in lipid leakage and SNR improvement can be observed for the spectra from the proposed method, especially for the edge voxels. Spectra are shown in real parts.



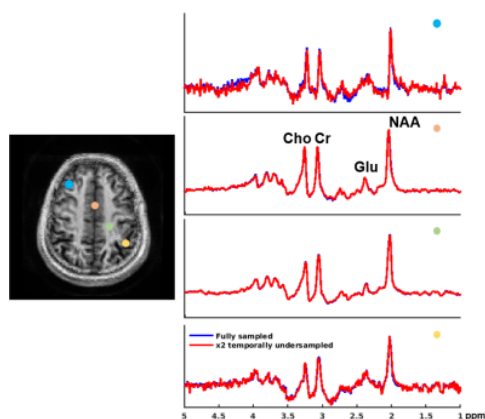
A similar comparison as Fig. 1 for the same data, for a 4x4 voxel array from a posterior brain region. The location of the region-of-interest is indicated by the red box in the anatomical image on the left. Significant improvement in spectral quality can again be observed, especially for the edge voxels with larger lipid contaminations and reduced SNRs.



Comparison of NAA/Cr (column 1), Cho/Cr (column 2), Glu/NAA (column 3) maps from the standard reconstruction and the proposed method for one subject. As can be seen, the metabolite ratio maps produced by the proposed method have less artifacts (examples indicated by the red arrows) and better gray/white matter contrast (e.g., the Glu/NAA maps). The color scales were the same for the same column. The metabolite levels were obtained using spectral integration for this preliminary study, and no relaxation correction was performed.



Metabolite ratio maps for three different subjects (shown in different rows) from the reconstruction produced by the proposed method.



Evaluation of the spatial-spectral reconstruction from x2 temporally undersampled data (corresponding to an only 1.1min scan with a single temporal interleave), against the fully sampled data (both from the proposed subspace reconstruction). Reconstructed voxel spectra are shown on the right with locations indicated by different colored circles in the T1-weighted image on the left. Very consistent reconstruction was produced from the undersampled data versus the full data, demonstrating the capability of the proposed method in achieving further acceleration for rapid RSI.