

High-Resolution Spectroscopic Imaging with Statistical Reconstruction

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INTRODUCTION

MRSI has been recognized for a long time as a powerful tool for biochemical imaging. However, its practical utility is still rather limited due to poor spatial resolution, low signal-to-noise ratio, and long data acquisition times. To address the sensitivity limitations of MRSI, several constrained reconstruction approaches have been proposed [1-5]. The constraints used by these approaches are derived from coregistered high-resolution anatomical datasets, and include boundary locations and regions of support. Previous approaches all have the same goal, which is to elicit high-resolution information from limited data with high SNR through the use of these anatomical constraints. The proposed method addresses the limitations of Fourier reconstruction from a completely new angle. We advocate the collection of higher k -space information at the expense of correspondingly lower SNR. From this noisy high-resolution data, we use anatomical constraints to reduce the noise contamination, while preserving the high-resolution anatomical structure.

THEORY

The MRSI imaging equation can be modeled in vector form as $\mathbf{d}=\mathbf{F}\boldsymbol{\rho}+\boldsymbol{\eta}$, where \mathbf{d} is the data, $\boldsymbol{\rho}$ is the desired spatial-spectral function, $\boldsymbol{\eta}$ is noise samples, and \mathbf{F} is the encoding matrix. The optimal solution for $\boldsymbol{\rho}$ using a penalized maximum-likelihood (PML) functional [6] is given by

$$\hat{\boldsymbol{\rho}}_{\text{PML}}(\mathbf{d}) = \arg \min_{\boldsymbol{\rho}} \|\mathbf{F}\boldsymbol{\rho} - \mathbf{d}\|_2^2 + \lambda\Phi(\boldsymbol{\rho}), \quad \Phi(\boldsymbol{\rho}) = \sum_{\ell=1}^L \sum_{p_1=1}^P \sum_{p_2 \in \Omega_{p_1}} w_{p_1 p_2 \ell} |\rho_{p_1 \ell} - \rho_{p_2 \ell}|^2 \mathbf{1}_{\{p_2 > p_1\}}$$

where $\Phi(\boldsymbol{\rho})$ is a regularizing penalty term, the w are positive weighting coefficients and Ω_{p_1} is the set of all voxels that are spatially adjacent to voxel p_1 , and ℓ indexes the different spectral components. This formulation has several distinct advantages for constrained reconstruction. First, through the w , we can effectively incorporate anatomical constraints (both certain and uncertain). Second, we purposely violate data consistency to reduce noise contamination, thereby enabling high-frequency k -space coverage. Third, there are exact characterizations of the spatial resolution and noise properties of images reconstructed with this method, making it possible to achieve a favorable balance between SNR and resolution.

RESULTS

Figure 1 illustrates the advantages of the proposed technique over conventional methods. As expected, DFT reconstruction suffers from severe noise contamination as the number of encodings increases. By incorporating known anatomical features into the reconstruction, the proposed method significantly improves the SNR, while reconstructing known image boundaries at high resolution. Unknown image features are reconstructed at resolution limited by the k -space coverage. With extended k -space coverage, the proposed reconstruction does well at reconstructing these features with greatly enhanced SNR and a minimal loss of resolution compared to DFT reconstruction.

The MRSI data in Fig. 2 was acquired on a healthy mouse using a Varian INOVA 11.74T MRI scanner. FIDs were acquired for each of 32x32 k -space samples in a standard spin-echo CSI acquisition (TE = 270 ms, TR = 1500 ms, bandwidth = 8000 Hz, FOV = 2.4 cm x 2.4 cm, slice thickness = 1.5mm). Standard DFT reconstruction from 32x32 data yields an image with voxel sizes of 0.075 x 0.075 x 0.15 cm³ = 0.00084 cm³. DFT and anatomically constrained reconstructions are compared in Fig. 2. The proposed method has significantly reduced the noise level, simultaneously preserving and elucidating features known from anatomical reference images.

CONCLUSION

We have proposed a new MRSI method to achieve high spatial resolution using extended k -space coverage and statistical reconstruction. The method should prove useful for a range of applications where high-resolution metabolic maps are desired (e.g., brain mapping).

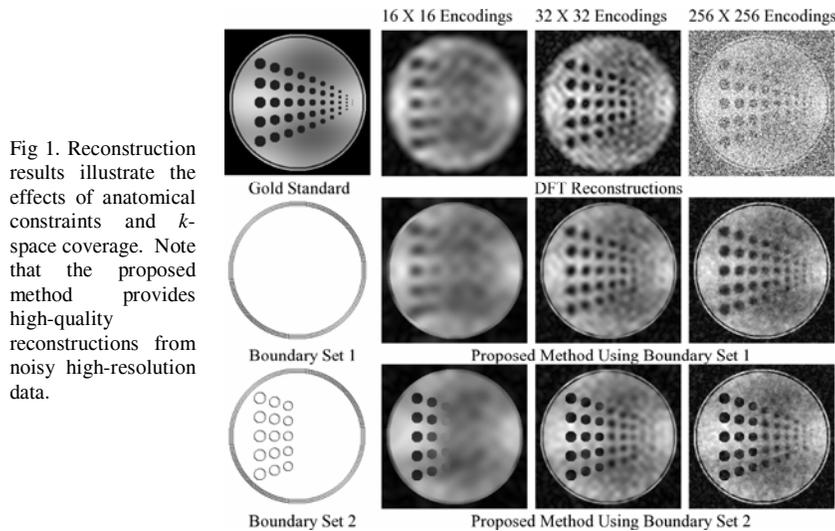


Fig 1. Reconstruction results illustrate the effects of anatomical constraints and k -space coverage. Note that the proposed method provides high-quality reconstructions from noisy high-resolution data.

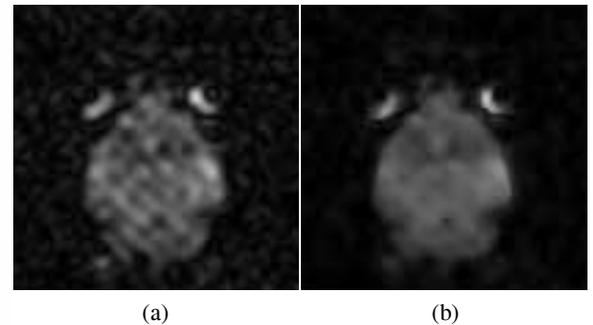


Fig 2. Reconstructed NAA peak from a mouse brain. (a) DFT method, and (b) proposed method.

REFERENCES

- [1] Hu X et al., Magn Reson Med 1988;8:314-322.
- [2] von Kienlin M et al., J Magn Reson 1994;94:268-287.
- [3] Liang ZP et al., IEEE Trans Med Imaging 1991;10:132-137.
- [4] Plevritis SK et al., Magn Reson Med 1995;34:686-693.
- [5] Hetherington HP et al., Magn Reson Med 1996;36:21-29.
- [6] Fessler JA et al., IEEE Trans Nuc Sci 1992;39:1464-1471.