Title: Tensor Signal Enhancement and Optimal Multichannel Receiver Combination Analyses For Human Hyperpolarized ^{13}C MRI

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Highlights:

A data-driven processing framework was proposed for dynamic HP ^{13}C-MRI, leveraging whitened-SVD to optimally combine array data and tensor signal enhancement to maximally extract diagnostic information from existing datasets and techniques. ~50x apparent SNR gain was observed, recovering otherwise undetectable downstream metabolites with minimal artifact.

Introduction:

Hyperpolarized ^{13}C is a powerful emerging stable-isotope imaging technology to probe metabolism in human cancer. As multisite HP-^{13}C trials begin, new coil development and acquisition methods are still work in progress, and there is a key unmet need to maximally extract diagnostic information[1] from datasets acquired with existing techniques. This report presents a new HP-MRSI processing framework to optimally combine phased data from receiver arrays using whitened-SVD(WSVD) or first-point phasing (FPphasing)[2], and to augment signal extraction using tensor signal enhancement(TSE)[3]. Optimization was evaluated on dynamic MRSI datasets from brain, abdomen and pelvis using array and single-element receiver configuration.

Methods:

<u>Patient Studies</u>: The patient data (N=38) used was acquired with a 2D MRSI sequence with EPSI readout(TR/TE=130ms/3.5ms, resolution temporal=2-5s, spatial = 1-4cc), following injection of 250mM HP-[1-^{13}C]pyruvate polarized using a 5T SPINlab. The ^{13}C receivers in this study includes 8 and 32-channel brain[4], 16-channel and surface abdominal, and an endorectal prostate coil[5]. All human studies were IRB-approved at UCSF.

<u>Image Processing Framework</u>: The processing and visualization, including noise decorrelation, SVD and TSE, are realized on MATLAB and SIVIC[6].

<u>MR Array Combination</u>: Two methods to optimally combine receiver channels were compared in this work: WSVD and FPphasing. WSVD is a spectral-domain method that extracts complex coil sensitivities and produces maximum likelihood spectra. FPphasing calculates the optimal weights using the magnitude and phase of the first point of the FID.

<u>Tensor Signal Enhancement</u>: HP-^{13}C MRSI data, consisting of spectral, spatial, and dynamic dimensions, can be formulated into tensor representation, which can then be restructured into an elemental representation consisting of a rank-deficient basis in each dimension and a truncated core tensor[7].

$$\mathbb{M} = \sum_{p,q,s,r} g_{pqsr} \cdot \mathbf{f}_{\mathrm{p}} \circ \mathbf{x}_{\mathrm{q}} \circ \mathbf{y}_{\mathrm{s}} \circ \mathbf{d}_{\mathrm{r}} \tag{1}$$

Leveraging spatiotemporal correlation, the tensor truncation distinguishes the signal "fibers" (eigenvectors) from noise.

Results and Discussion:

TSE and coil combination techniques together provided a 63-fold mean apparent SNR gain for receiver arrays (10-fold minimum), and 31-fold gain for single-element configurations, which particularly improved quantification of lower-SNR resonances such as [^{13}C]bicarbonate and [1-^{13}C]alanine, that were otherwise not detectable in many cases. Substantial SNR enhancement was observed for datasets that were acquired even with suboptimal experimental conditions, including delayed (114s) injection (8x SNR gain solely by TSE), or from challenging anatomy or geometry, as in the case of a pediatric patient with brainstem tumor (**Figure 1**, 597x using combined TSE and WSVD). Post-TSE maps of elevated pyruvate-to-lactate conversion displayed improved correspondence with biopsy-confirmed prostate cancer and anatomical lesions, strongly suggesting that TSE recovered quantitative diagnostic information.

Conclusions:

The findings indicated that the combined approach was versatile across imaging targets and receiver configurations, and could benefit ongoing and future HP-^{13}C MRI patient research and new probe development through SNR improvement.

References:

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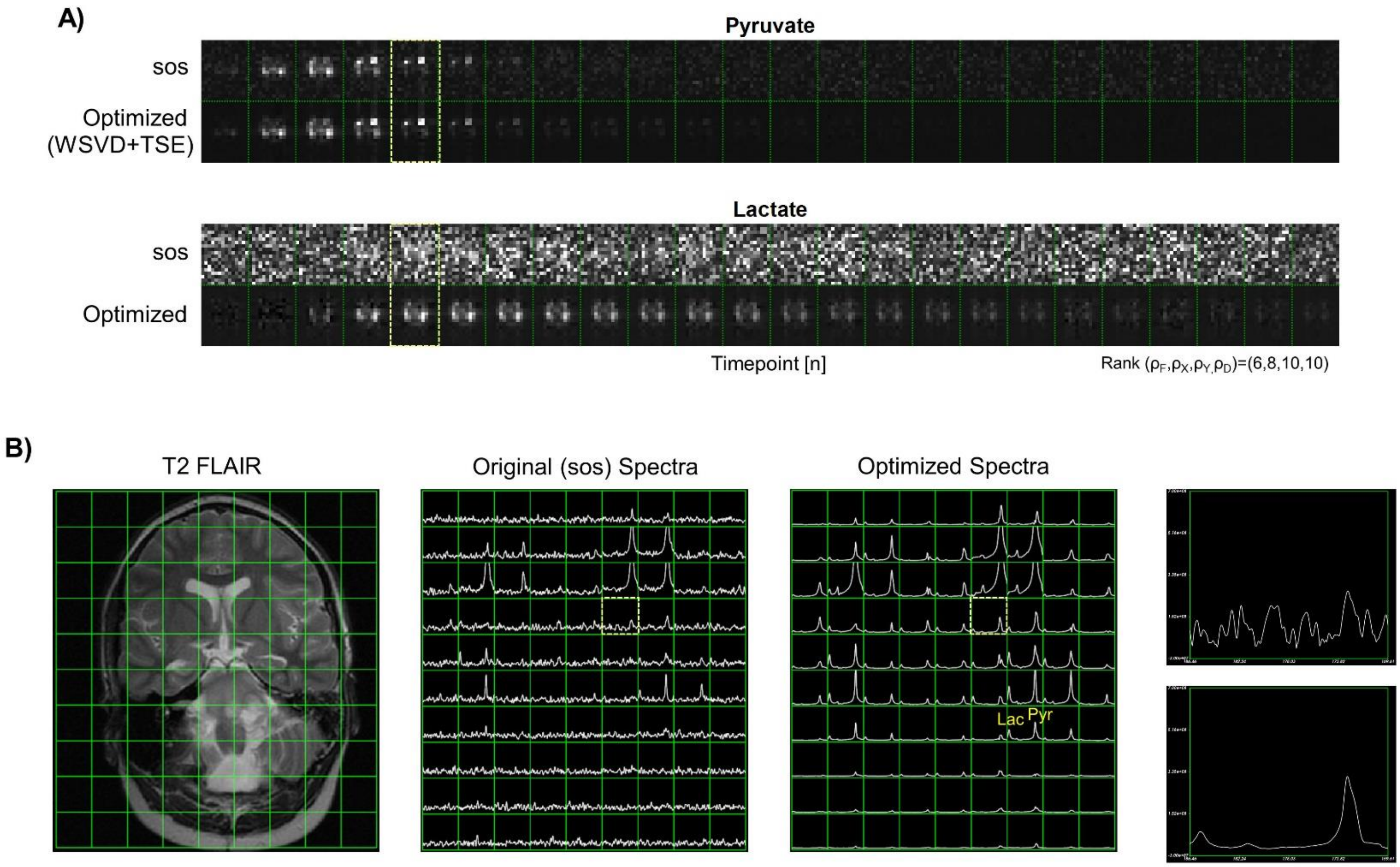

Figure 1. This figure portrayed the synergy of WSVD+TSE in the new processing workflow. **A)** The pediatric HP-^{13}C patient exams are notoriously challenging to perform due to their common localization near brain stem, limited injection dose and rate. The original data (sos) had relatively poor SNR. Comparison between optimized data versus original found 597-fold apparent SNR gain. Upon closer examination, 7 fold SNR improvement was attributed to WSVD array combination, whereas 88 fold was due to TSE. **B)** Snapshot at timepoint 5 showed substantially improved spectral characteristics.