Comparison of Several Coil Combination Techniques in Multi-Channel 3D MRSI for Brain Tumor Patients

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Purpose: To find the most robust and accurate algorithm for combining multi-channel multi-voxel 3D magnetic resonance spectroscopic imaging (MRSI) data for clinical purposes and to automate the data processing.

Introduction: MRSI is a noninvasive method for characterizing biologically important metabolic levels. The use of multi-channel receiver coils in MRSI can increase SNR and coverage. Optimal SNR from multi-channel acquisitions requires the constructive combination of signal from different receiver coils and thus robust phase correction of spectra from each channel prior to image reconstruction. Number of techniques for phased array spectroscopy combination have appeared during the past decade. Despite the innovative techniques presented in those papers, a fully optimal combination method for unknown coil sensitivities appears yet to be discovered. In addition most of those papers focus on single-voxel MRS signals whereas here we have studies those techniques for multi-voxel 3D PRESS with and without Lactate Editing MRSI on 55 brain tumor patients with 105 exams.

Techniques: Four most popular approaches for spectroscopy combination with multiple coils are proposed, implemented and tested on our patient population. 1) peak referencing [SW method] using suppressed water to phase the spectra in each voxel in frequency domain and then weighted prior to combination to correct for individual coil sensitivities. This approach approximates a matched filter. The weighting factor for each channel is from a calibration scan using a non-water saturated acquisition to insure large signals to improve the overall SNR. Phasing the spectra is done automatically by integrating over a reference peak and iteratively changing its value until the real part of reference peak in the spectrum has maximum area for each voxel. We have also considered determining the optimal phase from the central 8 voxels from each channel using suppressed water and then applying this phase to all voxels prior to combination [CV method]. 2) first point phasing [FP method] that is based on time domain combination, scaling and phasing each spectrum by the first point in its FID (i.e. by the mean value of spectrum). 3) whitened singular value decomposition [WSVD method] of the measurement matrix (rank 1 approximation) which is asymptotically optimal in the signal-to-noise ratio sense and is consistent with acquired data. The combined spectrum makes maximum use of available data, handles the correlations in the noise properly, and is computationally efficient. 4) general least squares method [GLS method], which incorporates a smoothness constrains on the coil sensitivities, is optimal solution in linear regression model when coil sensitivities are known or can be measured with sufficient accuracy (SENSE like techniques). In this method, the integral of the complex-valued spectral signal over the reference peak was used to create the sensitivity map using ESPIRiT algorithm for each channel and the combined spectrum was computed according to SENSE reconstruction.

Methods: MRSI data for initial analysis of the these methods were acquired from a commercially available MRS phantom and 3 volunteers. These algorithms were also applied to 105 MRSI datasets obtained from 55 patients with glioma. All imaging studies were performed on a GE 3T scanner (GE Medical Systems, Milwaukee, WI) with 8 channel head coil using either regular PRESS or PRESS with Lactate Editing. The TR and FOV were varied as follows: TR=(1104/1134/1140/1500)ms, FOV=(16x16x16 or 18x18x16) for flyback echo-planner readout gradients (with 1.014cc/1.013cc effective spatial resolution respectively), TE=144ms, Tacq=(4.7/4.8/6.2/8,1)min. The SNR values were corrected for difference in acquisition time and repetition time by using the relaxation constant for individual metabolites. The noise level in the data from the phantom was measured by averaging the standard deviation of the 50 points at the end of the raw FID signal in all voxels. Additional random noise was added to the original phantom data to simulate noise levels of 1 to 16 with step size of 0.2 (Figure 1). Patient data were separated into two cycles for lactate edited sequence, the cycle with and without water. Each cycle was analyzed separately to evaluate these techniques (Figure 4).

Discussion/Results: In phantom when there are strong reference peaks in the spectrum such as water, the SW, WSVD, FP algorithms perform similarly well, then the GLS and CV. (SW=WSVD=FP>GLS>CV) Without any strong peak such as water, the WSVD becomes specially effective in phantom, however, the WSVD method is very sensitive to baseline error originated from lipid signals from outside voxels of interest and as a result it doesn't perform well for patients data sets. If the lipid is removed by HLSVD techniques, then the WSVD performs better. The reproducibility of these techniques are shown in Figure 2. When comparing the performances of these five different methods in patients, CV performs the worse, and the most stable, robust technique for clinical use is using SW method for each cycles. The phase estimate from the first cycles could be used for the second cycles for the best outcome (Figure 4).

Conclusion: In our initial study, five techniques to combine the clinical 3D MRSI of multiple receiver channel data, while preserving the complex phase information are compared and the simple optimal, robust and accurate method is presented to be SW method. This technique requires no prior information or calibration of the coils and it is robust against noise and can determine the phase offset between physically separated channels.

References:[1]Rodgers et al. *Magn Reson Med 2010* [2]Bydder et al. *Magn Reson Med 2008* [3]An et al. *JMagn Reson Imaging 2012* [4]Birch et al. *Magn Reson Med 2014* [5]Brown *Magn Reson Med 2004* [6]Uecker et al. *Magn Reson Med 2014*

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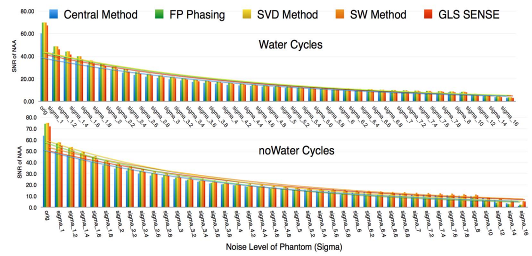

Fig1. Phantom: Comparison of Combination Techniques for variety of Noise

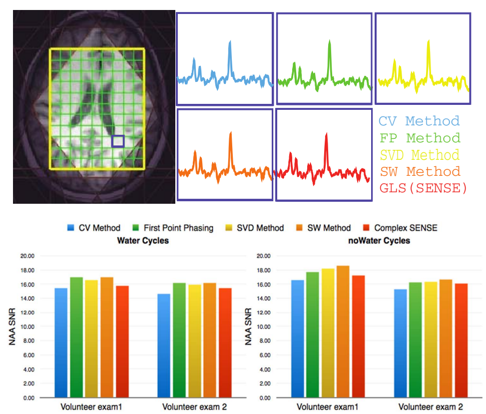

Fig2. Result from one Volunteer in 2 exams (Reproducibility)

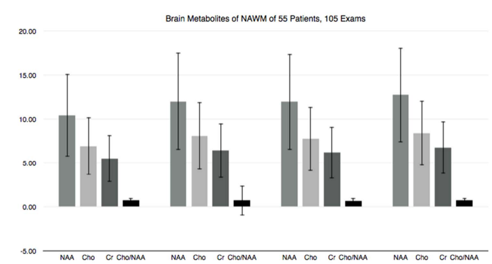

Fig3. Metabolites Levels and Ratios from 55 patients for all the Techniques

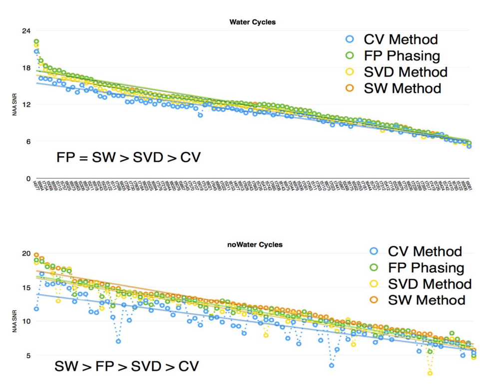

Fig4. NAA SNR from105 3D-MRSI exams to estimate the performance of each technique (linear regression fitting)