Elimination of Frequency-modulated sideband artifacts for in vivo Non-Water Suppression MRS

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Introduction

As an attractive alternative to water-suppressed (WS) MRS, non-water suppressed (NWS) MRS technique circumvents the disadvantages involving WS pulses which tend to suppresses surrounding metabolites. In addition, internal water references facilitate calibration of concentrations and retrospective motion correction [1]. However, parasitic frequency modulation (FM) sidebands are generally seen in NWS MRS. Although FM problem is not severe in long-TE spectra, the separation and removal of FM for short-TE NWS-MRS is difficult due to their decaying characteristics and the complexity of *in vivo* environments which contain multiplets, macromolecules, and distorted baselines.

Post-processing methods have the potential to fully remove the FM artifacts which were attributed to acoustic vibration caused by spoiler gradients [2]. Previous study has stated modulus signals to overcome FM sidebands [3], though no quantitative evaluations were made to compare its performance with WS spectra. In this study, we devised a novel algorithm based on time-domain model to remove the FM sidebands found in short-TE NWS MR spectra [2]. Since it is a post processing method without sophisticated prior knowledge, our method can be directly applied to practical usage. In addition, we quantitatively compare its performance with the modulus method and WS spectra.

Theory

Our work extends from time-domain algorithms, in which free-induction decays are modeled as the summation of complex sinusoids. First, by presuming eigenvalues of data matrices as the rotating and decaying rate of individual resonances, a pair of Hankel data matrices were built with FID. Second, to deal with FM sidebands, our method manipulates the FIDs with increases of the real-part of FID by $(1+\Delta)$, and decreases of the imaginary part by $(1-\Delta)$, where Δ is a freely adjustable parameter. Each of the original FIDs and the manipulated FIDs are used to build a pair of data matrices, which generate a total of four matrices. Ideally, these four matrices share the same eigenvalues and eigenvectors with additional information related to FM sidebands from the term $(1+\Delta)$ and $(1-\Delta)$. Thus, we can simultaneously solve these four matrices with two approaches of 1) generalized Schur decomposition (GSD, known as QZ) and 2) simultaneously GSD (SGSD) [4]. Notably, in the QZ method, we merely approximately enforce the transformation on the third and fourth matrices, since QZ is a method for two matrices. On the other hand, SGSD is a latest state-of-the-art algorithm which can deal with all four matrices. Finally, the FM sidebands are tracked by evaluating the changes of diagonal elements of these four matrices.

Methods

In vivo MR spectra were acquired from a 3T system (Trio, Siemens Medical Solutions, Erlangen, Germany) using an 8-channel coil array. Thirteen healthy subjects were included in this study under informed consent. Single-voxel PRESS sequence was used to acquire MRS data from a selected volume ($20\times20\times20$ mm^3) located in parietal lobe of the brain with experimental parameters of: TE=30 ms, TR=2000 ms, NEX=128, dummy scan =2, bandwidth = 2000 Hz, and spectral points = 2048. For each subject, NWS and WS scans were collected sequentially. NWS data were processed with four different procedures for FM sideband removal, including regular NWS MRS without FM sideband removal, NWS MRS with QZ algorithm, NWS MRS with SGSD algorithm, and modulus NWS MRS, respectively. Three major metabolites of brain, N-acetylaspartate (NAA), Creatine (Cre), and total Choline (tCho) was quantified by jMRUI package with baseline subtraction and water scaling to calibrate the metabolites concentration.

Results and Discussion

FM sidebands are noticeably embedded at 3.2 ppm and 6ppm in the NWS MRS which increase the peak at 3.2 ppm compared with WS-MRS (Fig. 1). Qualitatively, the elevated peaks were restored through correction by SGSD algorithm, yielding better similarity to the WS-MRS spectrum (Fig 1). Quantitatively the metabolite concentrations were overestimated in NWS spectra before FM sideband removal, accompanied by larger standard deviations than WS spectra (Fig. 2). After sideband corrections, the mean concentrations were reduced by the QZ and the SGSD methods. The modulus method showed relatively inconsistent alterations in the concentrations for NAA (relatively unchanged) and tCho and Cre (reduced to values lower than WS spectra). Among all three methods, SGSD method shows best estimation in metabolite concentrations compared with the WS spectra treated as standard reference. In conclusion, we have demonstrated that the proposed QZ and SGSD algorithms are able to reduce water related FM sidebands artifacts in NWS MRS, which makes NWS MRS more practical in general applications. Further researches may include prior knowledge about FM sidebands for each scanner and experimental environments.

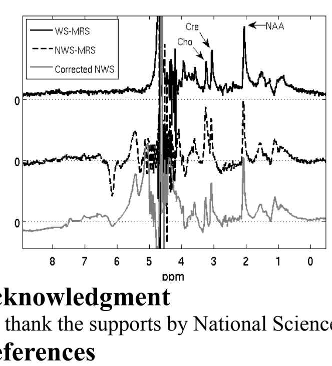

Fig.1. Representative spectra of WS MRS (upper), NWS MRS (middle) and NWS MRS after SGSD correction (bottom). Elevated choline peak can be clearly seen on the NWS MRS spectrum without sideband removal. After correction its level is reduced to the level close to that shown on the WS MRS spectrum.

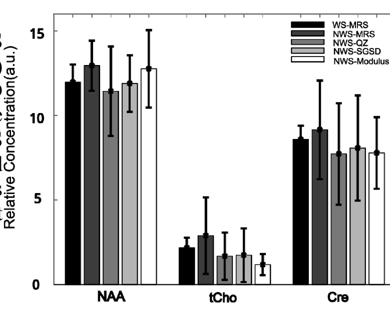

Fig.2. Mean and standard deviations of concentrations of NAA, tCho, and Cre from thirteen subjects. Clearly the FM sidebands caused over-estimation on the metabolic concentrations. SGSD shows restoration closest to the WS spectra treated as standard.

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References

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