Removal of FM Sidebands Artifacts in NWS MRS by QZ-bac Algorithm

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Introduction

Non-water-suppressed (NWS) MRS techniques [1,2] have been recently investigated for the benefits that the un-suppressed water signal in NWS MRS serving as an internal reference for reliable metabolic quantification while avoiding the possible distortion of metabolite signal by water suppression (WS) pulses. However there are still some problems originating from the huge water peak. First the main water peak needs to be removed by some post processing procedures. For this part several time domain SVD-based [2] water-modeling methods have been developed to deal with the huge water resonance. Secondly, the Frequency-Modulated (FM) sideband artifacts related to gradient oscillation have to be eliminated. Otherwise, the quantification of metabolites will be severely hampered by the sideband contaminations [3,4]. The FM sidebands artifacts originating from the frequency modulation of water signal caused by the oscillating spoiler gradients can be reduced by increasing the echo time [1] or other experimental method [4,5]. However post-processing methods is more desirable for the advantage that artifacts can be eliminated without modifying the pulse sequences. In this study, we develop a post-processing algorithm, named QZ-Based Artifacts Cancellation (QZ-bac), to remove the FM sidebands in NWS MRS. we will demonstrate the performance of QZ-bac by a computer simulation and *in vivo* experiment. The QZ-bac method is a purely post-processing algorithm, which is expected to improve the feasibility and popularity for current NWS MRS at both short and long echo time.

Theory and Methods

QZ-bac algorithm: The algorithm is based on the Filter diagnonalization Method (FDM) [6] and can be summarized as follow. First, we modify the real/imaginary signals with weighting by $(1+\Delta)$ and $(1-\Delta)$ respectively. the modified signal is the combination of original signal $s(t)$, the modified sidebands $(1-\Delta)\tilde{s}(t)$, and the Skew-Hermitian ghost $\Delta \cdot \overline{s(t)}$, related to signal from down-field. By FDM processing we can filter out the undesired ghost from $\Delta \cdot \overline{s(t)}$ such that only the up field signals are included. This process can be carried out for many times until all the sideband term $(1-\Delta)\tilde{s}(t)$ can be effectively reduced.

Simulation:

Three singlets were simulated to mimic the three metabolites, N-acetyl aspartate (NAA), Choline and Creatine, for *in vivo* condition. The complex Lorentzian spectral line was generated with additional water signal. The water is 10^4 times in the magnitude. The simulated spectrum was then modulated by 6.8Hz Gaussian decay and FM with following parameters: the modulation index m_f was 0.2% , modulation frequency ($\omega_G/2\pi$) was 191 Hz. In order to validate the efficiency of algorithm, we perform Monte Carlo simulation with 400 realizations. To evaluate the performance under different SNR, normally distributed complex noises were generated using true random seeds. The spectrum processed by QZ-bac was then compared with the spectrum without noise between spectral ranging from 3.3 ppm to 1.9 ppm.

NWS MRS Experiments: *In vivo* experiments were performed on healthy subjects on a 3T system (Tim TRIO, Siemens Medical Solutions, Erlangen, Germany). PRESS sequence was used with parameters: TE=30ms, TR=2000ms, NEX=130, Voxel size=20×20×20 mm^3. For each subject two scans including NWS and WS were performed sequentially at the same localization. WS scans were then taken as reference standard for the comparison. . Before data processing zero order phase correction and frequency shift correction was done according to the water peak. The water subtraction and associated FM sidebands artifacts cancelation were then carried out using the Matrix Pencil Method [1] and QZ-bac algoritm, with rank=20 and limited between ±100Hz. Tails of FID were also removed by fitting algorithm.

Results and Discussion

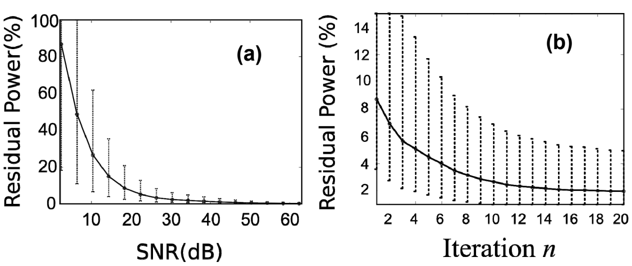

Figure 1. (**a**) Monte Carlo simulation with 400 realizations for different SNR. For each SNR the iteration of QZ-bac is 1 here (upper). It shows the biased and deviation was very low (< 10%) when the SNR is above 30 dB. The performance is optimal when the SNR is lower than 20 dB.
(**b**) Monte Carlo simulation with 400 realizations for 1~20 times of iteration. For each iteration number the SNR is fixed at 22.3dB (upper). Note that the there is obvious decreases in residue power when the iteration increases up to 15.

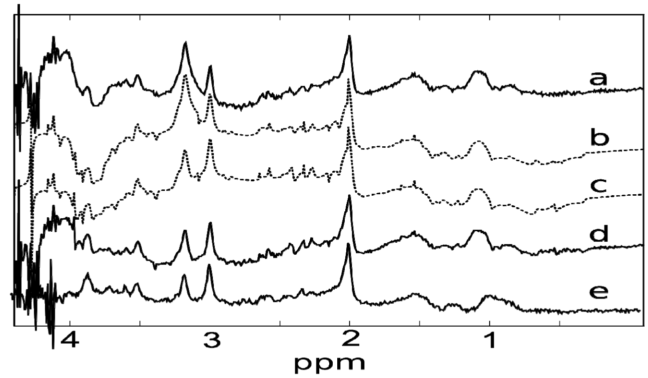

Figure 3. Demonstration of QZ-bac algorithm on an in vivo representative spectra (**a**) NWS spectrum after water substraction. (**b**) spectrum estimated from FDM (**c**) corrected spectrum at first iteration. (**d**) corrected spectrum after QZ-bac (**e**) WS spectrum. one can note that several significant markers for *in vivo* spectrum, i.e. the NAA, Choline, Creatine can be clearly observed on the WS spectrum and spectrum in (d) and (e) are very similar to each other.

Here we demonstrated that our proposed QZ-bac algorithm, a purely post-acquisitional method, can effectively suppress the sideband artifacts for in vivo MRS at short echo time. Computer simulations give the performance of QZ-bac algorithm (Figure 1). The QZ-bac algorithm is efficient and robust at SNR level over 20 dB. However we can further extend the QZ-bac to MRS data at lower SNR by using more number of iteration. The matrix decomposition is inherently time-consuming. Therefore more iteration will cost more computational time. According to our results it takes around half minute for a total 20 iterations, which will not be a crucial factor for the practicability of this method. The trade-off between number of iteration and computational time can be decided by the users according to different consideration.

In conclusion, we have demonstrated that the proposed QZ-bac algorithm is feasible to eliminate water related FM sidebands artifacts in NWS MRS. The effectiveness and robustness was presented using computer simulation and *in vivo* examples. The QZ-bac is a purely post-acquisitional algorithm which can be easily implemented on a modern PC with low computational burden. It can be used off-line or can be incorporated into on-line processing tools.

Acknowledgment

This study is supported by National Science Council under NSC 98-2320-B-182 -003 -MY2

References

1. Van der Veen JW., et al. Radiology, 2000;217:296–300.
2. Dong Z., et al. Magn Reson Med 2006;55:1441–6.
3. Clayton DB., et al. J Magn Reson., 2001;153:203-9
4. Z. Dong, et al. Magn Reson Med 2004;51: 602-6.
5.R. E. Hurd, et. Al.,Magn Reson Med 1998;40:343-7
6. V. A. Mandelshtam, et. Al., J Magn Reson 1998; 133: 304-12