Combination of Proton MRSI of the Brain Acquired Using a Multichannel Coil without Water Suppression

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INTRODUCTION

The use of multi-channel coils promises an efficient means to improve the SNR of MRSI data [1-5]. For multi-channel coils to increase SNR, however, the signals from each of the coil elements must be combined optimally through both the accurate alignment of phases and the accurate weighted summation, using reference signals. Unsuppressed water signal can be an ideal reference for phase alignment and for calculating WFs, in terms of optimal SNR and computational efficiency. In this report, we describe procedures for acquiring ^{1}H MRSI data using a multi-channel coil without WS and for using the unsuppressed water signal as a reference for the alignment of phases and the weighted summation of signals across coil elements. We show that using the unsuppressed water signal as a reference for combining multichannel signals allows for optimized SNR improvement compared with that using a metabolite signal as a reference.

METHODS

Data Acquisition MRSI data were acquired on a whole-body 3T scanner (Signa 3.0T, General Electronic Healthcare, Waukesha, WI) equipped with a single-channel quadrature head coil for transmission and an 8-channel coil for receiving. An axial, T1-weighted scout image was acquired first for localization, prior to MRSI acquisition. MRSI data were acquired with a sequence of multiplanar SI (MPCSI) [6]. The parameters for the MPCSI were as follows: TR/TE = 2300/288 ms; FOV = 24x24 cm^2; Number of phase encoding (PE) steps = 32x32; Spectral width = 2000 Hz; Number of slices = 4; Slice thickness/spacing = 10/2.5mm; a full echo was acquired with 512 complex data points. Outer volume lipid signal was suppressed by user-placed saturation bands. The WS option of the pulse program was turned off. Data were acquired in the Extended Dynamic Range (EDR) mode with an oversampling factor of 62.5 and were saved in 32 bits. The transmitter gain, digital receiver gain (R1), and analogue receiver gain (R2) were found by an automatic pre-scan procedure, and R1 and R2 were then manually adjusted to their highest possible values without signal saturation.

Subjects Four healthy adult volunteers participated in the human studies. The protocol was approved by the Institutional Review Board of the New York State Psychiatric Institute.

Combination of Signals from Multiple Channels The raw dataset acquired with the 8-channel coil was separated into eight datasets, one for each of the individual coil elements. We then used a 2-dimensional Hamming window to perform spatial filtering and subsequently applied Fourier transformation to transform those data into the spatial domain on a slice-by-slice basis. We calculated the phases of the signals from each of the coil elements on a voxel-wise basis according to the 256th complex data points of the signals. The first coil was designated as the reference coil against which the relative differences in phases, *Δφ's,* of the other coil elements were determined. The phases of the signal from each element were aligned to the phase of the reference coil by multiplying their signals with the corresponding terms of their differences in phase, $exp(i\Delta\varphi_c)$. The WFs were also calculated on a voxel-wise basis from quasi-SNRs calculated in each voxel, which was defined as the ratio of the amplitude of the signal in each voxel, a_v, to the relative overall noise level of that particular coil element R_r ($R_r = R_c/R_1$, where R_1 and R_c are the noise level of the 1st and the c-th element coil, respectively). These procedures for signal combination were implemented with software developed in-house and written with Matlab® (The MathWorks, Inc, Natick, MA). This program is fully automated and is computationally efficient. On a server with 2.7 GHz processor, the algorithm required approximately 10 seconds to combine raw SI datasets from 8 channels, each with 16x16 PEs and 4 slices.

RESULTS

Phases of the signals from each of the elements of the 8-channel coil were aligned in the time domain using the signal of the unsuppressed water as a reference. Aligning phases using the water signal in each voxel also aligns metabolite signals (Fig.1) [3]. The perfect phase alignment of the metabolite signals is attributable to the high SNR of the water signal. The metabolite spectra from these signals contained considerable noise with respect to the metabolite signals (Fig. 1), and therefore had lower SNR in contrast to the water signals. Presumably, using a metabolite signal as a reference would potentially introduce errors in phase detection and phase alignment, as well as errors in accurate calculation of WFs.

The superiority of SNR associated with use of unsuppressed water as the reference is confirmed by comparing it to use of NAA as a reference, with in vivo ^{1}H MRSI datasets reconstructed from 8-channel signals. Unsuppressed water as the reference produces spectroscopic images with high SNR in the ROI that delineates the distributions of the metabolites (Fig. 2). NAA as the reference, in contrast, produces noisy images that have voxels with low signals scattered throughout the ROI (Fig. 2). Computer simulation confirmed that the lower SNR of the MRSI when using NAA as a reference resulted from the errors caused by the noise in signal combination. A numerical calculation show that the SNR of NAA of the combined signal in this example is 1.44 times of the highest SNR of the component coil signals. The SNR of the multi-channel coil is superior to that from the volume head coil. The SNR of the averaged spectra from the combined signal of the 8-channel coil is 1.90 times of the SNR from the volume head coil.

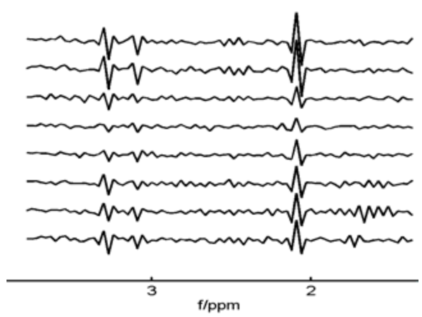

Fig. 1 Voxel spectra of metabolites from individual coil elements after phase alignments using water signal as a reference in the time domain. The metabolite spectra were obtained by FT after removing the dominant water components in the time domain. No zero- or first-order phase corrections were made.

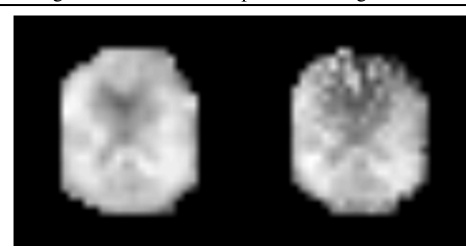

Fig. 2 Spectroscopic images of metabolites NAA reconstructed from multichannel signals combined using water as a reference in the time domain (left) and using NAA as a reference in the frequency domain (right), respectively. Both images are from the same 1H MRSI dataset acquired without WS. Before combining signals with NAA as a reference, water signal was removed from the raw signal and the metabolite signals were zero-filled from 512 points to 4096 points.

DISCUSSION and CONCLUSION

Measuring water and metabolite signals simultaneously, within a single scan instead of separate scans, reduces overall scan time, which is valuable when scanning vulnerable patient populations. Using unsuppressed water signal as a reference allows for more accurate alignment of phases and for improved SNR for the signals within the multiple elements of the coil. The computer algorithm for combination of multichannel MRSI data is fast and robust. Yet another possible advantage of our method is that the water signal can be used as an internal reference for the absolute quantification of metabolite concentrations. The method can be applied to ^{1}H MRSI data acquired as full-echos, if the subsequent spectral analysis is in the time domain, and as FIDs. A limitation of acquiring MRSI without WS is that the TE should be long (here 288 ms), otherwise the noise levels of the signal may be higher than are noise levels acquired with WS [7].

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