Multi-Channel Spectroscopic Imaging Reconstruction Using Water-Referencing with Compressed Sensing

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Introduction: Although the use of multi-channel receiver coils can increase the SNR of MRSI data, obtaining the optimal SNR from the raw data requires robust phase correction to achieve the constructive combination of signal from different receiver coils. The simplest strategy is to assume that there is a constant phase offset between the spectra in different channels and use the residual water from voxels in the central region of the selected volume to estimate these offsets prior to coil combination [1]. While this is robust for data with moderate SNR, voxels on the outer edge of the selected volume may not be optimally phased. Figure 3. shows that this assumption is not valid. Another, potentially more robust approach is to obtain a second dataset with unsuppressed water and to use that to estimate phase and frequency corrections [2]. Acquiring a separate dataset with no water suppression is time consuming, but the high signal to noise of the water resonance allows for an accurate estimate of frequency and phase parameters for all voxels in the selected region. In this study we propose a water referencing algorithm using accelerated imaging method with compressed sensing reconstruction in order to obtain optimal speed and spatial coverage.

Methods: Anatomic MR images and MRSI data were acquired from a commercially available MRS phantom and from human subjects using a GE 3T scanner (GE, Medical Systems, Milwaukee, WI) with 8 channel phased-array head coil using PRESS pulse sequence. The parameters for the data acquisitions were TR/TE = 1110/144 ms, with a FOV of 16x16x16 using flyback echo-planner encoding in the SI direction. The MRSI data were first reconstructed using either conventional Fourier transforms or a custom designed compressed sensing algorithm. The optimal phase for each voxel in each channel was then determined using the unsuppressed water peak by imposing symmetry upon the reference peak in the spectrum [1]. For the voxels with a water peak having a SNR of less than predefined threshold, nearest neighbor estimation was used to interpolate the phase values to yield a piece-wise constant interplant. The estimated phase and frequency corrections were then applied to the data set acquired with water suppression and the channels were combined.

According to compressed sensing theory if the underlying image exhibits transform sparsity, and if k-space undersampling results in incoherent artifacts in that transform domain, then the image can be recovered from randomly undersampled frequency domain data, provided an appropriate nonlinear reconstruction scheme is used. The random undersampling pulse sequence design that our laboratory has used extensively for FlyBack 3D-MRSI was simulated in MATLAB from the fully acquired k-space data for our initial tests [4]. The compressed sensing reconstruction was modified to further improve the quality of the reconstructed images and to reduce the computational complexity with a more efficient 2-stage nonlinear iterative reconstruction algorithm using Projection Onto Convex Sets (POCS) [3]. This POCS algorithm includes two projections for each iteration. The first projection applies a threshold to the input data. The second projection inserts the original observed measurement into the solution and essentially ensures that any solution proposed exactly fits the observed data or equivalently only the missing measurements are predicted.

Result and Discussion: Figure 1. illustrates the initial and improved phase estimation map for conventional vs rapid compressed sensing acquisition. The compressed sensing with POCS reconstruction does preserve the water phase information. To the best of our knowledge, this was the first time that POCS was implemented for undersampled MRSI reconstruction. Simulations showed that our algorithm would reduce the acquisition time by a factor of 5 (from 5 min to 1 min) for 3D data with a matrix size of 16x16x16. Unlike the method described by Hu et al [4], the sparsity is forced in the spectral domain vs. wavelet domain, which reduces the complexity and computation time. With 50 iterations the reconstruction took about 1.6 minutes. Applying the estimated frequency and phase correction to each voxel of each channel prior to coil combination results in constructive interference producing uniformly high SNR of metabolite peaks in the final data (Figure 2).

The fact that we used the water suppressed data for coil combination rather than separately acquired calibration images was a further advantage that is directly scalable for many different coil configurations.

Conclusion: We have demonstrated that compressed sensing can be used to obtain a water reference dataset for phase, frequency correct and coherently combine multichannel ^{1}H MRSI data from the brain with a 5-fold reduction in acquisition time over conventional phase encoding. This is an encouraging step forward in automating and optimizing the analysis of such spectra so that they can be used routinely in a clinical setting. Future work will include evaluation of the performance of this technique in whole-brain MRSI data sets for which phase correction is a challenge, investigating the benefits in terms of efficiency and quality of combining the compressed sensing and parallel imaging for highly accelerated 3D dataset and examining the use of the presented correction algorithm with rapid acquisition on the basis of the interleaved acquisition of a unsuppressed water navigator scan.

References: 1. Nelson. 2003. *Mol. Cancer Ther.* 2:497–507; 2. Spielman et al, MRM, 12: 38–49, 1989; 3. Candes et al, IEEE Trans. Signal Processing, 2005; 4.Hu et al MRM 2009

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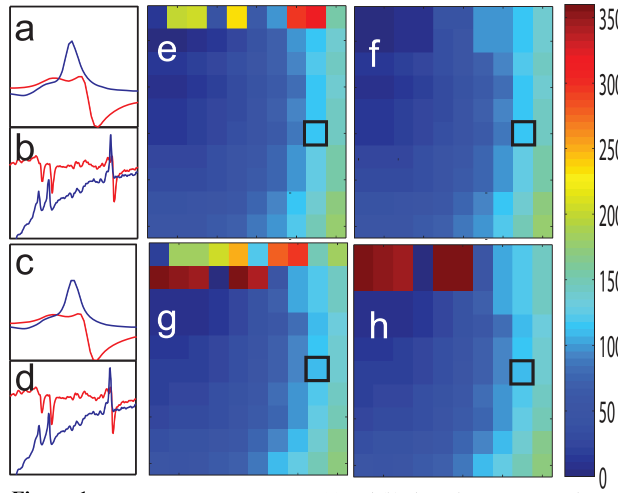

Figure 1. Conventional Acquisition: (a) and (b) show the unsuppressed water peak and metabolite peaks respectively phased with water-referencing (in red) and without (in blue). (e) and (f) show the initial and final phase-map from water-referencing respectively. **Rapid Acquisition:** (c) and (d) show the unsuppressed water peak and metabolite peaks respectively phased with water-referencing (in red) and without (in blue). (g) and (h) show the initial and final phase-map from water-referencing respectively. The comparison suggests the phase information is preserved by compressed sensing.

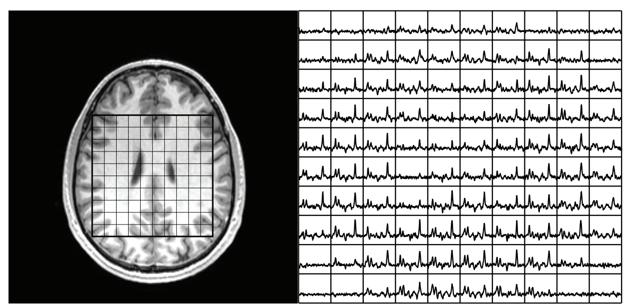

Figure 2. (a) T_1 weighted image from a healthy volunteer superimposed with PRESS box. The grid shows the voxel locations corresponding to the spectra on the right. (b) water-referenced spectra of the volunteer (after coil combination)

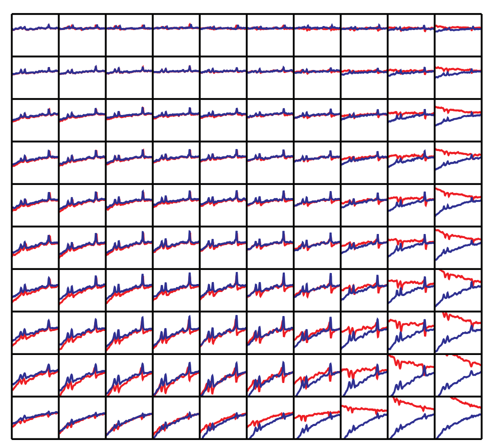

Figure 3. Phantom MRSI acquisition of one coil is presented with (blue) and without water-referencing(red).