Correlation Chemical Shift Imaging with Sparse-FFT and Real-time Motion and Shim Correction

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Introduction: In-vivo 2D Correlation Spectroscopy (COSY) allows the unambiguous assignment of metabolites in localized regions from brain or other organs. Several methods were demonstrated to acquire single-voxel COSY spectra [1,2] and showed great utility in detecting new molecular biomarkers of disease [3]. Correlation chemical shift imaging acquires multi-voxel 2D COSY spectra extending the spatial anatomical dimensions that can be probed [4,5]. However, there are several challenges for the wide-spread use of in-vivo 2D COSY. Two important aspects limit the quality of 2D COSY in-vivo: 1) due to long acquisition times the subject movement leads to motion artifacts and changes in the shimming, and 2) because scan time has to be kept as short as possible the indirect t1 dimension can not be sampled adequately leading to severe truncation artifacts of the diagonal that obscure cross-peaks. Here, we show that by combining sparse sampling of t1 dimension based on recently developed algorithms for the sparse Fourier (sFFT) transform [6,7] together with a new method for real-time motion correction and shim update (ShMoCo) [8] we can substantially improve the quality of multi-voxel 2D COSY spectra under the most unfavorable conditions.

Methods: Correlation chemical shift imaging was acquired with an adiabatic spiral COSY sequence [5] which was here improved with sFFT and ShMoCo. We adapted sFFT algorithms which are optimized for the reconstruction of approximately sparse signals in the Fourier domain. The 2D COSY spectrum is sparse, and hence lends itself naturally to such an approach. The sFFT-COSY algorithm [7] had two components: 1) a sparse sampling scheme, and 2) suppression of truncation artifacts of large diagonal peaks. Instead of taking consecutive increments along the t1-dimension, the algorithm takes subsamples of the time domain signal along t1 and uses filtering techniques described in [6] to recover the positions and values of the peaks in the frequency domain. This allows the algorithm to reduce the number of samples needed along the t1-dimension. The real-time ShMoCo was realized using a dual-contrast, multi-shot 3D-EPI navigator which was acquired interleaved with the spectra, prior to water suppression, and provided estimations of position and shim [8]. The navigator updated RF pulses and spiral gradients in each TR according to the head or phantom position, and concomitant the shims and main frequency were also updated. The experiments were performed on a whole-body 3T MR scanner (Tim Trio, Siemens, Erlangen). Acquisition parameters included TR = 1.8 s, TE = 30 ms, 72 sparse t1 samples out of 252 consecutive samples, 380 points in t2 zero filled to 512, 10 ppm spectral window in both f1 and f2 dimensions, 4 averages, matrix 16x16, FOV= 200x200 mm, acquisition time 17:32 min:s.

Results: We demonstrate that by using sparse-FFT we can: 1) reduce the measurement time by a factor of 3.5 (72/252) and 2) eliminate the t1 truncation artifacts resulting from the ringing tails of the diagonal. The real-time correction of motion and shim update reduces artifacts related to changes in position and drifts of the scanner frequency or the shims. Results are summarized in Figure 1.

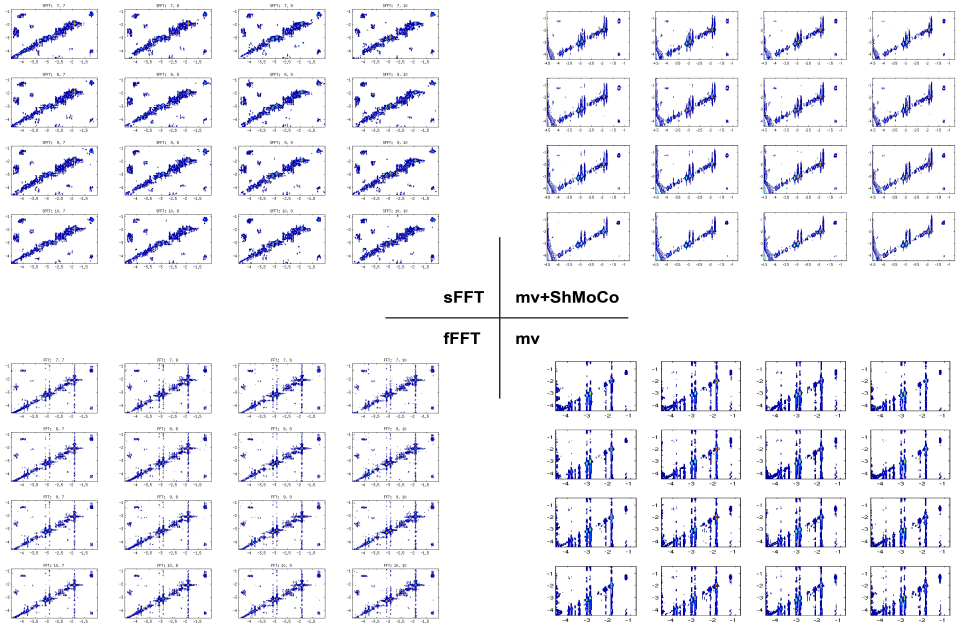

Figure 1. Correlation chemical shift imaging in brain phantom.

Left side: sparse-FFT multivoxel 2D COSY (up) vs. fully acquired FFT (fFFT) multivoxel 2D COSY (bottom). Four averages were acquired

Right side: multivoxel 2D COSY acquired in the presence of motion with real-time motion correction and shim update (mv+ShMoCo, up) vs. no correction (mv), bottom. Two averages were acquired.

sFFT data have less diagonal ringing along f1 dimension compared to fFFT data. Motion produces a smearing of diagonal and cross-peaks, which is reduced by real-time ShMoCo

Discussion & Conclusion: Our preliminary results indicate that sparse-FFT is useful for reducing acquisition time and reducing truncation artifacts in 2D COSY spectra. Typically, 2D COSY spectra reconstructed with conventional FFT use windowing functions such as qsine and linear prediction to improve cross-peaks and reduce the t1 artifacts. However, qsine windowing may selectively enhance only some of the cross-peaks, while linear prediction may reduce the SNR and introduce spiking artifacts. Sparse-FFT is less biased in finding the cross-peaks and may provide a more robust method in dealing with the limitation of in-vivo COSY. Real-time ShMoco recovers spectral resolution and reduces artifacts in both dimensions. Compared to retrospective correction schemes it has the advantage of accounting for all sources of errors, including the efficiency of water suppression, which decreases when frequency drifts out of the water selective bandwidth. Further validation is underway in human subjects for brain metabolic imaging.

References

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