Volumetric spiral chemical shift imaging with 32-channel receive coil at 3T with online gridding reconstruction

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Introduction: Field of view (FOV), resolution, and imaging time are strongly dependent parameters in conventional, phase-encoded (PE) chemical shift imaging (CSI). This dependence imposes imaging time constraints of at least one TR period per voxel, making PE CSI impractical for in-vivo studies beyond, say, a 32x32 voxel grid. CSI using time-varying, spiral-based readout gradients offers 2 orders of magnitude improved acquisition efficiency over the PE CSI without SNR tradeoffs, but at the cost of more complicated acquisition designs and image reconstruction.

Coil arrays with large number of receive elements are well suited for the time-efficient CSI acquisitions [1,2], as they provide important SNR gain for metabolite detection. In this work we make use of the encoding efficiency of the spiral CSI to quickly encode 3D volumetric brain acquisitions with small voxel sizes. We use a custom-built 32-channel coil array [3] to maximize SNR and fast online gridding reconstruction. We present in-vivo results demonstrating that combining the spiral CSI with large receive coil arrays yields large-volume, high-resolution spectroscopic imaging data.

Methods: Constant-density spiral readout was appended to a standard Siemens PRESS excitation of size 90x100x50 mm in (x,y,z) placed wholly within the brain. To minimize lipid contamination, 7 outer-volume saturation (OVS) bands were used. The in-plane FOV was 24cm and the encoding matrix size of (x,y) = 40x40 was zero-padded to 64x64 in the reconstruction. We applied phase-encoding in kz, collecting 16 slices over 10cm for an overall voxel size of 0.225cc. The readout duration was 320ms with 10us sampling time, and with a reconstructed spectral bandwidth of 800Hz we collected 256 k_f samples for each spatial location. The spiral designs used gradient slew rate and amplitude of 120 mT/m/ms and 10mT/m, respectively, for a total imaging time of 4.9 minutes (TR = 2s, TE = 144ms).

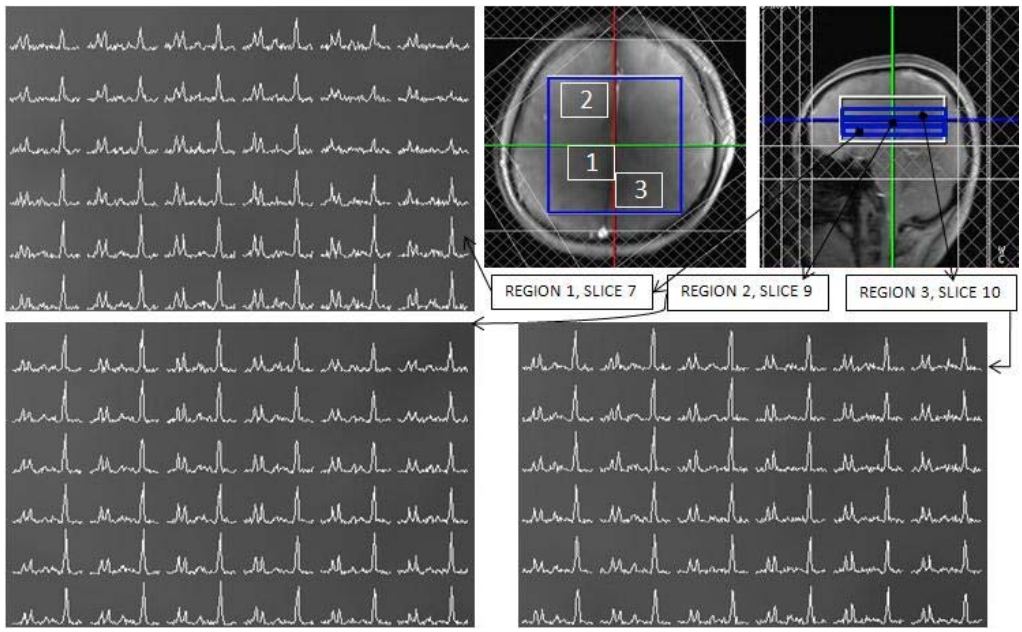

Fig. 1: magnitude spectra from three different slices and regions acquired in 15 minute long spiral CSI scan with voxel size of 0.225cc using 32 channel coil array.

The reconstruction was implemented using the Siemens online Image Calculation Environment (ICE). The in-plane (k_x,k_y) spiral encoded data from each of the 32 coils was reconstructed using 2X gridding routine with Kaiser-bessel kernel, followed by a tapered-cosine-shaped window in kf, but no spatial appodization. Gridding was not done along kf and kz, but appropriate phase correction was applied in kf prior to gridding in (kx,ky).

The spectroscopy data reconstructed on the 64x64x16x256 Cartesian grid from each coil were recombined using complex weights obtained from estimates of the coil sensitivities and a 32x32 noise covariance matrix that provides a noise correlation metric among the coils. Both the complex weights' estimates and the noise covariance matrix were obtained by running brief pre-scans (~30s total) prior to running the spiral CSI. For optimum SNR, the coil combination at sample (x_c, y_c, z_c, f_c) is $S_{x,y,z,f} = (C^H\Psi^{-1}D)/\sqrt{C^H\Psi^{-1}C}$, where C^H([1x32]) is a Hermitian vector of the complex weights from all the coils at (x_c, y_c, z_c), Ψ^{-1} ([32x32]) is the inverse of the coil covariance matrix, and D ([32x1]) is the vector holding the samples from all the coils at $(x_c, y_c, z_c, f_c,)$ [4].

The reconstruction time was approximately 7 min with initial reconstruction steps occurring in parallel with the acquisition. The main timing bottlenecks were the 2X gridding routine and the large number of matrix multiplications required for the coil combination.

Results and Discussion: We acquired in vivo spectroscopic data on a healthy volunteer subject with the imaging parameters given above, using three averages for a total imaging time of 15 minutes. Figure 1 demonstrates magnitude spectra from three different slices and locations of an in vivo scan on a healthy volunteer subject. Note that the upper right-hand side of the 7th slice (Region 1, Fig.1) is in the ventricles and therefore the amount of metabolites is decreased. The overall spectral quality and SNR is robust for the 0.225-cc voxel size.

Conclusion: Receive arrays with large number of coil elements offer excellent benefits for volumetric, time-efficient spiral CSI. The results shown in this work illustrate that 3D volumetric CSI with 0.225-cc voxels in 15 minutes yield good spectral quality and SNR. Future work on minimal oversampling [5] and multi-threaded reconstruction among the 8 available processors will significantly reduce the reconstruction time.

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