Feasibility of SNR enhancement in flyback echo planar spectroscopic imaging through parallel imaging with application to hyperpolarized 13C metabolic imaging

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Introduction- High spatial resolutions and wide spectral bandwidths, though desirable for spectroscopic imaging of hyperpolarized ^{13}C agents, compromise the SNR efficiency of flyback echo planar spectroscopic imaging (EPSI)[1,2], due to limitations in readout gradient performance and the low gyromagnetic ratio of the ^{13}C nucleus. Temporally interleaved readouts with reduced gradient amplitude can be implemented to regain high efficiency, as the time fraction for gradient rewind is reduced, at the expense of increased total imaging time[1]. Accelerated phase encoding by parallel imaging could be applied in conjunction with these highly efficient readouts in order to keep the imaging time fixed. Due to the limited duration of the hyperpolarized signal and low natural abundance of ^{13}C, an autocalibrating method such as GRAPPA is highly preferable. The purpose of this study was to investigate whether parallel imaging could in this manner provide a net increase in SNR for flyback EPSI.

Materials and Methods- Given a desired spatial resolution and spectral bandwidth, the maximum achievable SNR efficiency of a flyback EPSI readout waveform can be computed from the gradient specifications (i.e. 40 mT/m, 150 T/m/s). Applying typical requirements for hyperpolarized ^{13}C-1 pyruvate imaging of small animals (5.4 mm / 581 Hz, covering pyruvate to lactate at 3T)[2], an approximate 40% gain in SNR efficiency is expected by using two interleaves instead of the regular acquisition, as the duty cycle jumps from 37% to 73%. For the described method to be beneficial, this SNR advantage must not be outweighed by SNR losses related to rate-2 parallel imaging, which holds the total imaging time constant. In other words, the g-factor or noise inflation introduced by the parallel imaging reconstruction must be less than 1.40 in this case[3].

On a GE EXCITE 3T scanner, 3D EPSI data (16x8x16, 1 cm isotropic) were acquired from the whole body of a rat following tail vein injection of a 2.4 mL solution of hyperpolarized ^{13}C-1 pyruvate. Full echo data (TE = 150 ms, 59 time samples for each of 16 k_z locations) was acquired using an adiabatic double spin echo RF pulse scheme[4], with small, increasing flip angle over the 29 sec acquisition (TR = 225 ms). An insert clamshell transmitter coil, tuned to carbon and with proton traps installed[5], was paired with a prototype paddle receiver array with three non-overlapping elements arranged horizontally in the bore. Decoupling was achieved using capacitive decoupling networks and onboard low input impedance preamplifiers. Sagittal T2-weighted fast spin echo ^{1}H body coil images were first acquired for anatomic reference. In processing the EPSI data, the 16 horizontal k-space locations were undersampled by a factor of 2, and the missing data was reconstructed using a customized GRAPPA-based reconstruction[6], following an echo planar phase correction. 2D GRAPPA kernels (k_x,k_x) of sizes 3x3 and 5x5 were trained using one extra autocalibrating signal line, and used to fill the missing data for each coil image. Additional asymmetrical kernels were computed to fill the edges of the k-space matrix. Though the same GRAPPA coefficients would be expected for any spectral component, all were included in the fit in order to maximize the SNR of the fitting procedure. Coil images were combined using the sum of squares technique. Reconstruction errors were computed by comparison to the full data. To quantitate the reconstruction related SNR losses versus the expected SNR gain of the proposed interleaving scheme, a recently described method was implemented to estimate the g-factors of the GRAPPA reconstruction[7]. In this method, the g-factor is estimated directly from the GRAPPA coefficients, formulated in the image domain through a 2D Fourier transform of the GRAPPA convolution kernel[7].

Results- 3D MRSI demonstrated the presence of hyperpolarized pyruvate and its metabolic product lactate in the heart and liver, and its metabolic product alanine in the liver. Close agreement was achieved in the spectra obtained from the full and undersampled data sets (Fig. 1). Among the image voxels, the mean percent error in the pyruvate peak height for the undersampled versus fully sampled data was 9.2% (±7.4) for the 3x3 kernel and 10.7% (±6.6) for the 5x5 kernel. The errors are further reduced and a preference for the 5x5 reconstruction emerges if a few additional autocalibrating lines are included in the fitting procedure, but this is impractical due to the additional imaging time that would be required (3.6 sec / line). As for SNR, g-factor estimates based on the GRAPPA coefficients showed promise for the described interleaving scheme, as g-factor levels for R=2 reconstruction were mostly below 1.40. The mean g-factor over the imaging region with signal was 1.13.

Discussion- Parallel imaging allows greater flexibility in sequence design in comparison to pure gradient-based spatial encoding. In this application, the feasibility of using this flexibility for improved SNR in flyback EPSI was investigated. G-factors would be reduced to lower levels and g-factor hotspots would be mitigated by using more coils, maximizing the potential of this technique.

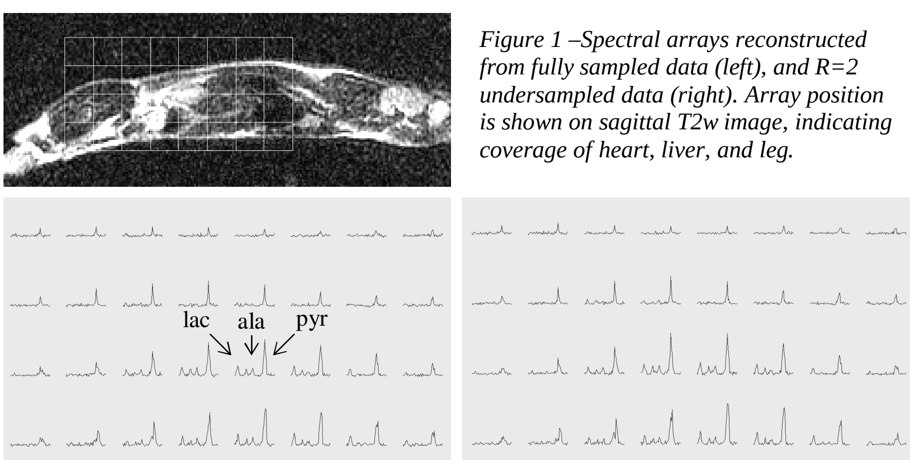

Figure 1 –Spectral arrays reconstructed from fully sampled data (left), and R=2 undersampled data (right). Array position is shown on sagittal T2w image, indicating coverage of heart, liver, and leg.

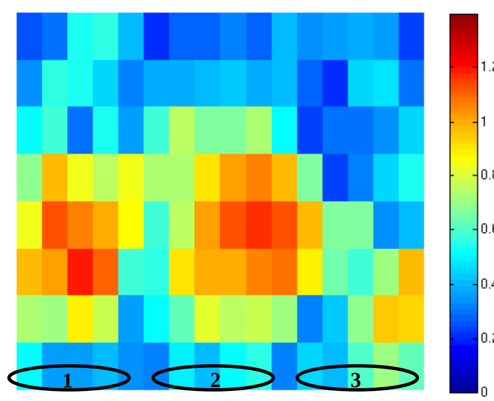

Figure 2- Computed g-factor map from representative axial data slice for GRAPPA reconstruction using 5x5 kernel. Approximate coil positions are shown.

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