Parallel Imaging with GRAPPA CSI for Hyperpolarised ^{13}C Metabolic Imaging

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Introduction

Metabolic imaging with hyperpolarised $^{13}C_1$ pyruvate [1] requires rapid acquisition sequences with high spatial and some spectral encoding to resolve the sparse spectra with at most four chemical shifts (pyruvate, alanine, lactate and bi-carbonate). Once the hyperpolarised sample is dissolved, the magnetisation is (non-reversibly) disappearing with the T_1 relaxation time. Also, exciting the magnetisation into the transverse plane leads to a loss of polarisation. Hence, sequences must be efficient and fast. Parallel imaging [2,3] can be combined with any sequence, increasing the information content of the acquired data by the coil encoding. This additional information can be used to increase the spatial resolution. Traditionally (i.e., in normally polarised MR), the SNR is proportional to the total acquisition duration. This general principle does not apply to hyperpolarised MR, because the spin polarisation is disappearing with T_1 [4].

Fig. 1: Four-channel ^{13}C-tuned receive coil with an inner diameter of 5.4 cm. The loops have inner and outer diameters of ~ 2.7 and 5 cm, respectively. Decoupling was improved by overlapping the elements.

Parallel imaging on hyperpolarised substances faces several difficulties. Both MR system and RF coil must be capable of receiving non-proton signal on multiple channels. Traditionally, MRI focused on protons and only few applications exist for other nuclei. Thus, a designated multi-channel carbon coil was built and the MR system modified (i.e., retuned TR switches and pre-amps). Another hurdle is the difficulty of measuring receive-coil sensitivities, as required for SENSE reconstruction [2]. The natural abundance ^{13}C signal *in vivo* is week and can, if at all, only be measured in fat tissue. Using hyperpolarised signal to determine sensitivity maps is generally undesired, as signal is depleting and the experiments cannot easily be repeated. Therefore, auto-calibrated parallel imaging is a natural choice for reconstruction. GRAPPA [3] is a highly robust, k-space based reconstruction technique. In this work, we introduce parallel imaging based on GRAPPA to chemical-shift imaging (CSI) for hyperpolarised $^{13}C_1$ pyruvate and show initial *in-vivo* results.

Methods

Hyperpolarised $^{13}C_1$ pyruvate solution (1 ml, 80 mM) was injected into the carotid artery of a healthy rat (200 g). MR measurements were performed on a 1.5T GE Signa HD system with a modified receive chain for acquiring 4-channels on the ^{13}C frequency (16 MHz). A custom-built, four-element rat-sized coil (Fig. 1) was used for signal reception, while a planar, single-channel coil was used for excitation. The signal was encoded with a FID CSI sequence with 24x24 spatial encodings, FOV=12cm, slice thickness=2cm, BW=5kHz, 256 spectral points and TR=80ms.

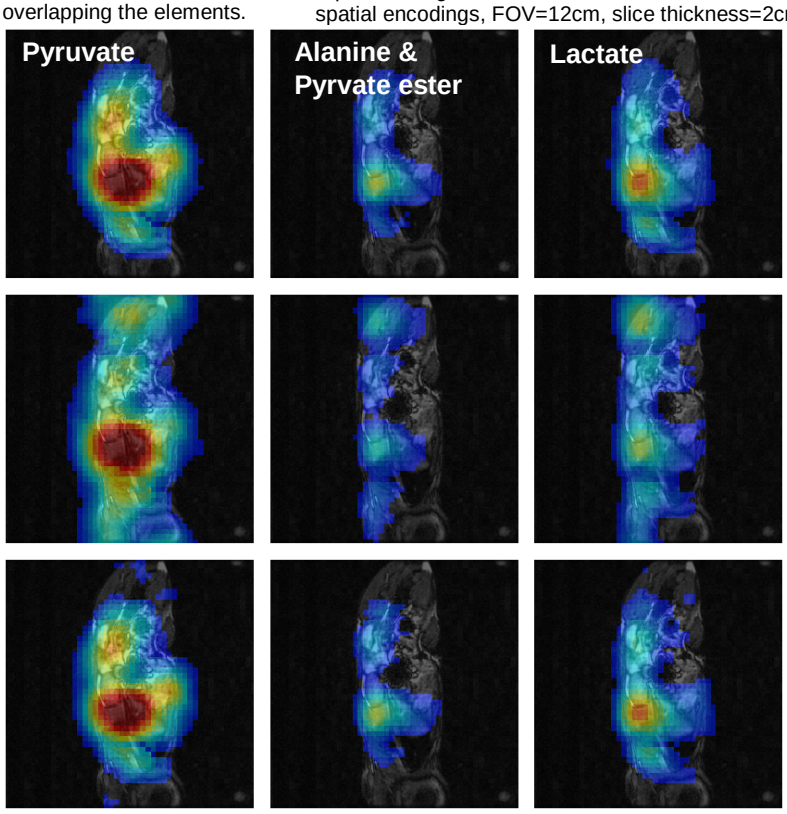

Fig. 2: Metabolic maps of pyruvate (left), alanine/pyruvate-ester (middle) and lactate (right) overlaid to the anatomical scout image (256x256) on protons. The fully sampled data is shown on top, the under-sampled in the middle and the GRAPPA reconstructed data in the bottom row.

The reconstruction problem separates into spatial and spectral domains, hence readily extending GRAPPA to chemical-shift imaging (CSI). First, the data was B_0 corrected and reconstructed in the frequency domain by matrix inversion to the chemical-shift frequencies of pyruvate, alanine/pyruvate-ester and lactate [5]. One GRAPPA kernel was fitted from multiple coils in the central k-space area (10-14 x 10-14) of the three chemical shifts. The data was artificially under-sampled in one spatial direction by omitting every other k-space line except for the inner calibration area, leading to a net reduction factor of ~2. The missing k-space points were interpolated from the surrounding samples and coils with the GRAPPA kernel. Finally, the data was zero-filled to twice the spatial dimensions (48x48) and Fourier transformed in the two spatial dimensions. The different coils were combined with root-of-sum-of-squares of the four sub-coil images.

Results and Discussion

The metabolic maps on pyruvate, alanine/pyruvate-ester and lactate are shown in Fig. 2. Under-sampling (middle row) leads to a fold over of the signal, which is slightly decreased due to the fully sampled k-space centre used for auto-calibration. This fold-over can be removed and the original image restored by GRAPPA reconstruction.

In conclusion, metabolic imaging with hyperpolarised ^{13}C can be combined with parallel imaging in order to shorten the acquisition time. Hence, the remaining polarisation can be utilised to improve either spectral or spatial resolution or acquire more time steps. Acquiring as much information as possible will be crucial for a clinical protocol on humans, because the polarisation is non-recoverably depleting, the SNR is limited and the dose can most likely only be given once. GRAPPA is a particularly well-suited technique for ^{13}C imaging due to its robustness and because no separate sensitivity maps are required. CSI consists of two phase-encoding directions, both of which can be under-sampled. Also, parallel imaging can be readily extended to other, more efficient sequences.

References

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