# Joint Field Map and Metabolite Image Reconstruction Framework for Hyperpolarized $^{13}$C Spiral CSI

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## Introduction

Hyperpolarized $^{13}$C metabolic imaging benefits from the enormous increase of signal, however this polarization must be used efficiently due to the irreversible $T_1$-decay and the loss of magnetization at every excitation. For this purpose spiral trajectories with long readout times are favorable. Compared to shorter trajectories they are more sensitive to off-resonance effects, which lead to blurring artifacts. In this work, a signal model is presented which allows searching for the reconstruction frequencies of each metabolite without the need of a FID. Furthermore, the model was extended with a $B_0$-map described by a linear combination of polynomial basis-functions. The parameters of the field-map are calculated simultaneously with the metabolite images using an iterative joint-estimation approach based on data consistency and a least squares minimization.

## Theory

IDEAL Spiral CSI with the trajectory $k_p$ encodes the spin density $\rho_{l,m}$ of the M metabolites with the CS frequencies $\omega_m$ at L Cartesian positions $r_l$. The IDEAL acquisition scheme uses Q different echotimes, equidistantly shifted by an increment $\Delta T_E$. The encoding times of each of the $Q \cdot P$ signal points are given as: $t_{p,q} = t_p + (q-1) \cdot \Delta T_E$

The signal equation which describes the encoding of the unknown metabolite images to the measured signal can be described by $s_{p,q} = E_{(p,q),(l,m)} \cdot \rho_{l,m}$ with the encoding matrix $E_{(p,q),(l,m)} = e^{ik_p \cdot r_l} \cdot e^{i\omega_m \cdot t_{p,q}}$ [1].
The metabolite images can be calculated by solving the overdetermined inverse problem of [1] using the Moore-Penrose pseudoinverse (†) of the encoding matrix: $\rho_{l,m} = \mathrm{E}^{\dagger}_{(p,q),(l,m)} \cdot s_{p,q}$ [2]

The matrix can be extended by accounting for spatially varying off resonance effects $\Delta\omega_l$

$$\tilde{\mathrm{E}}_{(p,q),(l,m)} = \mathrm{E}_{(p,q),(l,m)} \cdot e^{i\Delta\omega_l \cdot t_{p,q}} \quad [3]$$

To reduce the number of parameters for the minimization and hence obtain a better conditioned problem, a shimming approach is used

$$\Delta\omega_l = \sum_j A_j \chi_{j,l} \quad [4]$$

with $\chi_{j,l}$ 2D polynomial basis functions. By also considering $\Delta\omega_l$ (or $\omega_m$) as unknown, the joint estimation of the field map (or the CS frequencies) and the metabolite images becomes non-linear, which can be solved iteratively using Gauss-Newton minimization (2) of the data consistency equation

$$\min_{A_j, \rho_{lm}} \| s_{p,q} - data_{p,q} \| \quad . \quad [5]$$

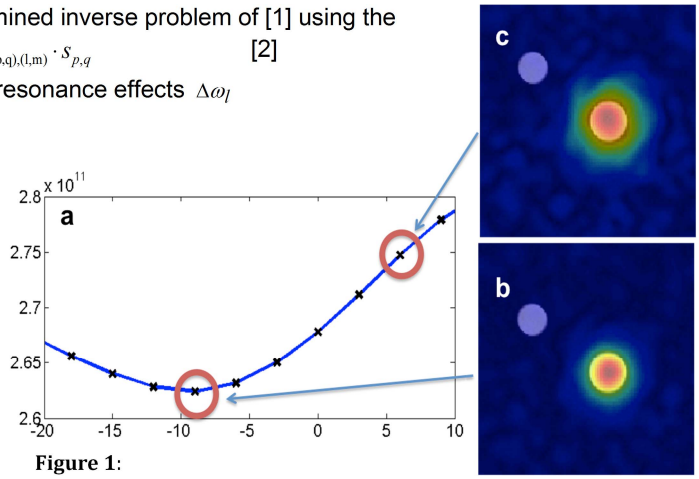


**Figure 1**: Calibration curve for the glycine frequency. The error in arb. units versus the test-frequencies (a). The test-frequency with the smallest errorfunction delivers the sharpest image (b) at 15Hz off-resonance increased blurring occurs (c).

## Results

In a first step the signal model was validated without field inhomogeneity [1], but unknown CS-frequencies $\omega_m$. A phantom consisting of tubes with $^{13}$C-labelled urea and glycine was measured using the same sequence as it was used for in-vivo rat experiments previously (IDEAL spiral CSI, FOV 8cm; $\Delta T_E$ =1.12ms; $T_R$=250ms; 7 echo times; 10mm slice thickness, real res. 5mm). As illustrated in Fig. 1 the joint estimation of the CS frequencies and corresponding images provides the lowest error with minimal amount of blurring. This is the case for both frequencies (urea not shown); furthermore these CS-frequencies are consistent with additionally acquired spectra.

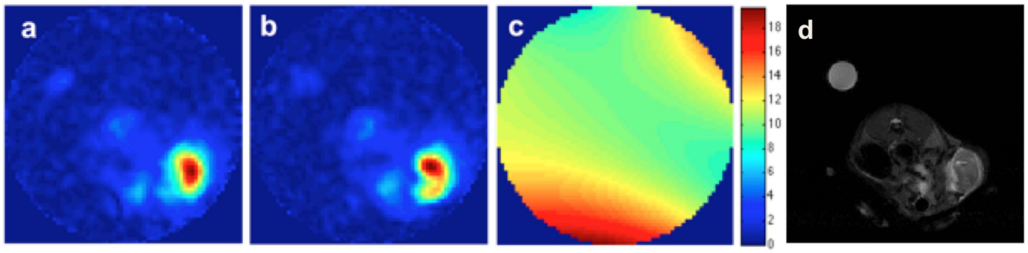


**Figure 2:** Lactate images of a reconstruction without (a) and with (b) a fieldmap Field in Hz (c). Additionally a proton FSE of the tumor slice is shown (d)

To include spatially varying $B_0$-inhomogenieties, the field map [4] was estimated by 3rd-order, 2D polynomials.
A 2D IDEAL spiral dataset acquired for a study on subcutaneous mammary adenocarcinomas in rats (sequence as described above; 0.2mmol/kg pyruvate injection) served as a test for the model under in-vivo conditions. Firstly, a fieldmap was extracted, using a resolution of 16x16 and only the inner k-space area to save computation time. For the reconstruction the fieldmap was extrapolated onto a 64x64 grid for the calculation of the encoding matrix [3]. The conditioning of the matrix was improved via singular value thresholding before inversion. For figure 2a the field map was set to zero, for figure 2b the encoding matrix was calculated with the fieldmap (2c). The lactate images summed over 5 timepoints (each represents 2s) starting 8s after the pyruvate injection. The corrected image indicates reduced amount of blurring and corresponding more detailed localization of the lactate metabolite signals especially in the tumor region.

## Conclusion

An algorithm searching for CS-frequencies during IDEAL Spiral CSI reconstruction was established, this allows to decrease the number of necessary excitations by saving the extra FIDs. The extension with off-resonance correction results in an increase of image quality of hyperpolarized $^{13}$C images.

**References:** (1) F. Wiesinger et al. MRM 2012
(2) J. L. Honorato et al. MRM2012

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