Advanced Single-Shot Parallel Imaging Strategies for Hyperpolarized 13C Chemical Shift Imaging

Markus Durst[1,2], Ulrich Köllisch[1,2], Francesca Frijia[3], Luca Menichetti[4], Maria Filomena Santarelli[5], Massimo Lombardi[3], Titus Lanz[6], Matthias Müller[6], Jan Henrik Ardenkjaer-Larsen[7], Marion I Menzel[2], Axel Haase[1], and Rolf F Schulte[2]

[1]*Institute of Medical Engineering, Technische Universität München, Garching, Germany,* [2]*GE Global Research, Garching, Germany,* [3]*Fondazione CNR-Regione Toscana G.Monasterio, Pisa, Italy,* [4]*Institute of Clinical Physiology of CNR, Pisa, Italy,* [5]*CNR Institute of Clinical Physiology, Pisa, Italy,* [6]*Rapid Biomedical, Rimpar, Germany,* [7]*GE Healthcare, Brøndby, Denmark*

Introduction: Metabolic imaging of the heart following injection of hyperpolarised pyruvate could allow new methods for diagnosis and characterisation of heart disease. In comparison to healthy tissue, abnormal concentrations of the downstream metabolites lactate, alanine and bicarbonate were detected in the area affected by an induced myocardial ischemia [1]. The hyperpolarised pyruvate signal rapidly decays due to T_1 decay ($T_1 \approx 30$s in vivo) and each RF excitation will irreversibly destroy some of the hyperpolarised longitudinal magnetisation. Therefore, fast and efficient imaging sequences are required to encode the desired dimensions with sufficient image resolution and quality. In this context, parallel imaging could be highly beneficial for in vivo metabolic imaging to speed up the acquisition process [2]. However, approaches presented to date are starting from intrinsically inefficient CSI encoding schemes which benefit a lot from reduced encoding. In this work, an efficient autocalibrated single-shot spiral parallel imaging sequence for metabolic imaging of hyperpolarised compounds is presented and applied to cardiac imaging in pigs after intravenous administration of hyperpolarised [1-^{13}C] pyruvate.

Materials and Methods:

The single-shot CSI sequence consists of a spiral trajectory with variable density undersampling (3-fold in k-space center, transition to 4-fold in k-space periphery, FOV 282mm, nominal resolution 10.25x10.25mm²). The same spiral interleave is encoded 16 times within a single excitation to obtain chemical shift information [3], the time delay between the single spiral interleaves which determines the spectral width was 3.6 ms (aliasing is optimised for pyruvate + metabolites). Additionally, temporal shifts of 1.2ms and 2.4ms were acquired to encode the unaliased spectrum. The trajectory was rotated by 90° after each CSI encoding set so that 4 rotations form a fully sampled k-space (3 excitations with different echo-times, then rotation by 90°, again 3 excitations and so on). The heart was imaged in short axis view (2 oblique slices, 12mm slice thickness, flip angle 20°) using ECG triggering. Experiments were performed on a 3 T HDx clinical scanner (GE Healthcare, USA), using a 1H body coil and a 16 channel ^{13}C cardiac coil (Rapid Biomedical, Germany). The preparation of a large dose of [1-^{13}C]pyruvic acid was optimised for bolus injection in pigs using a HyperSense DNP polariser (Oxford Instruments, UK) [4]. Hyperpolarised pyruvate solution (dose of 0.13mmol/kg bodyweight in 20mL) was administered over 10s by manual injection into the right ear vein of a healthy overnight-fasted male farm pig (body weight 25kg). The measurement was started 18s after injection at the estimated bolus maximum. Undersampled data were reconstructed using a combination of least-squares solution matrix inversion (LSCSI) [5] for chemical shift separation and SPIRiT [6] for parallel imaging reconstruction, where the calibration weights were obtained from the fully sampled dataset similar as in T-GRAPPA methods [7]. The fully sampled data were reconstructed using a simple gridding algorithm after chemical shift separation.

Results and Discussion:

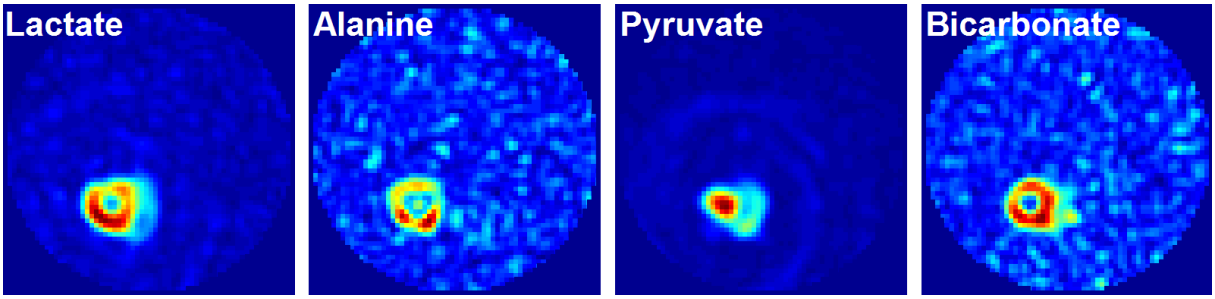

Fig. 1: Fully sampled image, reconstructed from all 12 excitations

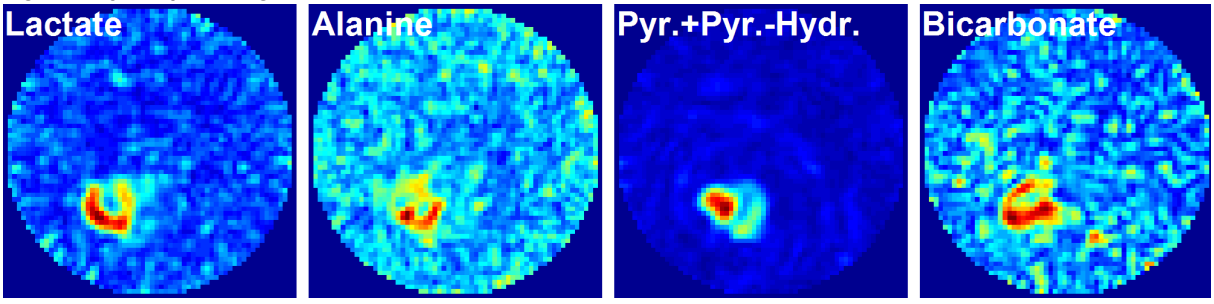

Fig. 2: Images from a single excitation reconstructed with SPIRiT

The left ventricle and parts of the right ventricle can be observed in the metabolite images. The metabolite maps from the fully sampled k-space data and the undersampled are comparable, although the SNR of the fully sampled images is higher compared to the single-shot images because it is computed from 12 excitations. Using the parallel imaging reconstruction, 12 separate time steps could be reconstructed from the 12 excitations.

Conclusion: It was demonstrated that parallel imaging enables single-shot dynamic hyperpolarised imaging of the pig heart, which is an important step towards human studies. By avoiding the additional acquisition of a calibration region, the hyperpolarised signal can be used more efficiently and the single-shot approach reduces motion and flow artifacts. Furthermore, multiple timesteps enable kinetic modeling for future studies. Those are the first results of an upcoming large-scale study with this sequence.

References: [1] K. Golman et al. *MRM.* 2008;59:1005-1013 [2] A. Arunachalam et al. *NMR Biomed.* 2009;22:867–873. [3] D. Mayer et al. *JMR* 2010;204(2):340-5. [4] L. Menichetti et al. *Contrast Media Mol. Imaging*. 2012, 7:85–94 [5] S.B. Reeder et al. *JMRI.* 2007;26(4):1145–1152 [6] M. Lustig et al. *MRM.* 2010;64(2):457–471. [7] F.A. Breuer et al. *MRM.* 2005;53(4):981–985.

Acknowledgements: Co-funding from BMBF grant # 01EZ1114