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Metabolic Imaging with Hyperpolarized ^{13}C and Multi-echo, Single-shot RARE

Introduction: Chemical shift imaging (CSI) has been the traditional method for encoding both spatial and spectral information into an MRI dataset. However, the long scan time and the large number of RF-excitations in a CSI scan is disadvantageous for imaging of hyperpolarized substances, since both factors result in an irrecoverable signal decay. Recently, new attention has been paid to multi-echo methods for the decomposition of water and fat [1,2]. By using a fast single-shot RARE sequence with additional echoes surrounding the central spin echo, we were able to separate and image several ^{13}C metabolites after injection of hyperpolarized 1-^{13}C-pyruvate in pigs, with a scan time of ~0.6 s.

Methods and Results: A multi-echo RARE sequence was implemented on a Siemens Sonata 1.5 T scanner. 13 echoes, separated by 1.07 ms, were acquired within one TR interval (Figure 1), and all phase-encoding steps were completed after a single 90° pulse. TR and matrix size were 18 ms and 64×32, resulting in a scan time of 0.58 s. ^{13}C-pyruvate was hyperpolarized to ~20% with Dynamic Nuclear Polarization (DNP) [3,4]. 16 ml 0.3 M solution was injected intravenously in the foreleg of a pig during 12 s and ^{13}C imaging was started 30 s after the injection. To compare the result of the multi-echo scan, a CSI scan was acquired with matrix 16×16 and a scan time of 24 s, after a separate ^{13}C injection.

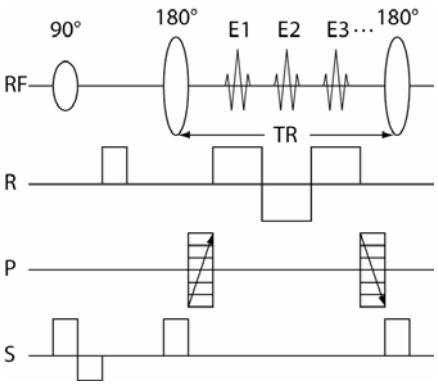

Figure 1. The multi-echo RARE sequence

Axial images were acquired through the head of the pig. Figure 2 shows five metabolite images (lactate, pyruvate hydrate, alanine, pyruvate, and bicarbonate) obtained from the multi-echo RARE scan. The separation of the metabolites was achieved with the iterative method described by Reeder *et al.* [5], including a correction step for B_0 inhomogeneities. Figure 3 shows the corresponding metabolite maps reconstructed by time-domain fitting of the CSI dataset [6]. The fit routine was not able to reliably detect any bicarbonate signal.

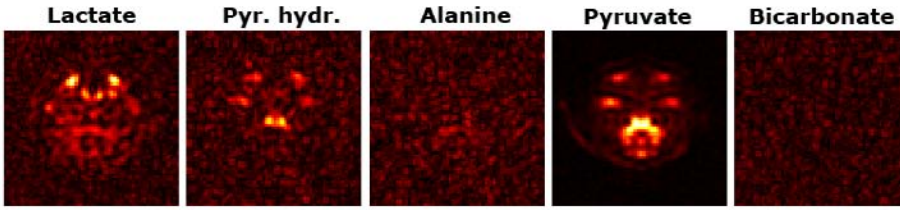

Figure 2. Multi-echo RARE acquisition from the head of the same pig as shown in Figure 2, with image reconstruction of five different metabolites. Imaging parameters were: matrix=64×32, FOV=50×25 cm, slice thickness=40 mm, scan time=0.58 s, in-plane resolution=7.8 mm. (Note: the pyruvate image has a different intensity scaling than the other four metabolites.)

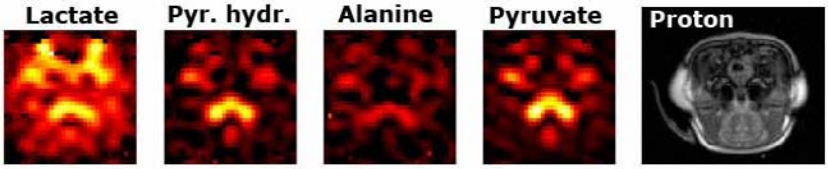

Figure 3. CSI images showing four ^{13}C metabolites in the head of a pig. Imaging parameters were: matrix=16×16, FOV=15×15 cm, slice thickness=40 mm, flip angle=10°, scan time=24 s, in-plane resolution=9.4 mm. (Note: the pyruvate image has a different intensity scaling than the other three metabolites.)

Discussion: After injection of ^{13}C-pyruvate, the metabolic products lactate and alanine are produced in the cytosol. Inside the mitochondria, $^{13}CO_2$ is formed by pyruvate oxidation and equilibrated to ^{13}C-bicarbonate. The latter product could be detected neither by the CSI scan, nor by the multi-echo RARE scan. In the CSI scan, but not in the multi-echo scan, a weak alanine signal was seen. The distribution of pyruvate differs notably from that of lactate: the intensity of pyruvate is very high in the feeding arteries to the head, whereas the highest lactate intensity is found in the major veins. This difference was clearly seen in both the CSI and the multi-echo scans. Additionally, pyruvate hydrate could be observed with both sequences, with a distribution similar to that of pyruvate. Pyruvate hydrate is formed under the conditions of pH 7.5–8.2 in the injection solution, but is not metabolically active in the body. The distribution of the hydrate is thus expected to be very similar to the pyruvate distribution. Overall, there was a good agreement between the multi-echo sequence and the CSI sequence. However, since the metabolite concentrations change dynamically after the injection, the big difference in scan time (0.6 s vs. 24 s) between the two sequences may result in different signal distributions in the images.

Conclusion: The results hold promise for the use of fast multi-echo imaging to map different metabolites after injection of hyperpolarized ^{13}C. Compared to the CSI technique, similar metabolite separation may be achieved with a substantially shorter scan time, and potentially with higher spatial resolution.

References:

[1] Wieben O, *et al.* 21th ESMRMB, p. 246, 2004.
[2] Reeder S, *et al.* MRM 54:636, 2005.
[3] Ardenkjaer-Larsen *et al.* PNAS 100:10158, 2003.
[4] Golman K, *et al.* PNAS 100:10435, 2003.
[5] Reeder S, *et al.* MRM 51:35, 2004.
[6] Vanhamme L, *et al.* JMR 129:35, 1997.