3D Whole-Heart Cardiac Metabolic Imaging with [1-^{13}C]pyruvate using IDEAL Spiral CSI

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Introduction

Metabolic imaging with hyperpolarized [1-^{13}C]pyruvate has high potential for examination of myocardial viability [1]. Pyruvate can be metabolized via pyruvate dehydrogenase to acetyl-CoA entering the Krebs cycle, whereby $^{13}CO_2$ gets produced, which converts to bicarbonate. In another pathway pyruvate gets converted into lactate mediated by lactate dehydrogenase. Since the first pathway only occurs in viable myocardium, the ratio of bicarbonate to lactate may be used for diagnosis of viability. In this work, a 3D CSI sequence was implemented for whole-heart cardiac imaging. The 3D spatial and 1D CS image encoding requires rapid repetitive excitation, which is advantageous for motion averaging but results in rapid depletion of the hyperpolarized magnetization. Addressing this problem, a multiband pulse was designed with a profile, tailored to the metabolites of interest and hence using the magnetization very efficiently.

Theory and Methods

The multiband pulse excites the lower concentrated metabolites with a fivefold higher flip angle than the injected molecule, saving the magnetization of pyruvate. Additionally the suppression of alanine and pyruvate-hydrate gains the possibility to reduce the number of CS encoding steps [2]. This allows to speed up the acquisition using higher flip angles. As a disadvantage the longer multiband pulse implies slight loss of signal due to T_2 -decay of the magnetization during the longer effective echo time. For the pulse design a flyback gradient modulation [2] with 15 sublobes and a total duration of 21ms was chosen. The pulse was fitted to the desired profile using a least squares approximation [3].

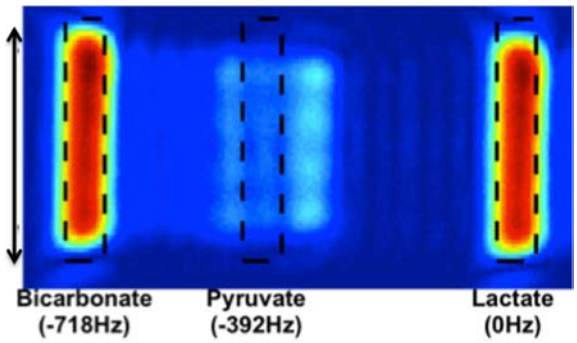
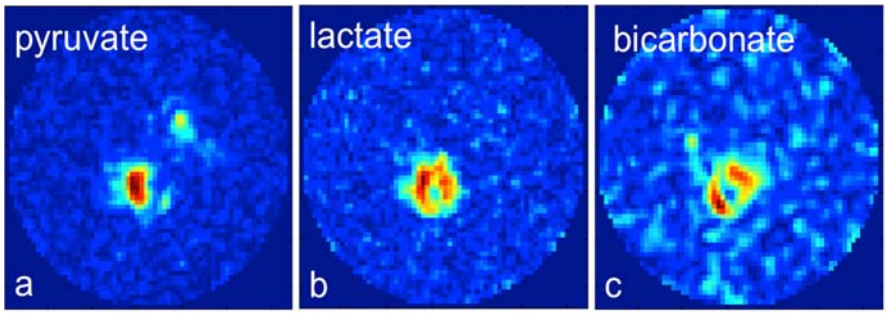


Figure 1: The spectro-spatial pulse profile

Measurements were performed on a 3T GE HDx scanner using the proton body coil for positioning and anatomical referencing and a ^{13}C quadrature transmit-receive birdcage coil. One male pig weighting 25kg was imaged three times after [1-^{13}C]pyruvate injections with concentrations of 180mM and an injection volume of 20mL achieving about 16% of liquid state polarization. For spatial image decoding a stack of single-shot spirals was designed for a FOV of 30cm, a nominal resolution of 8mm and a duration of 42ms using the maximal gradient strength of 40mT/m and maximal slewrate of 150T/m of the system. A single time step with seven echo time shifts and twelve phase encoding steps in z-direction was acquired over a FOV of 10cm in z-direction with a flipangle of 15° for lactate and bicarbonate and 3° for pyruvate. Additionally FIDs of the whole imaging slab were recorded during the acquisition, used for the IDEAL reconstruction [4] and for inspection of the signal development during the acquisition. The pictures shown in Fig.2 were recorded without using any motion correction or triggering.



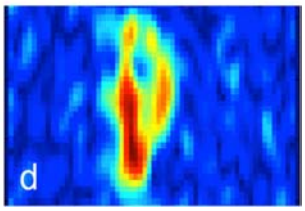


Figure 2: The metabolite maps of the porcine heart: Axial slices (a,b,c). Bicarbonate was visible in the whole left ventricle (d)

Results and Discussion

The myocardium of the whole left ventricle was clearly depicted in the bicarbonate images as well as in the lactate images. In Fig. 2 an axial slice of all metabolites through the ventricle is shown (a-c). While bicarbonate stays in the muscle tissue some lactate is also washed out into the blood. The pyruvate signal is mostly recorded out of the blood pool inside of the ventricle. Additionally a sagittal slice of bicarbonate (Fig.2d) shows that the metabolisms takes place over the whole ventricle, as it is expected for a healthy animal.

Conclusion

3D IDEAL spiral with multiband excitation was demonstrated to be feasible for [1-^{13}C]pyruvate metabolic imaging by accurately depicting pyruvate lactate and bicarbonate distributions over the entire left ventricle.

Acknowledgements

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References:

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