

Bolus Tracking for Improved Metabolic Imaging of Hyperpolarised Compounds

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Introduction

Dissolution dynamic nuclear polarisation has enabled real-time metabolic imaging of endogenous substances in vivo. After injection of a hyperpolarised substrate, the arrival of a bolus in the target tissue can be observed along with the build-up of downstream metabolites. However, during the bolus arrival, the substrate signal is mainly determined by perfusion and does therefore not provide reliable information for kinetic modeling [1]. Furthermore, when using a segmented kt readout, acquiring data during this period introduces artefacts due to rapid signal change and depletes substrate polarisation in the blood pool which is not available any more for subsequent conversion. For single time point imaging, quantification of metabolic activity is usually achieved by a metabolite substrate ratio at a fixed time point after injection, which can fluctuate significantly depending on perfusion. We present a fully automatic bolus tracking sequence for hyperpolarised substrates which starts the imaging acquisition at a defined point on the bolus curve to avoid those disadvantages.

Materials and Methods

Experiments were carried out on a standard clinical 3T GE HDx system (GE Healthcare, Milwaukee, WI). For bolus tracking, a slice selective excitation with a small flip angle (5°, sinc-shaped soft pulse) was used for pyruvate injections. A spectral-spatial excitation pulse [2] with 18° flip angle on the urea frequency was used for pyruvate/urea copolarised injections in combination with a single-shot spiral readout gradient. The data was sent to a reconstruction computer which evaluates the data during the scan and sends commands back to the MR scanner. To detect the bolus maximum, the algorithm searches for the turning point of the bolus curve where the slope becomes negative. Dynamic thresholds, which are computed from noise scans and current data points, guarantee a sufficient level of robustness also in conditions with low SNR. When a bolus maximum is detected, an IDEAL Spiral CSI imaging sequence (flip angle 10°, T_R 250ms, FOV 8cm, nominal resolution 2.5x2.5mm²) is started. A 10mm axial kidney slice was measured in 9 healthy Lewis rats after intravenous injection of 80mM [1-13C]pyruvate or [1-13C]pyruvate/[13C]urea solution. Each animal received two injections: For one injection, the acquisition was started at the beginning of the injection, whereas the other used the bolus tracked sequence. In 3 animals, pyruvate was injected and the bolus tracked sequence was compared to a spectral acquisition. In another 3 animals, dynamic IDEAL Spiral CSI images were acquired with pyruvate as a reference. Moreover, in 3 animals IDEAL Spiral CSI images were acquired with pyruvate/urea copolarisation.

Results and Discussion

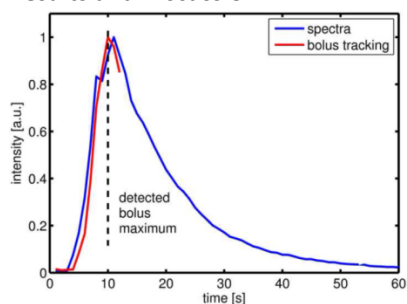


Fig. 1. Pyruvate time curves obtained from two subsequent injections in the same rat: bolus tracking data and data from slice selective spectra (peak integration)

The algorithm found a bolus maximum in 100% of acquisitions. Using the spectral acquisitions, it was verified that the correct bolus maximum was indeed found (see Fig. 1.). In the image time series of the conventional IDEAL Spiral CSI acquisition, strong artefacts resulting from rapid signal change and broad spectral point spread function can be observed, whereas the bolus-tracked acquisition is artefact-free (Fig. 2). The urea-tracked data shows the spatial localisation of the bolus which arrives first in the vena cava and then distributes to both kidneys (Fig. 3). This is especially beneficial for perfusion measurements because the incoming urea bolus curve can be sampled at a high temporal rate before starting the metabolic imaging sequence.

Conclusion

A fully automated bolus tracking sequence for imaging hyperpolarised compounds was implemented and successfully demonstrated with hyperpolarised pyruvate in vivo. In combination with a copolarised pyruvate-urea injection and a spectral-spatial tracking pulse, it was furthermore shown that tracking can be selectively performed on urea without depleting pyruvate magnetisation while at the same time obtaining localised perfusion information. Compared to existing imaging modalities, the proposed method reduces artefacts, allows for a more efficient use of hyperpolarised magnetisation and ensures a higher reproducibility and consistency of the data. This will be of particular interest in human applications, as the perfusion of the hyperpolarised substrate is less controlled.

References

[1] L.Z. Li et al. NMR Biomed. 26 (10) (2013) 1308-1320. [2] R.F. Schulte, et al. Magn. Reson. Med. 69 (2013) 1209-1216.

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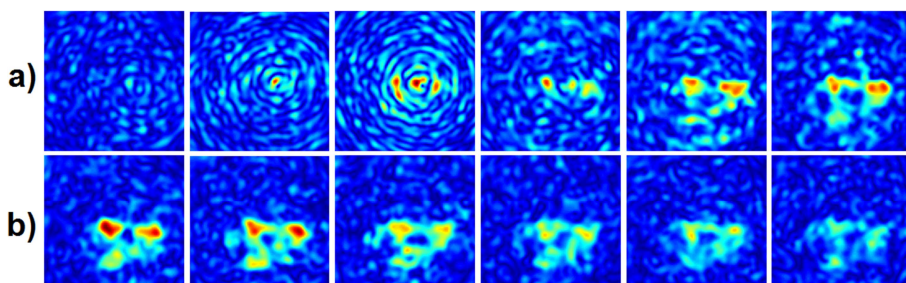


Fig. 2. Comparison of lactate time series obtained from two subsequent injections in the same rat: a) acquisition without bolus tracking, b) acquisition with bolus tracking

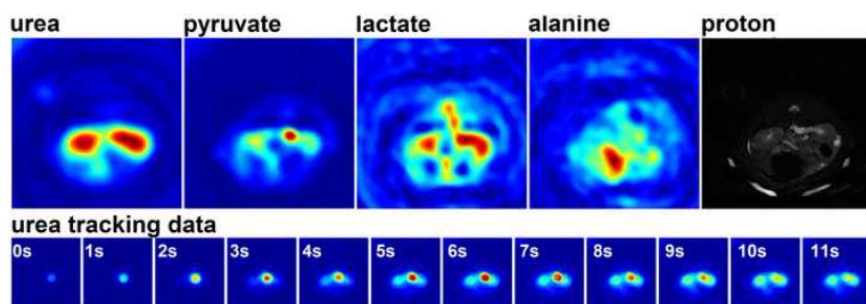


Fig. 3. Dataset with hyperpolarised [13C]urea tracking, 10 mm kidney slice after injection of co-polarised [13C]urea/[1-13C]pyruvate solution (upper row: sum over first 8 time steps).