Exploiting spatiotemporal correlations for accelerating dynamic 2D spectroscopic imaging of hyperpolarized pyruvate in the heart

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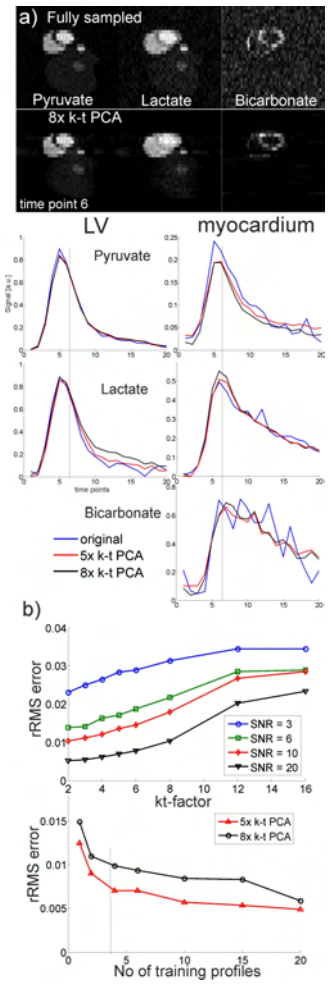

Figure 1: Simulation results. a) Fully sampled and 8-fold undersampled and k-t PCA reconstructed images and time series of the left ventricle (LV) and myocardium. The images are from the time point indicated by the vertical line in the time series. A SNR value of 50, 20 and 6 was assumed for pyruvate, lactate and bicarbonate respectively. b) Dependency of the relative root mean square (rRMS) error on k-t-factors and SNR and the number of training profiles.

Introduction

Hyperpolarized [1-^{13}C] pyruvate [1] is a promising tool to investigate cardiac metabolism in vivo. It has been shown that changes in metabolic substrate occur following induction of ischemia [2, 3]. To investigate metabolic changes high spatiotemporal resolution is required. In previous studies compressed sensing [4] or parallel imaging [5] has been used to address this need.

The present work aims to exploit both spatial and temporal correlations using k-t PCA [6] to undersample the spatiotemporal domain to speed up acquisitions. A numerical model was implemented to find optimal acquisition and reconstruction parameters for pyruvate, lactate and bicarbonate images of the heart. Subsequently in vivo data of the rat heart were acquired and reconstructed using k-t PCA.

Methods

Simulations:

Simulations were performed using a spatiotemporal numerical model derived from perfusion data (Figure 1a). Dynamics for lactate, bicarbonate and [1-^{13}C] pyruvate were modeled based on in vivo data from non-selective spectroscopic time series. Matrix size was 30 x 60 and SNR values of 50, 20 and 6 were used for pyruvate, lactate and bicarbonate images, respectively.

In vivo data:

A mixture of [1-^{13}C] pyruvic acid (Sigma-Aldrich), 15mM trityl radical OX063, and 1.5mM Dotarem (Guerbet) was hyperpolarized in a custom built DNP system [7]. All experiments were performed on a horizontal bore 9.4T Bruker Biospec system (Bruker BioSpin MRI, Ettlingen, Germany) using a combination of a ^{1}H/^{13}C transmit/receive birdcage coil and a ^{13}C receive only surface coil (Rapid Biomedical, Wuerzburg, Germany). Healthy rats (Wistar) were anaesthetized using isoflurane (2.25%) and 2 ml of 90mM pyruvate was injected via the tail vain. The imaging sequence was based on a spatial spectral excitation using fly-back gradients in combination with an EPI readout. Data acquisition was started prior to the injection of the hyperpolarized material. Imaging parameters were as follows; spatial spectral pulse: full band width 3125Hz, pass band width 600Hz, flip angle 10° for pyruvate and 70° for lactate and bicarbonate, acquisition matrix: 30 x 60, resolution: 2 mm x 1 mm, field of view: 60 mm x 60mm. Partial k-space coverage of 65% was used in phase encoding direction. All acquisitions were prescribed in short-axis view of the heart. To determined reconstruction accuracy, k-space data were decimated to simulate 5- and 8-fold undersampling. A total of 4 training profiles were used resulting in net acceleration factors of 3.5 and 4.9. Subsequently, the undersampled data was reconstructed using k-t PCA.

Results

Simulations:

Images and time curves for 5- and 8-fold undersampling are shown in Figure 1a) for pyruvate, lactate and bicarbonate. A set of 4 training profiles was found to be sufficient for appropriate reconstruction (Figure 1b). The original and reconstructed curves were found to be in good agreement for all time points. The relative root mean square (rRMS) errors for k-t PCA with different undersampling factors and SNR values are shown in Figure 1b. An rRMS error of < 2.5% was considered acceptable resulting in k-t undersampling factors of up to 8-fold for SNR values of 6 and higher (Figure 1b).

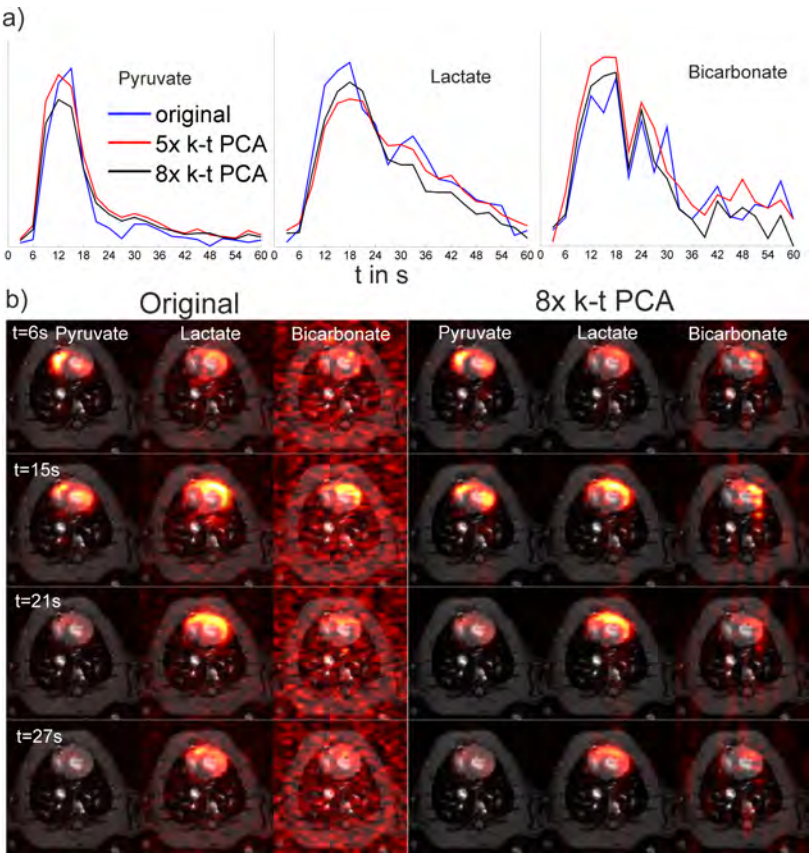

Figure 2: Results from in vivo data. a) Fully sampled and 5- and 8-fold undersampled time curves of one pixel in the region of interest. b) Images of the original data and the 8 fold undersampled and k-t PCA reconstructed images for a set of time points.

In vivo data:

Peak SNR of the in-vivo data was 50, 20 and 6 for pyruvate, lactate and bicarbonate, respectively. A good agreement between the time curves of the original data and the k-t PCA reconstruction was found (Figure 2a). Images of pyruvate, lactate and bicarbonate show the same signal pattern for the original and the 8-fold undersampled data (Figure 2b). Background noise is inherently suppressed in the k-t PCA reconstructions compared to the original data. This leads to an apparent increase in SNR in the undersampled images.

Conclusion

This work has demonstrated that k-t PCA reconstruction is suitable to speed up dynamic acquisitions of hyperpolarized pyruvate by exploiting spatiotemporal correlations within the data. The results show that spatial sparsity and temporal compressibility of the data allow for up to 8-fold k-t undersampling and accurate reconstruction from in vivo data. The inherent denoising properties of the k-t PCA reconstruction make the scheme ideally suited in particular for reconstructing low SNR data such as those from the bicarbonate resonance. To address signal contaminations from the blood pool future extensions of k-t PCA may incorporate compartments from high resolution proton images similar to the concept proposed in [8].

References

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