High-Resolution 3D First-Pass Myocardial Perfusion Imaging

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INTRODUCTION

First-pass myocardial perfusion imaging is an important application of cardiac imaging with the potential to provide tissue assessment and early detection of coronary artery disease, among other uses [1]. The standard technique for first-pass myocardial perfusion is ECG-triggered acquisition of a limited number of 2D slices every one or two cardiac cycles. This unfortunately leaves large gaps between slices where defects may go undetected, leading to interest in 3D myocardial perfusion imaging methods [2]. Fast 3D imaging methods can provide more complete spatial coverage to reduce or eliminate the problem of slice gaps. Temporal resolution is therefore a major concern for whole-heart 3D first-pass myocardial perfusion imaging, even more so when performing experiments in small rodents such as rats (which have heart rates above 300 bpm). We address this problem through integration of parallel imaging and sparse sampling of $(\mathbf{k}, t)$-space. Specifically, we use parallel imaging, partial separability (PS) [3], and compressed sensing (CS) [4] to accelerate imaging and experimentally demonstrate 3D first-pass myocardial perfusion imaging in rats with and without ligation of the left anterior descending (LAD) coronary artery.

METHODS

In an MR experiment, the measured signal from the cth receiver coil $s_c(\mathbf{k}, t)$ can be represented as $s_c(\mathbf{k}, t) = \int_{-\infty}^{\infty} S_c(\boldsymbol{r})\rho(\mathbf{r}, t)e^{-i2\pi\mathbf{k}\cdot\mathbf{r}}d\mathbf{r}$, where $S_c(\boldsymbol{r})$ represents the spatial sensitivity profile of the cth coil and where $\rho(\mathbf{r}, t)$ is the dynamic image function. We can sparsely sample $(\mathbf{k}, t)$-space using a scheme wherein two datasets are obtained: one dense subset with high temporal resolution and one sparse subset with high spatial resolution. In image reconstruction, both spatial-spectral sparsity and partial separability constraints are enforced. Mathematically, this can be formulated as [5]

$$\hat{\boldsymbol{\rho}} = \underset{\rho(\mathbf{r},t)\in\{\sum_{\ell=1}^{L}\psi_\ell(\mathbf{r})\hat{\varphi}_\ell(t)\}}{\arg\min} \|\mathbf{d} - \mathbf{E}\boldsymbol{\rho}\|_2^2 + \lambda\|\mathcal{F}_t\boldsymbol{\rho}\|_1,$$

where $\hat{\boldsymbol{\rho}}$ is the reconstructed image vector, $\mathbf{d}$ is the measured data, $\mathbf{E}$ is the imaging operator, and $\mathcal{F}_t$ represents the Fourier transform over the temporal dimension. The temporal basis functions $\{\hat{\varphi}_\ell(t)\}$ can be assumed to be known, as we can directly obtain them from the dense subset of the measured data, greatly simplifying image reconstruction. We solve the above optimization problem using an additive half-quadratic optimization algorithm with a continuation procedure [5].

The proposed scheme has been implemented on a Bruker Avance AV1 4.7 T / 40 cm scanner with a 4-channel phased array coil. First-pass myocardial perfusion imaging experiments using the proposed method were performed on Brown Norway rats with and without ligation of the LAD coronary artery. The experiments used a FLASH pulse sequence with the following imaging parameters: T_R = 7.5 ms, T_E = 2.4 ms, FOV = 40 mm × 40 mm × 40 mm, in-plane spatial resolution = 0.65 mm × 0.65 mm × 0.31 mm. A 0.2 mmol/kg bolus of gadolinium contrast agent was injected after the start of data acquisition. Data were collected continually with neither ECG gating nor breath holding.

RESULTS AND DISCUSSION

Two sets of results are pictured in Fig. 1, which depicts baseline-corrected signal intensity curves from four apical segments of the myocardium (i.e., anterior, septal, inferior, and lateral) as well as the left ventricle (LV). The top plot shows results from a healthy control subject and the bottom plot shows results from a subject with ligation of the LAD. The healthy subject shows no hypoperfused myocardial tissue, whereas the subject with ligation shows hypoperfusion of the apical anterior and septal segments, both of which are associated with LAD blood supply. Fig. 2 shows typical images from one subject using three perpendicular views of the heart. Whole-heart 3D coverage was successfully achieved at a frame rate of 67 fps.

CONCLUSION

We have performed whole-heart 3D first-pass myocardial perfusion imaging in high spatiotemporal resolution using sparse sampling of $(\mathbf{k}, t)$-space. High-quality images have been reconstructed from very sparsely sampled data using parallel imaging, partial separability, and compressed sensing. This imaging method was able to identify hypoperfused areas of the myocardium from ligation of the LAD. The 3D nature of the acquisition ensures that there are no gaps between slices, which should allow for more complete analysis than limited-slice 2D methods. We anticipate that the method will prove useful for a great many applications of first-pass myocardial perfusion imaging.

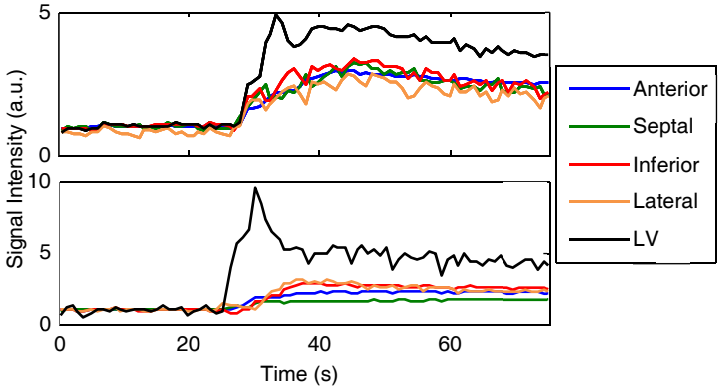

Figure 1. Baseline-corrected signal intensity curves from apical segments of the myocardium in a healthy subject (top) and a subject with ligation of the LAD (bottom).

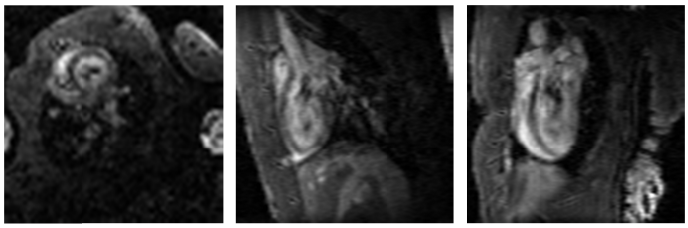

Figure 2. Perpendicular views of heart. From left to right: short-axis, vertical long-axis, horizontal long-axis.

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