Real-time Cardiac Imaging of Transplanted Hearts

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INTRODUCTION

The ability to assess organ rejection is crucial to the survival of heart transplant recipients. The current clinical standard for detection of acute rejection is endomyocardial biopsy, an invasive procedure that can lead to significant complications and/or missed diagnoses [1]. Cardiovascular MRI has shown promise for noninvasive assessment of the immune response in transplanted hearts [2]. However, its low imaging speeds have limited its practical utility. For example, in small rodent studies, heart rates can exceed 400 bpm, which largely precludes first-pass myocardial perfusion imaging experiments using conventional MRI methods. We demonstrate in this paper that we can significantly improve the speed of MRI for this type of experiments by utilizing the properties of the underlying signals (i.e., sparsity and low-rank structure) and that we can perform integrated anatomical (i.e., ejection fraction) and functional (i.e., first-pass myocardial perfusion) assessments of *in vivo* transplanted rat hearts in a single scan.

METHODS AND MATERIALS

We used sparse sampling of (**k**, *t*)-space to achieve real-time imaging and enable simultaneous functional and morphological assessment of the transplanted heart. Sparse sampling is achieved using an advanced compressed sensing technique, known as the PS-Sparse method [3], which jointly enforces two complementary properties of cardiovascular images: spatiotemporal partial separability [4] and spatial-spectral sparsity [5]. Integrated enforcement of these properties leverages the strengths of the PS model and compressed sensing to achieve higher imaging speeds. To aid image reconstruction, we sparsely sampled (**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.

Allograft heart and lung transplants were performed from male Dark Agouti to male Brown Norway rats, with each recipient gaining an additional heart and lung in the abdomen while the native organs supported life. The allograft hearts underwent different degrees of rejection over time, experiencing moderate rejection on post-operational day (POD) 5; by POD 7, the majority of the allograft hearts had become severely rejected. *In vivo* MRI scans were performed on POD 5 and POD 7 for longitudinal monitoring of rejection on the same animals. Real-time images of cardiac motion, respiratory motion, and first-pass myocardial perfusion were acquired via the PS-Sparse imaging method, using a FLASH sequence (T_R/T_E = 10.4/2.7 ms, FOV 40 mm × 40 mm, matrix size = 256 × 256, in-plane spatial resolution = 156 µm × 156 µm, slice thickness = 2 mm) which alternates between acquisition of the dense and sparse subsets of data. The resulting frame rate of each reconstruction was equal to 48 fps. For the purposes of assessing first-pass myocardial perfusion, a 0.05 mmol/kg bolus of Gd-based contrast agent after the start of data acquisition. No gating, triggering, or breathhold was used. All data were collected on a Bruker Avance III (7 T / 21 cm) instrument.

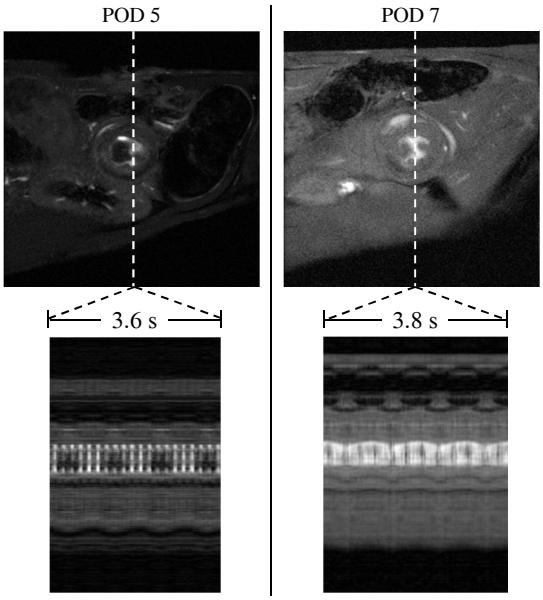

Figure 1. End-diastolic cardiac snapshots and spatiotemporal profiles from post-operational days POD 5 and POD 7. The later scan shows large reductions in ejection fraction and heart rate.

RESULTS AND DISCUSSION

Figure 1 shows typical anatomical results from POD 5 and POD 7 for the same subject. Snapshots from end-diastolic cardiac phases are pictured, as well as spatiotemporal profiles through the dotted lines. Ejection fraction was relatively low by POD 5 and virtually zero by POD 7, strongly indicating acute rejection of the transplanted heart; the heart rate also declined. Figure 2 depicts baseline-corrected myocardial perfusion curves from POD 7, taken from the very same scan depicted in Fig. 1. A large perfusion defect is apparent across the mid-ventricular inferior, inferolateral, and anterolateral myocardial segments.

CONCLUSION

This paper demonstrated real-time imaging using sparse sampling for detection of immune response in transplanted heart. By exploiting the partial separability and sparsity of the cardiac signals (using the PS-Sparse method), both anatomical and functional assessments of transplanted hearts in rats were enabled. These assessments are able to detect acute transplant rejection of allograft transplants. The integration of these assessments into a single scan shows promise for fast, noninvasive detection of acute heart transplant rejection and may provide a useful tool for studying organ rejection, even in small rodents.

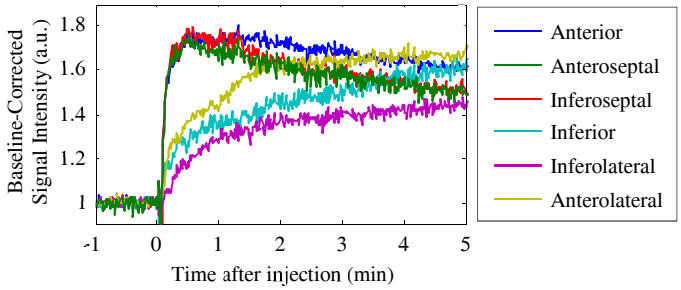

Figure 2. Baseline-corrected signal intensity curves from six mid-ventricular myocardial segments on POD 7. Severe hypoperfusion is evident in the inferior, inferolateral, and anterolateral segments.

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