Catheter Visualization for Endovascular MR using Compressive Sampling: Comparison against POCS

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Introduction: Endovascular interventions are minimally invasive clinical procedures used to treat vascular diseases. These procedures often rely on catheters to deploy therapeutic devices or drugs within the vasculature. Accurate localization and real-time visualization of the catheters are essential for both guiding and monitoring. Currently, x-ray fluoroscopy is the gold standard because it offers clinically acceptable catheter conspicuity, and high spatial and temporal resolution. X-ray imaging has the disadvantages of exposing patients and staff to ionizing radiation, and requiring iodinated contrast agents to visualize the vasculature. MR imaging is an alternate and promising approach to visualize catheters that offers many clinical advantages over conventional x-ray fluoroscopy, including the absence of ionizing radiation or iodinated x-ray contrast agents, superior soft tissue image contrast, and the ability to provide functional and physiological information. However, conventional MR imaging has insufficient temporal resolution for endovascular interventions. Compressive sampling[1] (CS) and projection-onto-convex sets[2] (POCS) are nonlinear reconstruction algorithms that accurately reconstruct MR images from undersampled k-space datasets, and thus allow shortening of the acquisition time. Here we evaluate and compare the reconstructed catheter images using CS and POCS. Our guiding hypothesis is that passive catheter tracking using multi-cycle projection dephasers[3] (mcPD, a background suppression technique) in conjunction with CS will (1) generate higher quality images compared to POCS, and (2) be fast enough to achieve real-time passive catheter tracking.

Method: Following a protocol approved by the local Animal Care Committee, we placed a 1-mm diameter (4 F) catheter into a common carotid artery of a dog and acquired fully sampled *k*-space data sets using the mcPD sequence on a 3.0 T MR scanner (Signa VH/i; General Electric Healthcare, Waukesha, WI). Undersampled *k*-space data sets providing various acceleration factors (varied from 4 to 32) were derived from these fully sampled *k*-space data by using elliptical stochastic variable density undersampling schemes[4] (Fig 1b and Fig 1c). The catheter images were then reconstructed using both CS and POCS. For CS reconstruction, we used both the wavelet and image domains as sparse domains, and we adjusted the regularization parameters to enforce sparsity in these two domains.

Results: Figure 1 illustrates the different *k*-space sampling schemes and their corresponding reconstructed *in vivo* images. Variable density sampling with POCS preserved spatial resolution of the catheter, however reconstructed images still have significant background noise (Fig. 1e). Conversely, variable density sampling with CS not only preserved high spatial resolution but also removed most of the background noise (Fig. 1f), thus yielding superior catheter conspicuity. This was also true for acceleration factors up to 32.

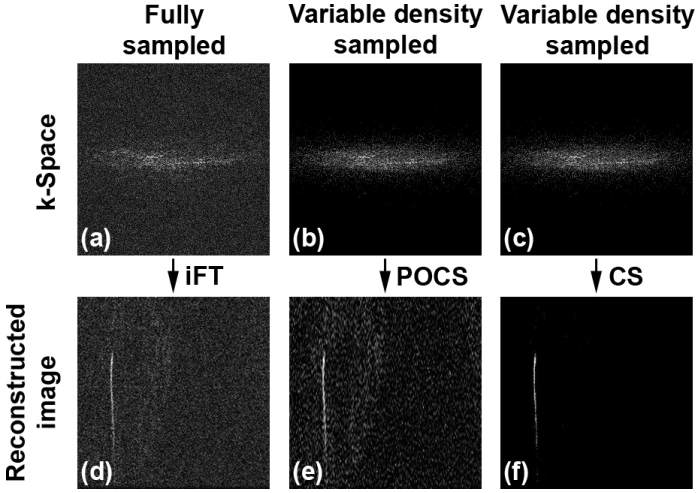

Fig. 1. Passive catheter images in a canine. The top row represents (a) the fully sampled, and (b-c) variable density sampled k-space data. The bottom row shows the corresponding reconstructed images using (d) the inverse Fourier transform (iFT), (e) POCS, and (f) CS, respectively.

Conclusion: Variable density sampling and CS reconstruction can produce catheter images with high accuracy from significantly fewer *k*-space samples than suggested by the Nyquist-Shannon sampling theorem. This makes it possible to significantly reduce acquisition time, and allows for real-time MR catheter tracking. The CS approach yielded superior catheter conspicuity, background suppression, and resolution than the POCS images. The CS-reconstructed images can be overlayed onto a vascular roadmap potentially without further post processing.

References: [1]Lustig M, *et al*. *Magn Reson Med* 2007; **58**: 1182. [2]Peng H, *et al*. *Magn Reson Imaging* 2006; **24**: 761. [3]Draper J, *et al*. *JMRI* 2006; **24**: 160. [4]Sabati M, *et al*. *Phys Med Biol*. 2003; **48**: 2739.