Highly accelerated dynamic contrast enhanced imaging with prospective undersampling

R. Marc Lebel[1], Jesse Jones[2], Jean-Christophe Ferré[2], Samuel Valencerina[2], Krishna S. Nayak[1], and Meng Law[2]

[1]*Department of Electrical Engineering, University of Southern California, Los Angeles, CA, United States,* [2]*Department of Radiology, University of Southern California, Los Angeles, CA, United States*

Introduction: Dynamic contrast enhanced (DCE) imaging employs serial T_1-weighted scans to quantify the pharmacokinetics of an injectable contrast agent. This allows assessment of tissue properties such as vascular permeability. Clinical applications of DCE, such as tumor characterization, will benefit from improvements in spatiotemporal resolution and volume coverage beyond what is possible today. Recently, numerous works have demonstrated accelerated DCE with constrained reconstructions of *retrospectively* undersampled data [**1-3**]. These works utilized a single data constraint and reported acceleration factors up to 6x. *Prospectively* accelerated acquisitions have yet to be demonstrated or validated but have the potential for full brain coverage and patient specific arterial input function detection.

Here, we present accelerated DCE imaging using both *prospective* and *retrospective* data undersampling and a constrained reconstruction employing parallel imaging and compressed sensing. We demonstrate high-resolution *in-vivo* DCE images acquired with an 8.5x acceleration rate in 2D mode. Retrospective reconstructions suggest even higher acceleration will be possible in 3D mode.

Methods: Prospectively undersampled DCE scans were acquired on a 3T GE Signa HDxt with an eight channel head coil using a custom 2D multi-slice spoiled gradient echo sequence. Undersampling was performed with a jittered grid algorithm **[4]** to provide both random yet uniform sampling. Undersampling was performed along the phase-encode, slice-select, and temporal dimensions. The net acceleration factor was 8.5x with the following parameters: eighteen 5mm thick slices, 320 x 256 matrix (0.8 x 0.8 mm^2 resolution), 126 ms TR, 3.3 ms TE, and 3.78 s temporal resolution. For validation purposes, nine fully sampled 3D DCE data sets were acquired and retrospectively undersampled. They were acquired with: six 6mm thick slices, 256 x 186 matrix (0.94 x 0.94 mm^2 resolution), 5.4 ms TR, 2.2 ms TE, and 10 s temporal resolution.

Images (m) were reconstructed from raw data (y) via conjugate gradient minimization of the l_1-SPIRiT **[5]** equation:

$$\min_m \left\{ ||\mathbf{F_u}\, m - y||_2^2 + \lambda_0 ||(\mathbf{G} - \mathbf{I})\, m||_2^2 + \lambda_1 ||\mathbf{W}\, m||_1 + \lambda_2 ||\mathbf{TV}\, m||_1 + \lambda_3 ||(\mathbf{V} - \mathbf{I})\, m||_1 \right\}$$

In addition to a parallel imaging constraint (**G**), three l_1-norm constraints were employed. A 4D wavelet transform (**W**) was applied along all spatial and temporal dimensions, total variation (**TV**) in the spatial dimensions, and a novel dynamic view-sharing kernel (**V**) further constrained the temporal dimension. Images were reconstructed on a 12-core workstation with 48 Gb of memory.

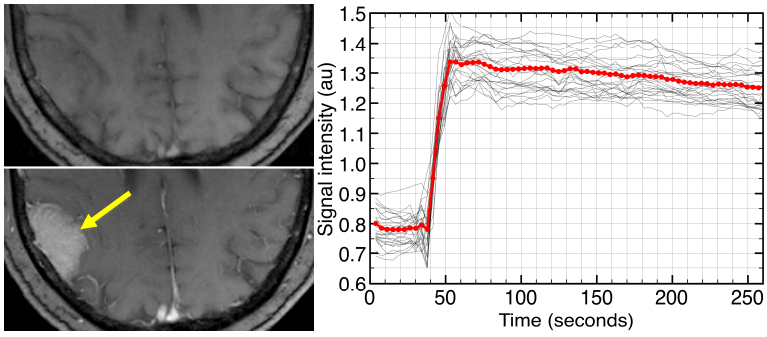

Figure 1: DCE scan of a Meningioma patient. LEFT: cropped 8.5x prospectively accelerated images of (top) pre-bolus arrival and (bottom) post-bolus arrival. RIGHT: Time-intensity curves for a subset of voxels (thin black lines) within the tumor (arrow) and the average tumor signal (thick red line).

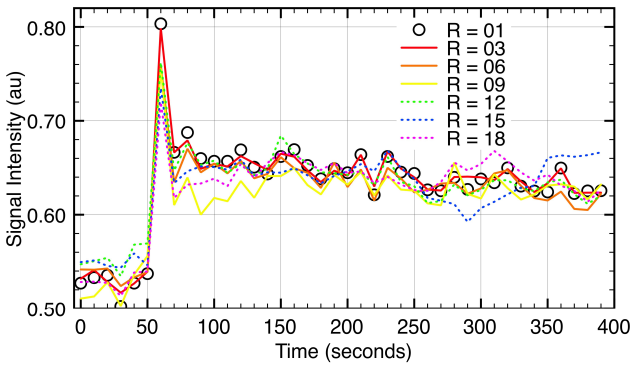

Figure 2: Time-intensity curves from a small arterial ROI in a retrospectively undersampled DCE series. Accurate reconstructions were produced at acceleration factors up to 18x.

Results: Figure 1 contains highly accelerated frames from a prospectively undersampled 2D DCE scan of a meningioma patient. The combination of parallel imaging with multiple spatial and temporal constraints produced images that are free of residual undersampling artifacts. Dynamic information was preserved, as evidenced by time curves from individual voxels and the average tumor signal as a function of time. The temporal constraints did not appear to compromise the temporal resolution: abrupt transitions and rapid signal changes were observed as the contrast agent perfused through the tumor (arrow). The effects of different acceleration factors are presented in Figure 2 using retrospectively undersampled 3D data. Acceleration rates up to 18x provided high data fidelity, but decreased signal intensity was observed during bolus arrival (at ~60 seconds) with these high acceleration factors.

Conclusions: We have combined parallel imaging with multiple spatial and temporal constraints to reconstruct highly accelerated DCE images with no substantive compromise in image quality or in the most critical information from voxel time-intensity curves. Prospective data undersampling enables significantly improved spatiotemporal resolution along with improved volume coverage relative to fully sampled or retrospectively undersampled data. This permits considerably higher acceleration rates than those currently reported in literature. We demonstrate 8.5x acceleration in 2D imaging; however, retrospective undersampling of 3D volumes suggest much higher rates will be possible. Development of 3D prospective undersampling is ongoing.

References: **[1]** Adluru, G. *et al.* JMRI 2010. **[2]** Chen, L. *et al.* MRI. 2010. **[3]** Smith, D. *et al.* Phys.Med. Biol. 2011. **[4]** Cook, R. ACM TOG. 1986. **[5]** Lustig, M. and Pauly, J. MRM. 2010.