An application of compressed sensing for improved temporal fidelity in DCE breast MRI

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Introduction: Historically dynamic contrast enhanced (DCE) breast MRI has favored high spatial resolution at the expense of temporal resolution. Recent work exploring the potential of pharmacokinetic modeling in breast MRI has precipitated the desire for higher temporal resolution[1,2], which would require undersampling levels beyond capabilities of standard reconstruction techniques such as parallel MRI. Several studies have demonstrated the use of undersampled k-space segmentation schemes to improve the temporal resolution while maintaining high spatial resolution[3,4,5]. To compensate for the unacquired k-space data, these methods use view-sharing, filling the unsampled positions in *k*-space with the data acquired in the neighboring frames. Low frequency information is updated more often, while high frequency information is sampled less often. However, the use of view-sharing may lead to modification of temporal waveforms, usually in the form of smoothing[6] and compromise certainty of diagnosis. Compressed sensing is a recently developed mathematical theory that provides a means to accurately reconstruct images that adopt a sparse representation in some basis from incomplete data with a randomized sampling pattern producing incoherent artifacts. DCE-MRI is particularly amenable to compressed sensing because it allows for randomized sampling in the temporal dimension as well as in the ky-kz dimensions. The purpose of this work was to demonstrate feasibility of a CS technique based on second order differences in temporal dimension to reconstruct DCE breast MR images with a pseudorandom k-space undersampling scheme. This CS technique was previously demonstrated with time-resolved intracranial CE MRA[7] to improve reconstructed image quality and preserve temporal fidelity.

Theory: The problem of reconstructing image series $\mathbf{f}$ is a system of linear equations $\mathbf{Ef} = \mathbf{b}$, where $\mathbf{E}$ is the encoding matrix, and $\mathbf{b}$ is the vector of measured *k*-space data for all time frames. If *k*-space data is incomplete, the above equation has infinitely many solutions. To isolate a single solution prior information about the image series is invoked using spatial and/or temporal constraints. CS reconstruction is performed through minimization of a cost function: $\min_{\mathbf{f}}(\|\mathbf{Ef}-\mathbf{b}\|_2 + \lambda\|\mathbf{Df}\|_1)$ **Equation [1]**, whose size is measured by ℓ_p norms ($\|x\|_p^p = \sum|x_n|^p$), where a transform $\mathbf{D}$ reflects prior information about the images by providing a sparse representation. It is accepted clinically that in DCE MRI of the breast typical contrast propagation curves are smoothly varying. It was previously demonstrated in other applications[8] that such curves can be efficiently sparsified by the second discrete derivative operator in temporal dimension, hence, choosing $\mathbf{D} = \Delta_t^2$ in Eq. 1.

Methods: A patient known to demonstrate focal enhancement on breast DCE-MRI was scanned on a 1.5T MRI scanner (GE Healthcare Optima MR450W, Waukesha, WI) with an 8 channel breast coil and a dual-echo SPGR sequence with a pseudo-randomly undersampled k-space segmentation scheme[9] as part of an IRB approved, HIPPA compliant breast MRI research study. A fully sampled mask and 20 undersampled dynamic phases were acquired; contrast injection of 0.1 mmol/kg of gadobenate dimeglumine at a rate of 2 ml/second (s) followed by a 20 ml saline flush began simultaneously with the start of dynamic imaging. Within each dynamic phase, the central portion of k-space and one-third of the peripheral region of k-space were acquired. The spatial resolution was 0.8 x 0.8 x 1.6 mm^3 with a frame rate of 27 s. Images were reconstructed both by backward view sharing over three phases (81 s temporal footprint) and CS of a single phase (27 s temporal footprint).

Results: Figure 1 shows images reconstructed using CS (temporal footprint 27 s) (Fig. 1a) and view sharing (temporal footprint 81 s) (Fig. 1b). Note improved image resolution of CS reconstruction. Figure 1c shows temporal waveforms in two representative ROIs with different wash-out characteristics.

Conclusions: We demonstrated the feasibility of using a temporal CS technique with undersampled breast DCE-MRI. We successfully reduced the temporal footprint by one-third (27 s versus 81 s) with similar image quality. Further study is warranted to investigate the potential of our novel CS technique to reduce the temporal footprint, eliminate view sharing, and improve image quality for clinical breast MRI.

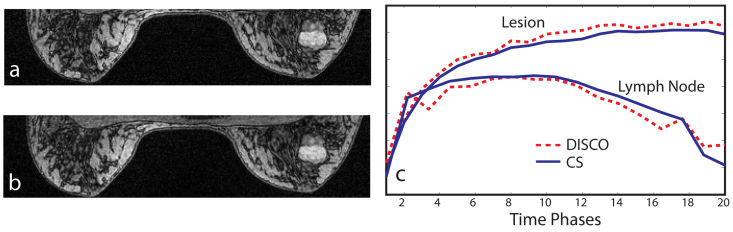

Figure 1. Comparison of high temporal fidelity CS with standard view sharing reconstruction. **a:** Representative CS time frame. **b:** Corresponding view sharing time frame. **c:** Time courses in lesion and lymph node ROIs. Note improved resolution of CS image and view-sharing induced variations in the temporal curves.

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