Compressed sensing (CS) for dynamic contrast enhanced (DCE) MRI of atherosclerosis: preliminary experience in a rabbit model of disease

Claudia Calcagno[1], Hadrien Dyvorne[1], Ricardo Otazo[2], Philip M Robson[1], Mark E Lobatto[1], Sarayu Ramachandran[1], Venkatesh Mani[1], and Zahi A Fayad[1]
[1]*Mount Sinai School of Medicine, New York, NY, United States,* [2]*New York University, New York, NY, United States*

Introduction: Cardiovascular disease caused by atherosclerosis is the main cause of morbidity and mortality worldwide. In recent years, dynamic contrast enhanced (DCE) MRI has been used to characterize vulnerable atherosclerotic plaques [1,2], the lesions responsible for sudden, dramatic clinical events (stroke, myocardial infarction and sudden death). However, several challenges still hinder the future translation of this technique into clinical practice. For example, while extensive plaque volumetric coverage is desirable, it can only be achieved at the expenses of in-plane spatial resolution and/or with extended scan time, two variables that can highly impact the accuracy of DCE-MRI results. DCE-MRI time series are appealing candidates for compressed sensing (CS) acceleration techniques [3], since their representation in the temporal principal component analysis (PCA) domain is sparse (**Figure 1**)and the incoherence required for CS reconstructions can be effectively accomplished by *k-t* random under-sampling (**Figure 1**). ***In this study we investigate the feasibility of applying sub-Nyquist under-sampling and compressed sensing (CS) reconstruction to DCE-MRI of atherosclerosis, with the aim of accelerating tissue acquisition without sacrificing in-plane resolution or volumetric coverage.***

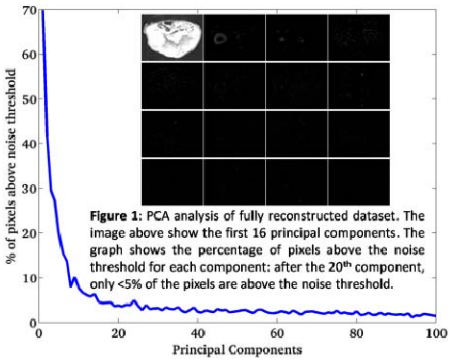

Figure 1: PCA analysis of fully reconstructed dataset. The image above show the first 16 principal components. The graph shows the percentage of pixels above the noise threshold for each component: after the 20th component, only <5% of the pixels are above the noise threshold.

Methods: *Data Acquisition*: One New Zealand White (NZW) atherosclerotic rabbit was used for imaging. Atherosclerosis was induced prior to imaging by a combination of high cholesterol diet and double balloon injury of the abdominal aorta [2]. Imaging was performed on a 3T clinical system (Philips, Achieva) using a conventional 8 channel knee coil. DCE-MRI was performed on one selected axial slice in the abdominal aorta using a double inversion recovery (DIR) turbo spin echo (TSE) T1 weighted sequence (acquisition time per frame: 6.4 s; number of frames acquired, 100). After acquisition of 5 pre-contrast frames, 0.1 mmol/Kg of Gd-DTPA (Magnevist) was injected manually, followed by a 10 ml saline chase. ***No k-space under-sampling and no parallel imaging was used during acquisition, therefore resulting in a fully sampled k-space dataset.*** *Compressed sensing reconstruction*: A k-t SPARSE-SENSE multi-coil reconstruction was used, with temporal PCA as sparsifying transform, where temporal sparsity and coil sensitivity encoding are jointly exploited using the idea of joint multicoil sparsity[4]. An iterative soft thresholding [5] algorithm was used to reconstruct the image by enforcing image sparsity while keeping exact data consistency with k-space. **Fully sampled k-space data were reconstructed with 10 different acceleration factors (R= 2 to 20). For each acceleration factor 6 different threshold values (lambda = 0.01 to 0.11) were used in the algorithm, thus yielding a total of 60 different reconstructed dynamic series**. *Data Analysis*:

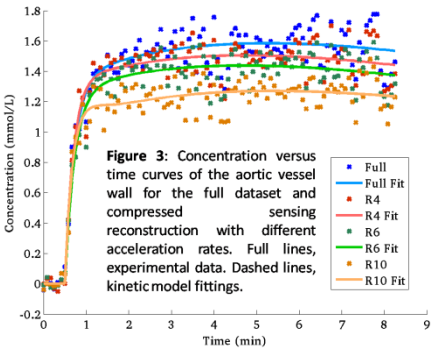

Figure 3: Concentration versus time curves of the aortic vessel wall for the full dataset and compressed sensing reconstruction with different acceleration rates. Full lines, experimental data. Dashed lines, kinetic model fittings.

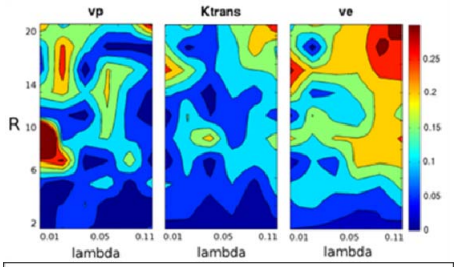

Figure 2: Contour plot of relative error of kinetic parameters derived from compressed sensing reconstruction and fully sampled dataset. X axis, lambda threshold. Y axis, R (acceleration factor).

Regions of interest (ROI) encompassing the whole visible vessel wall were traced on the fully reconstructed dataset and propagated through all the reconstructed series to obtain signal intensity (SI) versus time curves, for a total of 61 curves. Dynamic curves were converted to concentration assuming linearity. Kinetic modeling was performed using a modified Tofts model[6] and a population arterial input function. The calculated kinetic parameters are v_p (fraction of vascular volume), K^{trans} (exchange rate between plasma and tissue compartment) and v_e (fraction of extra-vascular extra-cellular space). The relative error (RE), defined as $\frac{abs(P_{FS} - P_{R,\lambda})}{P_{FS}}$ was used to evaluate parameters accuracy with respect to the fully sampled case.

Results: **Figure 2** shows a contour plot of the RE for all kinetic parameters. The color scale represents RE from 0 to 30%, with a step of 5% (the deep blue: 0<=RE<5%; lighter blue: 5%<=RE<10% and so on). From the plot it can be observed that while there may be significant loss in parameters' accuracy at very high acceleration rates, up to R=4 the error for all 3 parameters is less than 10% if an appropriate lambda is chosen. Since this error is in the range of the coefficient of variation for DCE parameters, we conclude that it is feasible to accelerate DCE-MRI acquisitions using compressed sensing reconstructions. **Figure 3** shows dynamic curves and model fitting for the fully-reconstructed dataset and several accelerated datasets. **Figure 4** shows average images across the dynamic series for the fully reconstructed and several accelerated reconstructions. While some artifacts are visible in the images for higher acceleration rates, the dynamic curves up to R=4 show high similarity with fully sampled dataset.

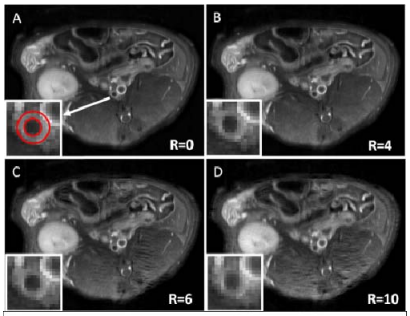

Figure 4: Average dynamic series. A, fully sampled dataset. B,C and D, dataset reconstructed with compressed sensing (acceleration factors 4,6 and 10 respectively). Red contours, vessel wall tracings. White arrow, abdominal aorta.

Conclusions: In this preliminary work, we demonstrate the application of compressed sensing acceleration to DCE-MRI in an animal model of atherosclerosis. Our results show that this approach is feasible and, for acceleration rates up to 4 folds, does not significantly impact kinetic parameters quantification. Although this topic needs further investigation, we envision that compressed sensing in combination with parallel imaging could provide the necessary temporal resolution for volumetric DCE-MRI of atherosclerosis, without sacrificing in-plane spatial resolution.

References: 1. Kerwin W, Circulation, 2003; 2. Calcagno C, Arterioscler Thromb Vasc Biol, 2008; 3. Lustig M, Magn Reson Med, 2007; 4. Otazo R, Magn Reson Med, 2010; 5.Daubechies I, Comm on Pure and Applied Math ,2004; 6. Tofts PS, J Magn Reson Imaging, 1999. Grant support: NIH NHLBI R01 HL071021.