Accelerated 3D carotid vessel wall imaging using Compressed Sensing

M. K. Makhijani[1], and K. S. Nayak[1]

[1]Electrical Engg., University of Southern California, Los Angeles, CA, United States

Introduction: Multi-contrast MRI is widely used to image the vessel wall and characterize the composition of atherosclerotic plaques. Standard multi-slice methods suffer from long scan times, have limited practical resolution due to SNR constraints and are not suited for plaque quantitation. Multi-contrast bilateral carotid imaging using 3D Inner Volume Fast Spin Echo Imaging (3D IVI FSE) has been previously demonstrated [1]. 3D scans offer SNR benefits but are more susceptible to artifacts from swallowing during long scans. The surplus SNR typically associated with 3D imaging can be expended for total scan time reduction by incorporating parallel imaging or compressive sensing (CS). Recent developments in information theory have lead to several emerging non linear reconstruction algorithms based on the CS framework which offer flexible sampling constraints without compromising image quality [2]. In this work we accelerate data acquisition for 3D IVI FSE carotid scans by incorporating 4 fold random undersampling and minimum L_1 norm reconstruction. The effect of the sparsifying basis and regularization penalties on fine anatomical details of the wall-lumen interface is analyzed.

Methods: CS theory suggests that if any signal of interest has underlying structure which renders the data compressible in some appropriate transform domain then even in the presence of noise the entire signal can be substantially recovered with considerably fewer but CS optimized measurements. Initially the appropriate under-sampling pattern is identified which maximizes the incoherence of the spatial domain aliasing artifacts. Since this involved a 3DFT acquisition, measurements along the two phase encoding axes ($\mathbf{k_y}$ and $\mathbf{k_z}$) were variably under-sampled with a quadratic probability roll off only for the higher spatial frequencies. The lower spatial frequencies [25%] are fully sampled to estimate a full FOV but lower resolution phase map. For a faithful reconstruction it is important to ensure that the assumption of sparsity holds and an appropriate transform domain is chosen for L_1 minimization. Different sparsifying bases were considered including the various wavelets [Haar, symlet, Daubechies], curvelets, and finite difference, were used for reconstruction with varying degrees of acceleration. Experiments were performed on a Signa Excite 3T scanner (GE Healthcare) using a 4-channel carotid array coil (Pathway MRI). The proposed imaging sequence consisted of 3 modules: DSG (or DIR) preparation, fat saturation and 3D-IVI FSE imaging. Relevant scan parameters are summarized as [FOV-Matrix-Resolution-eff_TE-ESP-TR-ETL]: [16x2.0cm^2-320x128x8-0.5x0.5x2.5mm^3-8ms-8ms-1RR-12].

Results and Discussion: Figure 1 contains images reconstructed from retrospectively undersampled data with 4 fold acceleration using the TV+wavelet penalties along with fully sampled reconstructions. L-curve analysis was used to estimate the appropriate regularization parameter values. We specifically examined the effect of penalties on the sharpness of the vessel wall-lumen interface. We found that a strong TV penalty denoises the image at the cost of over estimating the wall area, while a strong wavelet penalty reconstructs the fine features with high fidelity but at the cost of poor overall image quality. One of the main problems with using a wavelet penalty is the appearance of spurious ridge like artifacts in the direction of under-sampling. By visual inspection, we found an acceptable combination of wavelet and TV penalties to be 0.04 and 0.12, which resulted in minimal artifacts and accurate quantitative measurements of the vessel wall thickness and lumen contour compared to the fully sampled datasets.

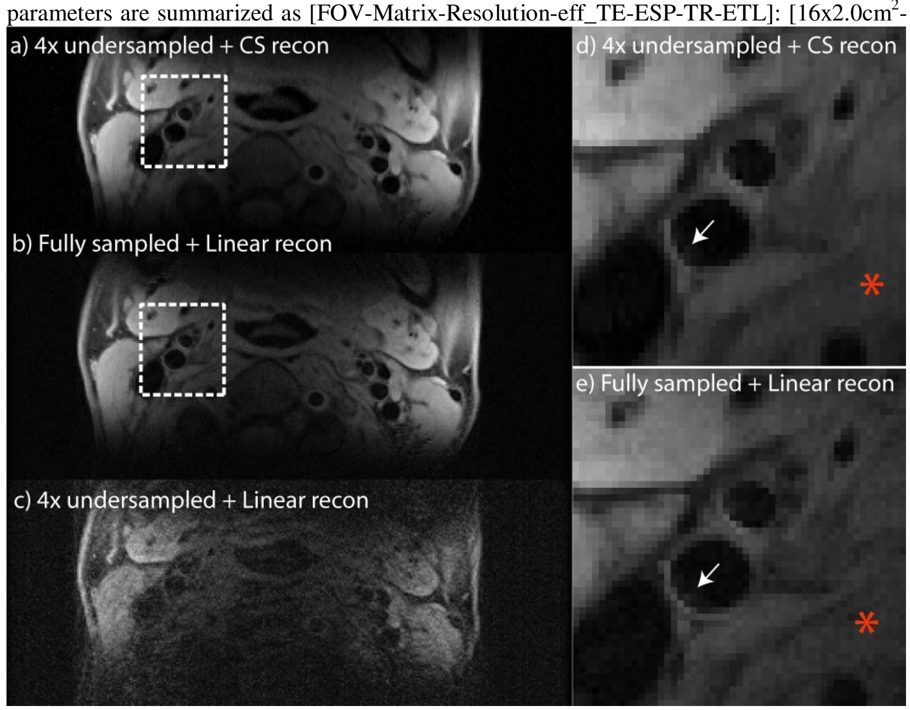

Figure 1: a-c) Preliminary data from a representative volunteer comparing nonlinear CS reconstruction method with the conventional linear Fourier reconstruction. The CS reconstructed images are qualitatively comparable to the fully sampled reconstructions. d-e) Enlarged view of the vessel wall-lumen interface. The CS reconstruction denoises the image as denoted by * while preserving the fine features, importantly the sharp boundary between the vessel wall and lumen as denoted by the arrow

Conclusion: 3D FSE bilateral carotid wall imaging can be accelerated by a factor of 4 using Compressed Sensing with TV + wavelet as the sparsifying transforms. If undersampling is done prospectively the proposed method results in the ability to cover 2 cm (S/I) of the bifurcation with 0.5x0.5x2.5mm resolution in a single 22 second scan. The CS reconstruction parameters were optimized to maintain qualitative and quantitative agreement with the fully sampled reconstructions.

Table 1: Comparison of measured vessel wall and lumen area measured from fully sampled and accelerated acquisition.

Table 1	**4 fold with CS Recon (cm^2)**	**Fully Sampled Linear Recon (cm^2)**
Wall Area	0.47	0.49
Lumen Area	0.081	0.078

References:

1)Makhijani et al. ISMRM 2008; 1254. 6)Lustig et al. MRM 2007; 58 : 1182-95.