Investigating Spatiotemporal Sparse SENSE Reconstruction to Preserve Geometric and Temporal Fidelity

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Introduction: A frequent challenge in MR is the time-efficient acquisition of temporally resolved images. Although stenosis is important for stroke prevention [1], the structure, composition, dynamics, and stiffness of atherosclerotic lesions are better indicators of plaque vulnerability. [2,3] High-resolution MR imaging using fast spin echo (FSE) provides excellent soft tissue contrast within the vessel wall and can distinguish intact, thick, fibrous caps (*i.e.*, stable plaques) from thin, ruptured caps (*i.e.*, vulnerable plaques) [4]. Unfortunately, time-resolved FSE acquisitions are often prohibitively lengthy. Here we investigate and apply spatiotemporal sparse SENSE [5] to reconstruct dynamic retrospectively gated FSE data. This technique allows vessel wall characterization over the course of the cardiac cycle within acceptable clinical acquisition times.

Methods: We acquired 2D axial FSE images at the carotid bifurcation in six healthy volunteers using a 3 T MR scanner (Discovery MR 750; General Electric Healthcare, Waukesha, WI) with a 12-channel receive-only head/neck coil. The imaging parameters were: TR/TE of 2500/9.4 ms, FOV of 14 cm^2, acquisition matrix of 256×252, and slice thickness of 2 mm. We modified the phase-encode table such that every k-line was acquired at least once, but those near the center of k-space were acquired more frequently, for a total of 1008 phase-encodes. We also recorded the R-wave of the cardiac cycle with a pulse oximeter and used this to retrospectively rebin the FSE data into 12 uniformly spaced cardiac phases.[6] The 3D stack (2D spatial + 1D temporal) of undersampled k-space data was then reconstructed using a sparse SENSE model with spatial and temporal constraints:

$$\arg\min_{\mathbf{m}} \ \|\mathbf{Em}\text{-}\mathbf{y}\|_2^2 + \lambda_1\|\Psi\mathbf{m}\|_1 + \lambda_2\|\bar{\mathbf{m}}\text{-}\mathbf{m}\|_1 + \lambda_3\|\mathbf{Tm}\|_1$$

where **E** is the sensitivity encoding matrix, **m** is the stack of 2D time-resolved images to reconstruct, **y** is the acquired k-space data, Ψ is the 3D spatial wavelet transform, $\bar{\mathbf{m}}$ is the temporally-averaged fully-sampled image using all k-lines, and **T** is a temporal high-pass filter. Coil sensitivity maps were computed using the eigenvector decomposition method.[7] The regularization parameters, λ_n, were selected empirically by visual inspection of the reconstructed images to 1) maintain high data consistency and 2) avoid geometric artifacts and temporal blurring. The vessel wall location was determined at each cardiac phase by finding the maximum intensity gradient. Then, the effective carotid wall motion was calculated as the difference between the maximum and minimum vessel diameter (d_{max} - d_{min},).

Results: Figure 1a shows the location of one cross section of the right internal carotid artery investigated in one of the volunteers. The temporally averaged image, $\bar{\mathbf{m}}$, is a static image and its cross section is shown for reference in Figure 1b. Figure 1c and 1d compare the time course of the carotid vessel wall over a cardiac cycle using the zero-filled (ZF) and spatiotemporal sparse SENSE reconstruction approaches, respectively. The incoherent aliasing artifacts in the ZF reconstruction prevented us from accurately determining/locating the vessel wall. In contradistinction, spatiotemporal sparse SENSE reconstruction yielded readily interpretable and quantifiable vessel wall motion; we measured a change of approximately 0.5 mm between d_{max} and d_{min} with regularization parameters $\lambda_1 = 0.002$, $\lambda_2 = 0.05$, and $\lambda_3 = 0.05$.

Discussions: We demonstrated that retrospectively gated FSE combined with spatiotemporal sparse SENSE reconstruction enables temporally efficient, time-resolved characterization of the motion of the carotid vessel wall over a cardiac cycle. Our measurements of the change in diameter over the cardiac cycle are in good agreement with previously reported values from studies using ultrasound.[8] To measure small changes more precisely and reliably, however, an increase in spatial resolution or signal-to-noise ratio, or both, is necessary. Although this could potentially increase scan time, dedicated multi-channel carotid coils coupled to spatiotemporal sparse SENSE reconstruction could mitigate this drawback. Selection of the optimum regularization parameters was difficult because of the tradeoff between geometric fidelity and temporal resolution. Excessive increase of the temporal parameters, λ_2 and λ_3, yielded significant temporal blurring and hindered the characterization of vessel wall dynamics.

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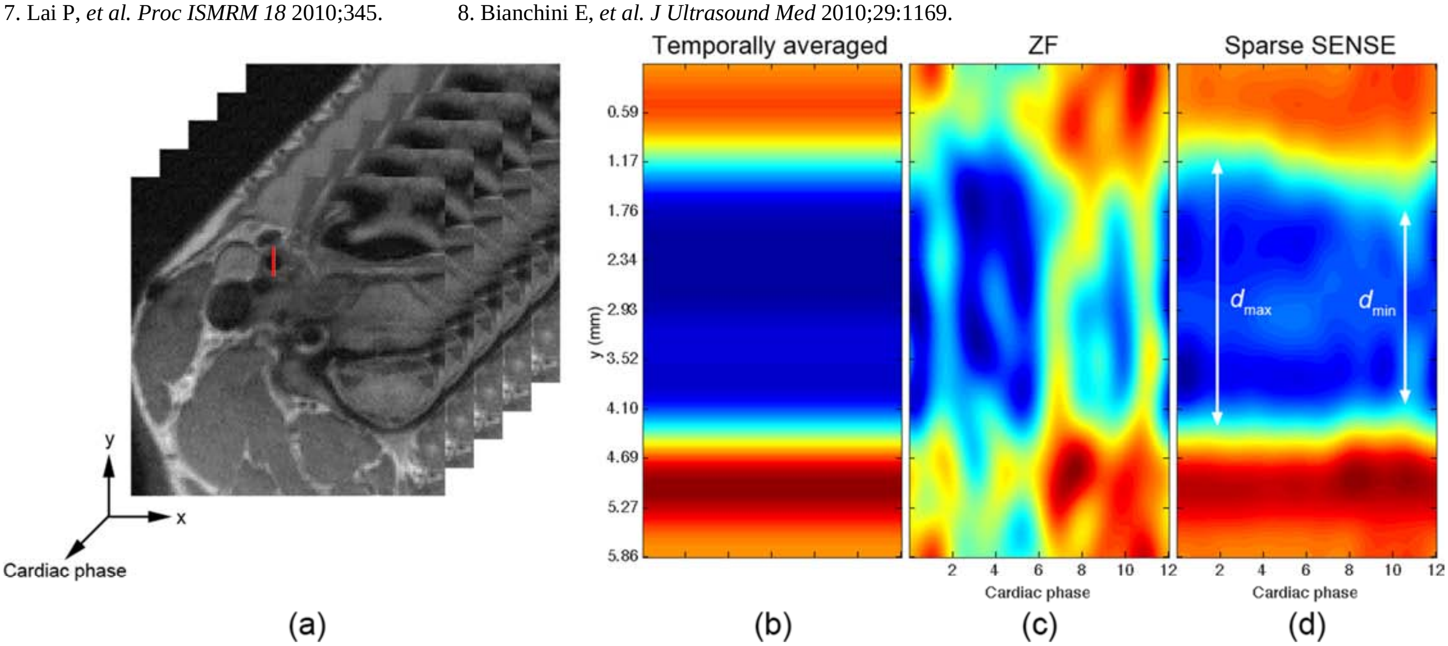

Figure 1: Example of a cross section of the right internal carotid artery investigated in one volunteer (a), the temporally averaged image, $\bar{\mathbf{m}}$*, repeated over 12 cardiac phases (b), and the ZF (c) and spatiotemporal sparse SENSE (d) reconstructions of the time-resolved FSE images over the course of the cardiac cycle. The maximum and minimum vessel diameters (*d_{max}*,* d_{min}*,) are shown on the spatiotemporal sparse SENSE image.*