ACCELERATED AORTIC FLOW ASSESSMENT WITH COMPRESSED SENSING USING SPARSITY OF THE COMPLEX DIFFERENCE IMAGE AS AN ADDITIONAL CONSTRAINT

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Introduction: One of the major limitations of the phase contrast imaging is its long scan time. Conventional compressed-sensing (CS) has the potential to reduce the scan time [1-3]. One of disadvantages of the standard CS reconstruction is the blurring effect around the perimeter of vessels, which makes drawing region of interest for calculation blood flow challenging. In this study, we introduce a new accelerated phase contrast MR approach in which sparsity of the complex difference (CD) image is used as an additional sparsifying transform to improve image reconstruction. Both retrospective and prospective undersampling phase contrast imaging of the blood flow through ascending aorta is used to assess the efficacy of the proposed method.

Methods: The objective function of the proposed reconstruction is:

$$J_i = \|\boldsymbol{F_\Omega m_i}\text{-}\boldsymbol{y_i}\|_2+\lambda\|\Psi \boldsymbol{m_i}\|_1+\lambda_{CD}\|\boldsymbol{m_1}\text{-}\boldsymbol{m_2}\|_1,$$

where $\boldsymbol{F_\Omega}$ is the partial Fourier transform, Ψ is a sparsifying transform, $\boldsymbol{y}_{i=1,2}$ are the measurements for the two bipolar encodings, $\boldsymbol{m}_i$ is the relevant image, and $|\boldsymbol{m_1}\text{-}\boldsymbol{m_2}|$ is the complex difference image. λ and λ_{CD} are the regularization parameters for the balancing between the data fidelity and the image sparsity. The reconstruction is performed iteratively between two bipolar images as given in Figure 1. Every iteration, the reconstruction of $\boldsymbol{m_1}$ generates the intermediate image of $\boldsymbol{m_1}$ and pass it to the reconstruction of $\boldsymbol{m_2}$, which uses it for calculating the CD image and generates the intermediate image of $\boldsymbol{m_2}$ and pass it back to the reconstruction of $\boldsymbol{m_1}$.

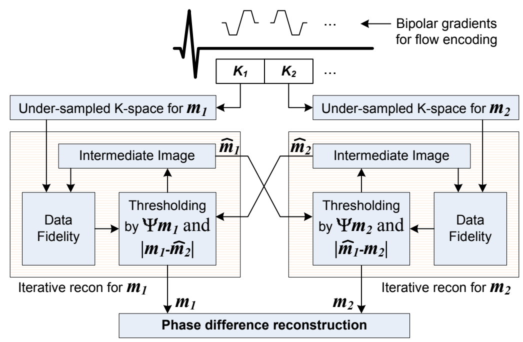

Figure 1. CS reconstruction algorithm for phase contrast MR using complex difference sparsity

Imaging Experiment: To evaluate the proposed method, two sets of studies were performed. Initially, in a retrospective study, we studied the accuracy of the flow quantification for different acceleration rates and different parameters of λ and λ_{CD}. Subsequently, we performed a prospective accelerated image acquisition to better assess accuracy of the method. Phase contrast images were acquired using an axial slice of the ascending aorta at the level of the bifurcation of the pulmonary artery. For both studies, a prospectively ECG-triggered flow-encoded 2D PC MRI pulse TFE sequence was used with the typical parameters of: FOV= 320×(320-400) mm^2, resolution = 2.5×2.5 mm^2, slice thickness = 8mm, TR/TE=4.6/2.7ms, flip angle=12°, temporal resolution = 28.3~39.1 ms, and VENC = 300 cm/s. For the retrospective study, fully-sampled phase contrast data were acquired in 15 healthy subjects (5 males, 20-70 years) and the under-sampled data for rates 2-5 were subsequently synthesized from this dataset. For the prospectively accelerated study, under-sampled data were acquired in 9 subjects (3 males, 20-45 years). In the prospectively accelerated acquisition, each subject was imaged with acceleration rates (R) of 1 (i.e. fully-sampled) to 5. To assess the scan-rescan variability, each scan was repeated twice, one after the other.

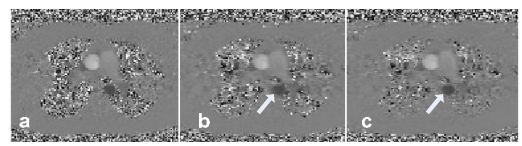

Figure 2. CS reconstructed phase difference image with CD sparsity (c) were compared with the conventional CS without using CD sparsity (b) and the full sampled data (a).

Results: Figure 2 shows the CS reconstruction using the additional sparsity term of the complex difference image. Better delineation of aorta (arrow) can be seen which facilitate flow quantification. Table 1 summarizes the Bland-Altman analysis of blood volume through the cardiac cycle for the retrospective undersampling study. Accurate agreements between fully-sampled and retrospectively under-sampled data can be seen for up to rate 5. Figure 3 shows Bland-Altman results on the blood volume measurements of the prospectively accelerated acquisitions. Figure 3-A shows the agreements between scan-rescan of the fully sampled data, which shows differences between two scans presumably due to physiological changes. Figure 3-B,C,D shows the agreements between a fully-sampled and the accelerated acquisitions for rates 3-5. Up to rate 4, the difference is in the range of that of the scan-rescan of the fully-sampled. However with rate 5, comparatively large variation in flow measurement can be seen.

Acceleration rate	Difference (L/min)	Upper 95% (L/min)	Lower 95% (L/min)	Pearson Coefficients R
Rate 2	-0.004	0.120	-0.129	0.999
Rate 3	0.018	0.152	-0.117	0.999
Rate 4	0.052	0.429	-0.326	0.991
Rate 5	0.153	0.867	-0.562	0.970

Table 1. Bland-Altman analysis of the blood volumes between the fully sampled data and CS reconstruction of the retrospectively under-sampled data

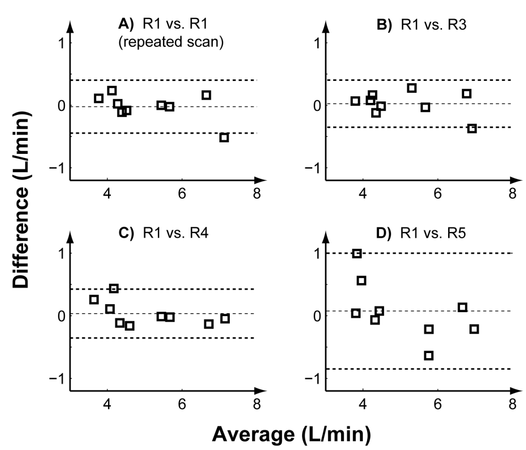

Figure 3. Bland-Altman analysis of the prospective study

Conclusion and Discussion: CS with additional complex difference sparsity allows accurate flow assessment for up to 4-fold acceleration. The error in estimation of the flow volume through the aorta is similar to the error in the inter-scan repeatability of a fully sampled scan. Additional studies in patients are needed to further evaluate the proposed method.

References: [1] Kim, ISMRM, 2011 [2] Hsiao, ISMRM, 2011 [3] King, ISMRM, 2009

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