Phase-sensitive reconstruction to improve visualization of ablation scar in left atrium wall

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Introduction: Atrial fibrillation (AF) is the most common cardiac rhythm disturbance affecting more than 2 million people in the United States. Pulmonary vein isolation (PVI) procedure has emerged as a new promising treatment approach. The goal of PVI is to electrically isolate pulmonary veins along with their AF initiations from the left atrium (LA) by using RF ablation [1,2]. High-resolution, delayed enhancement MRI (DE-MRI) has been recently proposed to visualize post-ablation scarring in the LA wall [3], to predict outcome of the procedure [4], and to guide follow-up PVI procedures by detecting gaps in scar pattern. Visualization and detectability of the scar tissue in LA wall strongly depends on choice of inversion time (TI) for DE-MRI scan (Fig. 1). Furthermore, lipid-rich structures adjacent to left atrium (Fig.1) can be easily mistaken for scar making accurate segmentation and quantification of scar problematic. In this work, we consider application of phase information to resolve the above mentioned problems.

Theory and Methods: Utility of phase information to reduce sensitivity to choice of TI parameter and to enhance contrast between infarcted and healthy myocardium in DE-MRI of left ventricle has been proposed earlier [5]. This phase-sensitive approach requires two images: inversion recovery prepared and proton density (reference) images. In the case of high-resolution 3D DE-MRI of LA, acquisition of these two contrasts is less feasible due to long scan time (5-10 minutes per contrast). Thus, it is desirable to use some internal phase reference to apply phase-sensitive reconstruction for DE-MRI of LA. Phase information can also be used to increase contrast between scar and lipid tissues using difference in resonance frequencies of water and fat. To achieve this goal, TE of pulse sequence should be chosen such that scar and lipid tissue have different, desirably, opposite phases.

Our phase-sensitive reconstruction for 3D DE-MRI of LA is a self-reference method based on the following observations: a) phase changes slowly through the image region occupied by LA and surrounding structures when complex images are reconstructed using the adaptive combine algorithm [6]; b) abrupt changes in phase image correspond to lipid structures (Fig. 1c) or structures with significantly different contrast agent kinetics (Fig. 1d); c) anatomical structures with high concentration of fibrous tissues such as aorta wall and vertebrae have similar contrast agent washout kinetics as scar tissue of LA due to RF ablation (Fig. 1c,d). Aorta is adjacent to the posterior wall of LA making aorta wall an ideal reference for phase-sensitive reconstruction of DE-MRI of LA. Our algorithm is implemented as follows: 1. Find mean phase for aorta wall from the central slice of 3D image volume. 2. Remove this phase term from complex DE images. 3. Calculate real part.

Imaging studies were performed on a 1.5T Avanto MR system (Siemens Healthcare, Erlangen, Germany). High resolution DE images of LA were acquired about 15 minutes after contrast agent injection (0.1 mmol/kg, Multihance (Bracco Diagnostic Inc., Princeton, NJ)) using a 3D respiratory navigated, inversion recovery prepared GRE pulse sequence with TR/TE=2.38/5.4 ms, flip angle of 20^{o}, bandwidth=220 Hz/pixel, FOV=360x360x100 mm, matrix size=288x288x40, 10% oversampling in slice encoding direction, voxel size=1.25x1.25x2.5 mm, phase encoding direction: left to right, fractional readout=85%, partial Fourier acquisition: 90% in phase-encoding direction and 80% in slice-encoding direction, GRAPPA with R=2 and 46 reference lines in phase encoding direction. Inversion pulse was applied every heart beat and fat saturation was applied immediately before data acquisition (23 views per heart beat). Fat signal has non-zero intensity because of non-ideality of fat saturation RF pulse and fat signal recovery during data acquisition. To preserve magnetization preparation in image volume, navigator was acquired immediately after data acquisition block. Typical scan time for DE-MRI study was 5-10 minutes depending on patient heart rate and respiration pattern. TE of DE scan (TE=2.38 ms) was chosen such that water and fat have opposite phases. Adaptive combine algorithm [6] was used to construct complex images from coil images.

Results: Typical magnitude and phase images from DE-MRI of LA are shown in Fig. 1. Post-ablation scar has similar intensity to fat in Fig.1a and is practically not-visible in Fig. 1b. It is obvious that scar in LA and aorta wall have similar phase value regardless of the TI value used for typical DE-MRI scan of LA. Lipid-rich structures adjacent to LA have phase opposite to the phase of aorta wall. Figure 2 demonstrates the DE-MRI images of LA reconstructed using our phase-sensitive method. In comparison with the original magnitude images shown in Fig. 1, visualization and detectability of the scar tissue is significantly improved in these images.

Discussion and Conclusion: Self-reference, phase-sensitive method for DE-MRI of LA has been developed. The method restores contrast between post-ablation scar in LA and normal myocardium for the cases when non-optimal TI parameter was prescribed. Fat signal is considerably reduced in the phase sensitive reconstructed images, making segmentation and quantification of scar tissue in LA easier and more reliable.

Acknowledgments: This study was supported in part by Siemens Healthcare, SurgiVision Inc., Ben B. and Iris M. Margolis Foundation.

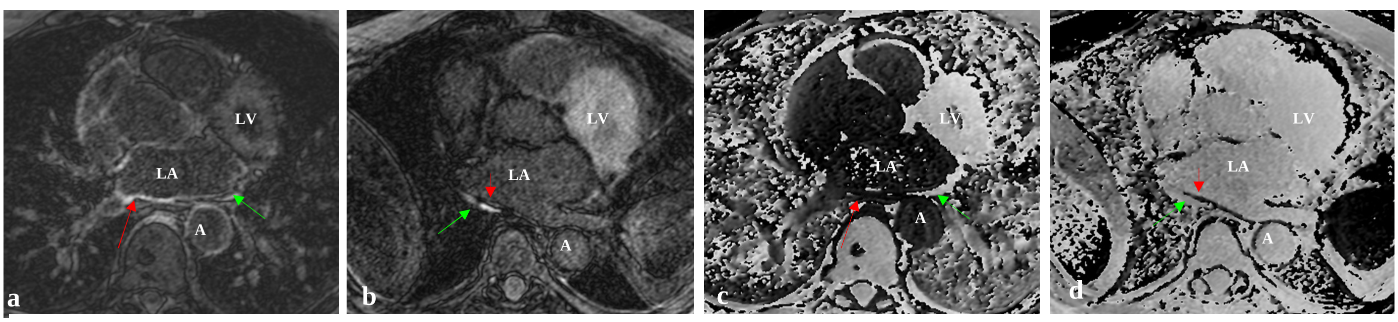

Figure 1. Scar imaging of left atrium using DE-MRI with (**a, c**) close to optimal TI, (**b,d**) too short TI. **a** and **b** – magnitude images, **c** and **d** – phase images. Red arrows indicate post-ablation scar in the posterior wall of LA, green arrows show lipid-rich structure. LA – left atrium, LV- left ventricle, A – Aorta.

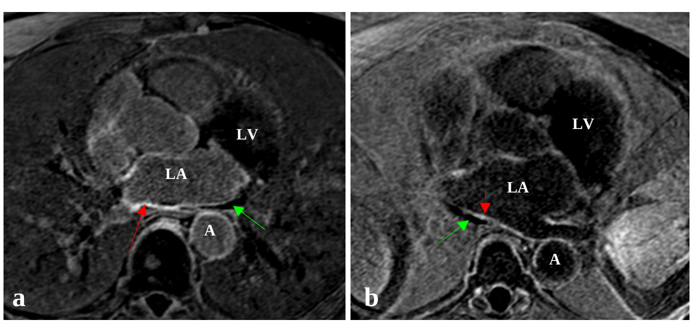

Figure 2. DE-MRI images of left atrium reconstructed using phase-sensitive method. The same images reconstructed by the conventional technique are shown in Fig. 1a and 1b.

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