COMBINED FREE-BREATHING 3D LGE AND T1 MAPPING FOR SIMULTANEOUS ASSESSMENT OF SCAR AND DIFFUSED FIBROSIS

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INTRODUCTION: Imaging of scar and diffuse fibrosis provides diagnostic and prognostic information in various cardiovascular diseases. Late gadolinium enhancement (LGE) using an inversion recovery sequence allows imaging of scar in the left ventricle (LV) (1). T_1 mapping using Look-Locker based sequences provides information about diffuse fibrosis in the myocardium (2). LGE and T_1 mapping images are usually acquired using two different imaging sequences. Conventionally, T_1 mapping is performed by acquiring a series of 2D multi-slice images in a single long breath-hold. Therefore, it requires numerous breath-holds for LV coverage. In this study, we sought to develop a combined 3D free-breathing LGE/T_1 mapping sequence for simultaneous evaluation of myocardial scar and fibrosis in a single exam.

METHODS: Fig. 1 shows the schematic of the proposed combined LGE/T_1 mapping sequence. Four inversion recovery images are acquired with different inversion times. The data from all four images are used for estimating T_1 maps by voxel-wise curve fitting. One dataset is acquired using a pre-determined T_{inv}, chosen to null the healthy myocardium. This dataset is additionally used to reconstruct the conventional LGE image. To reduce the scan time, the three supplementary T_1 weighted images, were undersampled by a factor of 3, however the data for LGE was fully-sampled.

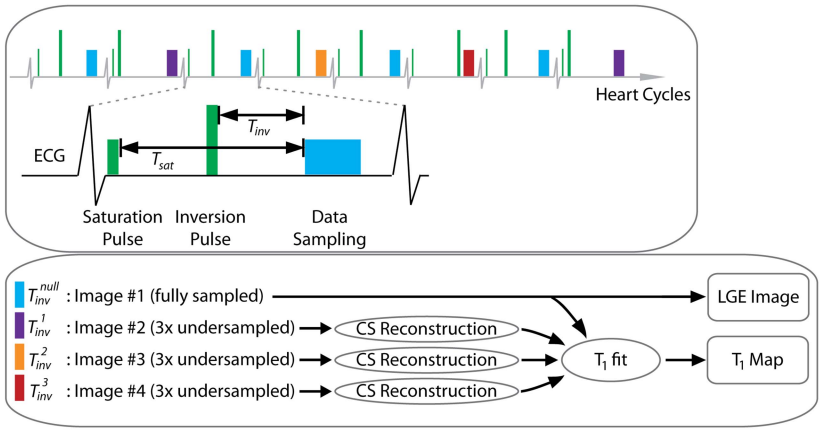

Fig. 1: *Sequence diagram depicting the interleaving of a fully-sampled LGE image and three undersampled supplementary T_1-weighted images. The LGE information is obtained from Image #1, whereas Images #1 - #4 are used for the generation of the T_1 maps.*

To provide adequate spatial alignment among all images, which is necessary for the voxel-wise processing, the acquisition is performed with two interleaves. The first interleaf always acquires data for the LGE scan. The acquisition in the second interleaf cycles through the three supplementary scans with different inversion times, leading to three undersampled k-spaces (each with 3-fold acceleration). To avoid issues arising from insufficient longitudinal magnetization recovery, a saturation pulse was added right after the detection of each R-wave, which erases the magnetization history. Respiratory motion compensation for this sequence is performed in two phases: 1) The outer k-space parts are acquired using joint navigator (NAV)-gating of the two interleaves, i.e. a segment is accepted only if both interleaves are within the gating window. 2) The k-space centers of the four different images are acquired sequentially at the beginning of the scan with regular, prospective NAV gating. The dynamic acquisition of k-space centers improves imaging efficiency, since joint NAV-gating is not required. Furthermore, we hypothesize that this dynamic acquisition of centers does not cause image misregistration, since it takes a relatively short scan time, and because the central k-space does not contain high-resolution details of the image.

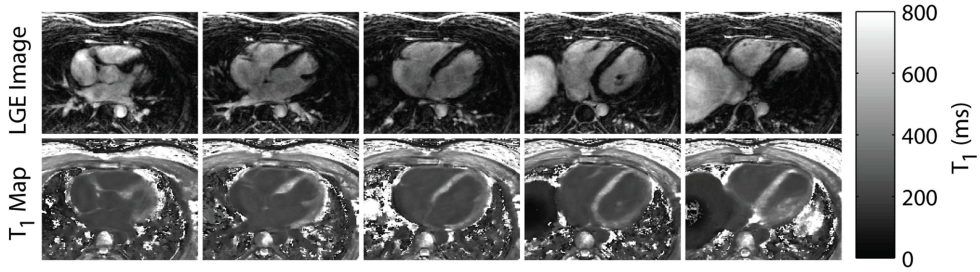

Fig. 2: *Representative slices of combined free-breathing 3D LGE/T_1 mappping sequence.*

Reconstruction: The 3-fold undersampled supplementary images are reconstructed with an improved compressed sensing algorithm (3). The LGE information is obtained from the fully-sampled data. The T_1 maps are generated by a voxel-wise fit to the image intensity of all four images. The fit function is derived from the Bloch equations, incorporating the saturation pulse at the beginning of each heart cycle.

In-vivo Imaging: All imaging was performed on a 1.5T Philips Achieva system. In-vivo images were acquired in six healthy subjects in axial or short-axis view 5 to 20 minutes after contrast injection of Gd-BOPTA. An ECG-triggered free-breathing 3D GRE sequence was used for the proposed method with spatial resolution=1.3×1.3×4 mm^3. Comparison T_1 maps were acquired using the conventional multi-slice 2D MOLLI SSFP sequence (4) with resolution = 1.7×2.1mm^2 and slice thickness = 10mm.

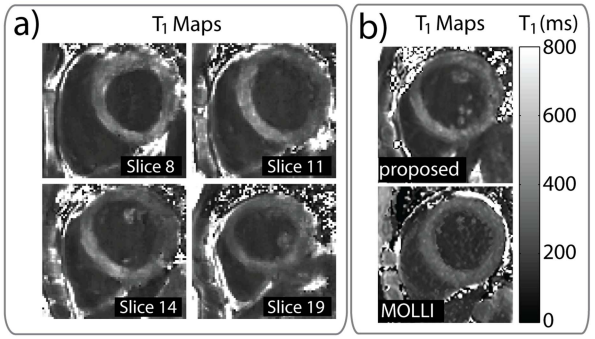

Fig. 3: *a) shows representative slices of the 3D T_1 maps acquired with the proposed sequence. In b) one slice of this map is compared to a corresponding slice of the 2D MOLLI T_1 Map.*

RESULTS: Figure 2 shows multiple representative slices of an axial LGE image acquired using the proposed sequence seven minutes after contrast injection in the top row. The lower row shows the corresponding T_1 maps. Figure 3 shows multiple representative slices of a short-axis 3D T_1 map acquired with the proposed sequence. The image acquisition of this case took 11 minutes for LV coverage. In Figure 3b, a single-slice of the 3D T_1 map is compared to a slice of a 2D MOLLI sequence. The proposed method achieves improved signal homogeneity in the T_1 maps even at a higher spatial resolution (average reduction of the variance in the blood pools=37%). No significant difference was found between the T_1 times of the two sequences for the blood pools or the myocardium ($P > 0.76$). The T_1 times assessed with the proposed sequence were 306.4±79.7ms in the myocardium, 193.5±60.8ms in the LV and 182.5±63.3ms in the RV. For reference the MOLLI sequence estimated T_1 times of 314.1± 59.9ms, 189.1±41.9ms and 185.7±45.7ms for the myocardium, the LV and the RV respectively.

CONCLUSIONS: We have proposed a novel sequence that integrates high resolution 3D LGE imaging with 3D T_1 mapping. The T_1 maps generated using the proposed sequence are more homogenous and have improved spatial resolution and volumetric coverage compared to existing techniques.

REFERENCES: 1. Kim, R.J. NEJM, 2000; 2. Messrohgli, D.R. Radiology, 2006; 3. Akçakaya, M. MRM, 2011; 4. Messrohgli, D.R. MRM, 2004;