Fast simultaneous T_1 and T_2 mapping of the heart

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Target audience. Basic scientists involved in sequence development and clinical scientists involved in cardiovascular MRI

Purpose. This study aims to develop, optimize and validate a new MR method using inversion recovery balanced steady-state free precession (IR-bSSFP) for relaxometry of the cardiac muscle. Quantitative imaging of the heart has become a major focus of interest in the recent years and its applicability to both chronic (in the form of T_1 quantification for the detection of fibrosis[1]) and acute (in the form of T_2 quantification for the detection of edema[2]) conditions. Acquiring T_1 and T_2 within the same acquisition has the advantage of minimizing scan time and producing two already closely coregistered datasets that can be used for the production of synthetic contrasts.

Methods. For data acquisition, a custom two-dimensional, real-time IR-bSSFP sequence was used. The sequence was triggered on the ECG signal and at the beginning of the heart diastolic phase; a 180° inversion pulse preceded a train of real-time bSSFP acquisitions (130ms/image). Image acquisition was continuously running for 15 repetitions (approximately two heartbeats), then a recovery period of three heartbeats was introduced, before the acquisition started again, but now with a delay between the inversion pulse and the next train of image acquisitions, as realized by dummy TR periods (fig. 1). All acquired images were then processed with a customized reconstruction pipeline in order to produce the T_1 and T_2 maps. Each image was Wiener-filtered prior to a nonrigid mutual-information-based b-spline registration that compensated for cardiac motion. Based on the trigger time, systolic images were then discarded and a pixelwise fit of the remaining images was performed[3] to calculate T_1 and T_2 times. T_1 and T_2 values were then corrected for slice-related flip angle variations based on slice profile simulations (fig 2). The method was validated on 5 healthy volunteers at 1.5T and the resulting T_1 values were compared with a commercial T_1-mapping implementation (MOLLI[1]), as provided by the manufacturer. Scans performed on a single short-axis slice (resolution 1.9x1.9x7mm3, FOV: 320x220 mm^2, 8 heartbeats). Regions of interest (ROIs) were extracted from the calculated maps in the septum. Average T_1 and T_2 and standard deviation over each ROI were calculated. The pooled standard deviation of all the volunteers was used as indication of scan precision, whereas intersubject variability was evaluated by taking the average and standard deviation of the averaged ROI values across subjects.

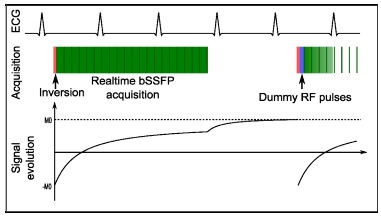

Fig 1: Sequence scheme and signal evolution

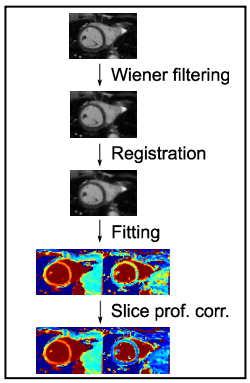

Fig 2: Postprocessing pipeline

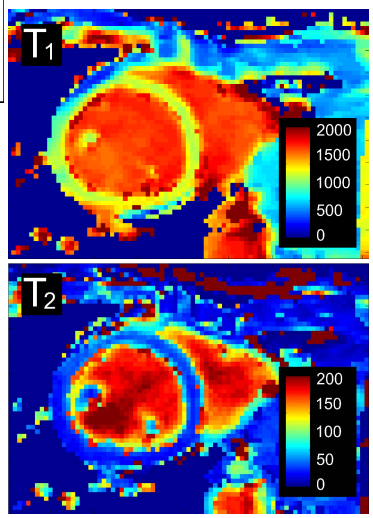

Fig 3: T_1 (top) and T_2 (bottom) map of a healthy volunteer (values in ms).

Results T_1 and T_2 maps were calculated directly on the scanner console with a smooth and homogeneous appearance in the myocardium for all volunteers (fig 3). The average T_1 over all volunteers calculated by IR-bSSFP was 1079±86 ms (973±30 ms by MOLLI, $p<0.01$). The pooled standard deviation of the T_1 measurements was 47 ms (compared to 55 ms of MOLLI). For the T_2 measurements, the average over the volunteers was 43.4±7 ms and the pooled standard deviation 6 ms.

Discussion. For T_1 quantification, the average values calculated with IR-bSSFP exhibit a statistically significant bias with respect to MOLLI, however the T_1 values are within the range of expected literature T_1 values for myocardium. The intersubject variability is higher, probably due to lack of compensation for heart rate variations, but still acceptably low (<10%). The intrasubject variability, however, is lower indicating a higher precision as compared to MOLLI. Cardiac T_2 quantification lacks a gold standard, but also in this case the measured range agrees with literature values for healthy myocardium. The homogeneous appearance of both the T_1 and T_2 maps also outside the selected ROIs demonstrates a good robustness of the method with respect to off resonances.

Conclusion. The proposed implementation of simultaneous T_1 and T_2 mapping of the myocardium by means of a custom IR-bSSFP sequence and reconstruction shows good potential for an integrated quantitative cardiac MRI protocol.

References. 1. Messroghli DR, Radjenovic A, Kozerke S, Higgins DM, Sivananthan MU, Ridgway JP. Modified Look-Locker inversion recovery (MOLLI) for high-resolution T1 mapping of the heart. *Magnetic Resonance in Medicine: Official Journal of the Society of Magnetic Resonance in Medicine / Society of Magnetic Resonance in Medicine.* 2004;52(1):141-146.**2.** Thavendiranathan P, Walls M, Giri S, et al. Improved detection of myocardial involvement in acute inflammatory cardiomyopathies using T2 mapping. *Circulation. Cardiovascular Imaging.*5(1):102-110.**3.**Schmitt P, Griswold MA, Jakob PM, et al. Inversion recovery TrueFISP: Quantification of T1, T2, and spin density. *Magnetic Resonance in Medicine.* 2004;51(4):661-667.