High-resolution T1 mapping of the myocardium within a single breath-hold

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Background

In-vivo T_1 mapping of the myocardium is challenging because of severe time constraints. In a 1.5 T MR system as commonly used in a clinical setting, myocardial T_1 is too long (ca. 1000 ms) to acquire a sufficient number of inversion recovery (IR) images within one breath-hold. Continuous image acquisition as used in one-shot approaches such as Look-Locker (LL) is not suitable for cardiac applications because of cardiac motion. To overcome these problems, we introduce two principles into the conventional LL method: (1) Selective image acquisition in diastole and (2) Merging of images from multiple experiments into one data set.

Methods

The modified LL IR (MOLLI) scheme consists of three ECG-triggered LL experiments with different initial inversion times (100, 200, 350 ms), which are performed consecutively within one breath-hold's time (Fig. 1). Eleven images (3 + 3 + 5) are acquired and merged into one image set in order of their time from inversion. A balanced steady-state free precession (SSFP) pulse sequence (TR 3.9 ms, TE 1.95 ms, FOV 380 mm, voxel size 1.6 x 2.3 x 8 mm) is used for readout. Single images are acquired in end-diastole in <200 ms using sensitivity encoding (SENSE). T_1 values are calculated both for regions-of-interest and pixel-wise from modulus images by performing three-parameter non-linear curve fitting on multiple data sets with varying signs and by selecting the set with the best fitting quality *(Nekolla et al. 1992)*. Accuracy of the technique is tested at different simulated heart rates (HR) in seven Gadolinium-doped gel phantoms with T_1 values between 60 and 1196 ms as assessed by a standard multi-point IR spin echo technique. In-vivo applicability is demonstrated in a healthy volunteer and in a patient with acute myocardial infarction.

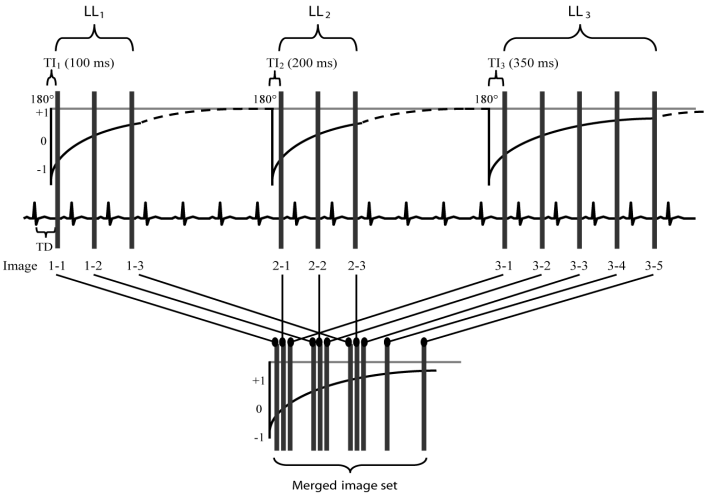

Fig. 1. MOLLI pulse sequence scheme. Vertical bars represent image acquisition.

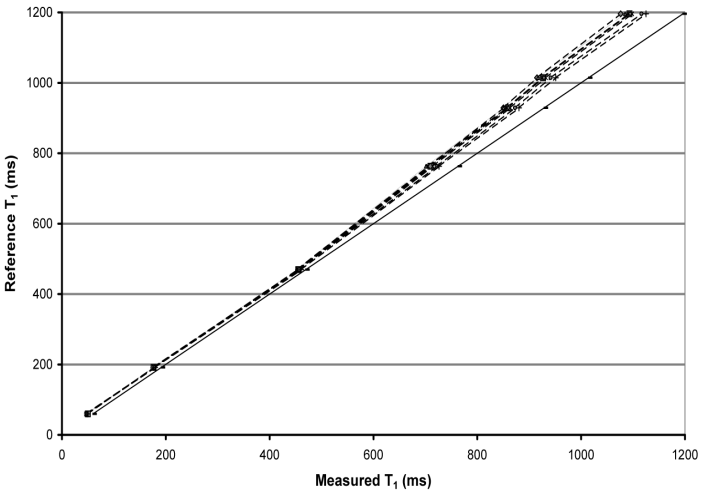

Fig. 2. T1 values for seven phantoms at heart rates from 40 to 100 beats/ min; solid line = reference values.

Results

Fig. 2 shows the results of the phantom measurements at simulated HR from 40 to 100 beats/ min. There is minor systematic T_1 underestimation over a T_1 range from 191 to 1196 ms (-1.8 to –10.0%) and a maximal error of -22.0% for T_1 = 60 ms. The maximum measurement difference at HR from 40 to 100 beats/ min for a nominal T_1 of 1014 ms was 3.6%. Fig. 3 shows a mid-cavity short-axis T_1 map of a 33 years old healthy male volunteer (HR 80 beats/ min). T_1 values derived from the T_1 maps are in good agreement with values available from literature (myocardium 1076 ms; skeletal muscle 794 ms; liver 666 ms; subcutaneous fat tissue 187 ms). Fig. 4 shows a mid-cavity short-axis T_1 map which was acquired 10 min after the application of Gadolinium-DTPA (0.15 mmol/ kg) in a 46 year old male patient 3 days after acute anteroseptal myocardial infarction (HR 90 beats/ min). The area of infarction is clearly delineated and exhibits strongly decreased T_1 values (308 ms) as compared to remote myocardium (487 ms). Each of the in-vivo data sets were acquired within one breath-hold.

Discussion

A pulse sequence scheme is presented which allows for accurate myocardial T_1 mapping within a single breath-hold. The LL method has been shown to be highly efficient and is the technique of choice for T_1 measurements of the brain. MOLLI introduces two key features to make LL accessible to cardiac applications: Selective image acquisition in diastole eliminates cardiac motion artefacts by reducing the number of images acquired during each LL experiment to one per heart beat. The merging of image data from three consecutive LL experiments with different inversion times into one data set re-establishes a total number of images (= data points for the fitting procedure) which is sufficiently high for accurate T_1 estimation. Further measures to optimize T_1 accuracy and image quality include the application of an IR preparation pulse, the choice of a SSFP readout to minimize deflection of the relaxation curve *(Scheffler and Hennig 2001)*, and the use of SENSE. The results of the in-vitro studies indicate that the measurement error of MOLLI is comparable to that of conventional fast T_1 measurement techniques used for brain imaging, for the full range of T_1 values that can be anticipated for both native and contrast media-enhanced applications. The in-vivo examples demonstrate the high image quality that can be achieved with this method.

Conclusion

MOLLI allows for the acquisition of high-resolution T_1 maps of the heart within a single breath-hold on a 1.5 T MR system under native and contrast media-enhanced conditions. In-vitro T_1 accuracy of the approach is comparable to that achieved with fast techniques used for brain studies.

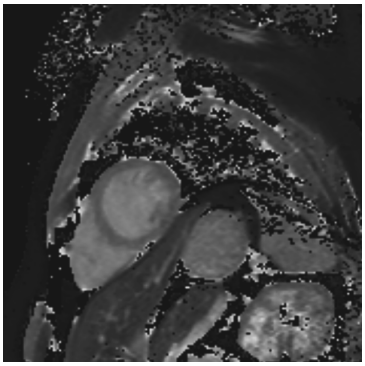

Fig. 3. Healthy volunteer (native)

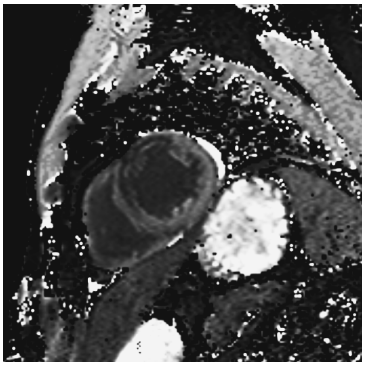

Fig. 4. Anteroseptal infarction (post-Gd)