Free-Breathing Quantitative T_2-mapping of the Heart Designed for Longitudinal Studies at 3T

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Introduction

Recently, the T_2 relaxation time has attracted increased attention in cardiac MRI, since the T_2 uniquely and non-invasively characterizes myocardial edema after an infarction [1]. T_2-weighted MR imaging could thus be used to guide and monitor therapy. Simultaneously, the recently proposed combination of balanced steady-state free precession (bSSFP) imaging and a T_2-preparation module (T_2prep) have enabled cardiac T_2-mapping at 1.5T and thus a rapid quantitative cardiac T_2 estimation [2,3]. However, the accuracy of this method may still be limited due to the complex T_2/T_1 signal weighting of the combined magnetization preparation and segmented bSSFP data acquisition. For longitudinal studies that are designed to monitor and/or guide therapy, accurate and reproducible T_2 measurements will be essential and therefore an external T_2-reference phantom with known T_2 may be indispensable for improved accuracy and reproducibility of the T_2 computations among scans. For these reasons, a novel T_2-mapping protocol with an external reference phantom was developed and implemented at 3T. The accuracy and reproducibility of T_2 measurements was ascertained *in vitro* and subsequently *in vivo* in healthy adult subjects. Finally, the new method was applied in myocardial infarction patients and its correspondence with other modalities was investigated.

Materials and Methods

An adiabatic T_2prep [4] with 3 incremental echo times (TEs), affine coregistration, a lung-liver-interface navigator for respiratory gating and tracking and segmented 2D radial gradient echo imaging were combined for free-breathing T_2-mapping at 3T with a spatial resolution of 1.25mm. Bloch-equation simulations of the pulse sequence were used to optimize scan parameters and to determine an empirical equation that compensates for T_1 relaxation and which returns the "true" T_2. The T_2-mapping sequence was then validated in a series of 9 agar/$NiCl_2$ phantoms with "true" T_2 ranging from 41 to 84ms, which was determined with a spin-echo sequence in which TE was varied from 4 to 500ms in 9 steps. The T_2 values obtained by fitting the standard and empirical equation were compared for significant differences with paired two-tailed Student's t-tests. Next, the myocardial short axis transverse relaxation time $T_{2myo,meas}$ of 9 healthy volunteers was mapped in two different scan sessions while a reference phantom ($T_{2phan,true}$=43.1±0.7ms) was placed adjacent to the thorax in the field of view. The average T_2 of the entire myocardium was computed for both sessions with and without the use of the "true" reference phantom $T_{2phan,true}$. The corrected T_2 was then calculated as $T_{2myo,corr}=T_{2myo,meas}\cdot T_{2phan,true}/T_{2phan,meas}$. Next, the percentage of difference between the two scan sessions was calculated for both $T_{2myo,meas}$ and $T_{2myo,corr}$ and paired two-tailed Student's t-tests were used to test whether there was a significant difference among the methods. Finally, the optimized and validated protocol was used in 7 patients in the subacute phase after revascularization of acute ST-elevation myocardial infarctions. In these patients, regions of significantly increased T_2 in the left ventricle myocardium were compared to hyperintense regions in colocalized T_2-weighted TSE images and x-ray coronary angiograms where available. Institutional Review Board permission was obtained for all volunteer and patient studies.

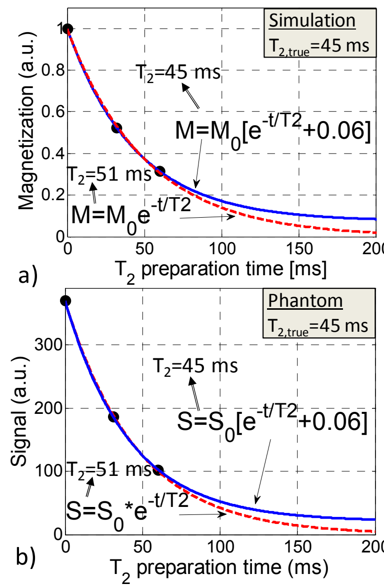

Figure 1. T_2-mapping in a simulation and phantom scan. **a)** Simulated magnetization (black dots) for myocardium with input T_2=45ms at the T_2prep times (60, 30 and 0ms) and fitted curves with the standard (dashed line) and new, empirical (solid line) equation. The new equation leads to more accurate T_2 computations. **b)** Similar results are measured in a T_2-map of a phantom where the T_2 was determined to be 45ms with a 9-TE spin echo scan.

Results and Discussion

As a result of both the simulations and phantom scans, optimized sequence parameters included: T_2prep echo times TE_{T2prep}=60/30/0ms, trigger interval=3 heartbeats, 20 spokes per segment, TR/TE=5.3/2.4ms. The empirical equation to determine T_2 was $S=S_0[\exp(-TE_{T2prep}/T_2)+0.06]$, where S and S_0 are the measured and steady-state signal (Fig. 1a). Measurements in phantoms with known T_2 confirmed a 12±2%($p<0.001$) improvement in T_2 estimation as a result of using the empirical equation (Fig. 1b). Without the use of the reference phantom, the overall myocardial T_2 in the volunteers was homogeneous (42±5ms over all volunteers) and showed a 5±2% difference between the two scan sessions on average. When compensated with the T_2 from the reference phantom, this difference decreased to 2±1% (p=0.01). In all patients, T_2-maps could successfully be obtained and a clear demarcation of regions with elevated quantitative T_2 values was consistent with the findings on T_2-weighted MRI and X-ray coronary angiography as shown in the example in Fig. 2. The average T_2 in these regions over all patients was 56±3ms, while in the non-enhanced, healthy myocardium by T_2-weighted TSE imaging, a T_2 of 42±3ms ($p<0.001$) was measured with the proposed method.

We conclude that the methodology presented in this study enables robust and accurate cardiac T_2-mapping at 3T, while the addition of a reference phantom improves reproducibility. Therefore, it may be well-suited for longitudinal studies in patients with ischemic heart disease.

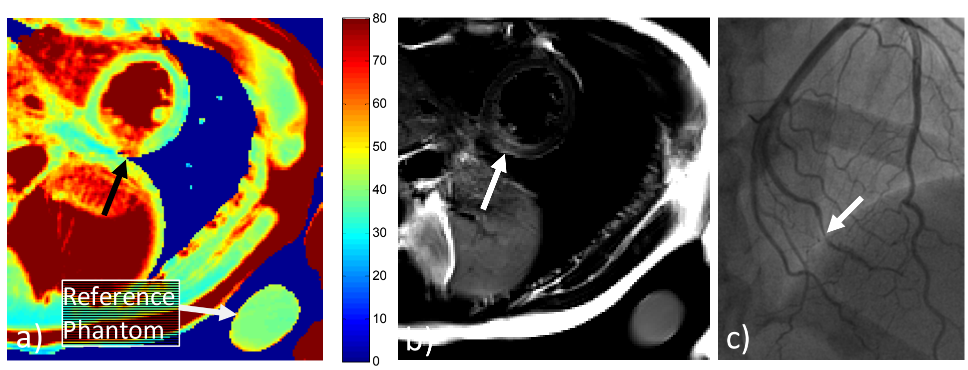

Figure 2. Short-axis T_2-map together with conventional T_2-weighted turbo spin-echo MRI and an X-ray coronary angiogram in a patient with a relatively small myocardial infarct. **a)** A clearly demarcated zone with elevated T_2 can be seen in the region of the black arrow, which might indicate myocardial edema. The non-infarcted tissue has a homogenous T_2, while the reference phantom adjacent to the thorax appears homogeneous with T_2 values similar to those in healthy tissue. Scaled color bar in ms. **b)** The conventional T_2-weighted TSE image confirms the elevated T_2 in the region of the infarct (arrow). **c)** Consistent with these findings, the x-ray coronary angiogram shows a severe stenosis in an obtuse marginal artery (arrow).

References

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