Introduction

Recently, the T₂ relaxation time has attracted increased attention in cardiac MRI, since the T₂ uniquely and non-invasively characterizes myocardial edema after an infarction [1]. T₂-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 T₂-preparation module (T₂pre) have enabled cardiac T₂-mapping at 1.5T and thus a rapid quantitative cardiac T₂ estimation [2,3]. However, the accuracy of this method may still be limited due to the complex T₂/T₁ 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 T₂ measurements will be essential and therefore an external T₂-reference phantom with known T₂ may be indispensable for improved accuracy and reproducibility of the T₂ computations among scans. For these reasons, a novel T₂-mapping protocol with an external reference phantom was developed and implemented at 3T. The accuracy and reproducibility of T₂ 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 T₂prep [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 T₂-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 T₁ relaxation and which returns the “true” T₂. The T₂-mapping sequence was then validated in a series of 9 agar/NiCl₂ phantoms with “true” T₂ 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 T₂ 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 T₂corr,meas of 9 healthy volunteers was mapped in two different scan sessions while a reference phantom (T₂phant,meas=43±10.7ms) was placed adjacent to the thorax in the field of view. The average T₂corr,meas of the entire myocardium was computed for both sessions with and without the use of the “true” reference phantom T₂phant,ref. The corrected T₂corr,meas was then calculated as: T₂corr,meas=1/T₂corr,meas/T₂phant,ref/T₂phant,meas. Next, the percentage of difference between the two scan sessions was calculated for both T₂corr,meas and T₂corr,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 T₂corr in the left ventricle myocardium were compared to hyperintense regions in colocalized T₁-weighted TSE images and x-ray coronary angiograms where available. Institutional Review Board permission was obtained for all volunteer and patient studies.

Results and Discussion

As a result of both the simulations and phantom scans, optimized sequence parameters included: T₂prep echo times TE1/2prep=60/30/0ms, trigger interval=3 heartbeats, 20 spokes per segment, TR/TE=5/3.2/4ms. The empirical equation to determine T₂corr,meas was S=S₀[exp(-TE/T₂pre)+0.06], where S₀ and S are the measured and steady-state signal (Fig. 1a). Measurements in phantoms with known T₂ confirmed a 12±2%(p<0.001) improvement in T₂ estimation as a result of using the empirical equation (Fig. 1b). Without the use of the reference phantom, the overall myocardial T₂corr 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 T₂ from the reference phantom, this difference decreased to 2±1%(p=0.01). In all patients, T₂-maps could successfully be obtained and a clear demarcation of regions with elevated quantitative T₂ values was consistent with the findings on T₁-weighted MRI and X-ray coronary angiography as shown in the example in Fig. 2. The average T₂corr in these regions over all patients was 56±3ms, while in the non-enhanced, healthy myocardium by T₁-weighted TSE imaging, a T₂ 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 T₂-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.

References