Characterization of the Accuracy and Precision of Radial Cardiac T_2 Mapping at 3T

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Introduction: In recent years, cardiac T_2 mapping has seen increased use for the quantification of edema. The T_2 mapping techniques that have been established in recent years involve acquiring several images with different T_2 preparation module echo times (TE_{T2prep}), combined with a robust cardiac imaging pulse sequence [1,2,3]. After the acquisition, T_2 values are computed by fitting an exponential decay curve across the multiple images in each pixel, using a two-parameter exponential decay equation. However, the variability of the accuracy (i.e. how close the measured T_2 value is to the 'true' T_2 value) and the precision (i.e. the T_2 standard deviation) of these pulse sequences have not been investigated. The aim of this study was therefore to evaluate the accuracy and precision of radial cardiovascular T_2 mapping at 3T as a function of confounders such as the signal-to-noise ratio (SNR), acquisition in systole vs. diastole, and the off-resonance frequency, using both numerical simulations and in-vivo imaging of healthy adult volunteers.

Methods: Approval was obtained from the institutional review board. Bloch equation simulations were used to establish ideal magnetization behavior for the radial ECG-triggered and navigator-gated gradient-echo-based cardiac T_2 mapping sequence [3]. Monte Carlo simulations were then used to add 10'000 different combinations of Rician noise per SNR level and TE_{T2prep} series, in order to ascertain the influence of the SNR (determined at TE_{T2prep}=0 ms) and the choice of the number and spread of TE_{T2prep} increments on the T_2 fitting accuracy and precision. Next, in-vivo imaging was performed in eleven healthy adult volunteers to establish the difference in reproducibility of short-axis T_2 mapping in diastole and systole, and the blinded intra- and inter-observer variability was ascertained through Bland-Altman plots. A segment-wise SNR analysis of these T_2 maps was performed to determine the correlation between the SNR and the accuracy. Finally, the effect of an off-resonance excitation frequency (from -200 to +200 Hz) on the accuracy of T_2 maps was studied in eight healthy volunteers.

Results: The Monte Carlo simulations demonstrated that a higher number of TE_{T2prep} with intermediate increments results in the highest precision of the fitted T_2 value (Figure 1), while the apparent T_2 value remains within 1 ms of the 'true' value for SNR~10 and higher. Systolic T_2 maps resulted in a larger available myocardium per 2D slice than diastolic T_2 maps (Figure 2), but did not result in different myocardial T_2 values (41.6±4.5 vs. 41.7±5.1 ms, respectively, p=0.8). The intra-observer 95% confidence interval (CI) was [-1.5 ms to 1.6 ms] for systolic T_2 maps, while it was [-1.9 ms to 1.9 ms] for diastolic T_2 maps (p=0.05). The inter-observer CI was [-2.0 ms to 2.7 ms] for systole and [-2.1 ms to 2.8 ms] for diastole (p=0.86). There was no significant correlation between segmental myocardial SNR and T_2 standard deviation in these T_2 maps. In the off-resonance study, the overall apparent T_2 values increased with the frequency offset, although the segmental pattern differed for the individuals: certain volunteers for example demonstrated elevation in septal segments, while others would mainly demonstrate elevation in inferior segments. Off-resonance frequencies beyond ±100 Hz caused a significant decrease in both the accuracy and precision of the T_2 maps: in the septal segments, the average T_2 value increased from 40.0±1.4 ms on resonance to 63.0±4.1 ms at -200 Hz (Figure 3).

Discussion: The Monte Carlo simulations suggest that the increment between the individual TE_{T2prep} does have an influence on the precision, and the use of an intermediate TE_{T2Prep} increment (25-30ms) is recommended. The volunteer studies demonstrated that systolic T_2 mapping is at least as reproducible as diastolic T_2 mapping, while there is no statistically significant difference between the measured T_2 values. There is no correlation between the segmental SNR levels and the T_2 values in healthy volunteers, which indicates that the SNR obtained in vivo (i.e. >10) does not affect the accuracy of the T_2 computations. Furthermore, similar to T_1 mapping [4], frequency offsets larger than ±100Hz have a large and detrimental effect on the accuracy of T_2 maps, and optimized shimming is mandatory for adequate performance. In summary, the above findings will help better guide protocol definition of studies that include T_2 mapping.

References: [1] Foltz et al. MRM 2003 [2] Giri et al. JCMR 2009 [3] van Heeswijk et al. JACCImaging 2012 [4] Kellman et al. JCMR 2013

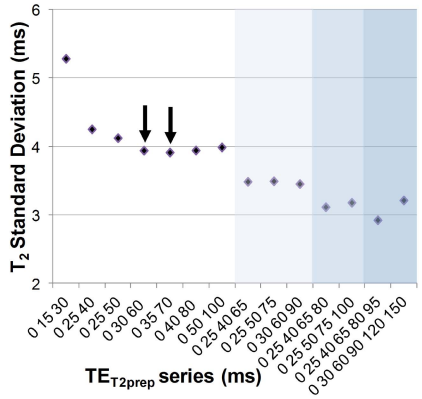

***Figure 1**. The standard deviation (i.e. precision) of the TE_{T2prep} series for Monte Carlo simulations of SNR=10. As the number of TE_{T2prep} is increased, the standard deviation decreases. The TE_{T2prep} increment furthermore also affects the fitting precision, with the moderate TE_{T2prep} series resulting in slightly lower standard deviations (arrows).*

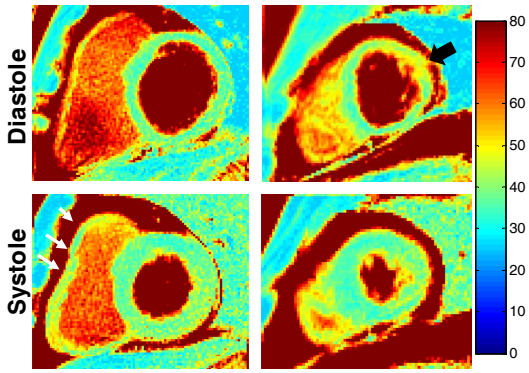

***Figure 2:** T_2 maps of an example volunteer at the left-ventricular base and apex in diastole (upper row) and systole (lower row). The myocardium appears thicker in systolic than in diastolic maps. The wall of the right ventricle is also more distinct in systole (white arrows). In the apical image, there is a blurred area in the diastolic image (black arrow) on the lateral side, which is not present in the systolic image. The color bar indicates the T_2 relaxation time in ms.*

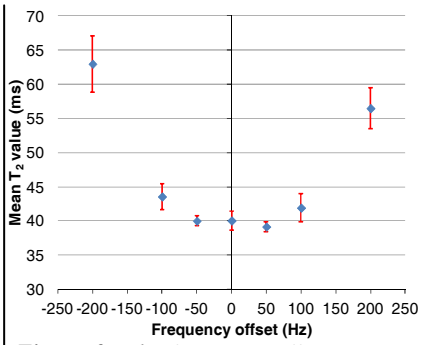

***Figure 3:** The frequency offsets versus mean T_2 values in the septal myocardium of healthy volunteers. There was no significant difference between the on-resonance T_2 values and those at frequency offsets of ±50 Hz or for the offset of +100 Hz (all p>0.05). For the offsets of -100Hz and ±200 Hz, there was a significant T_2 elevation (all p<0.01).*